



AgroMak 2026

SECOND INTERNATIONAL SCIENTIFIC AGRI-BUSINESS CONFERENCE

PROCEEDINGS

Local Resources and Global Challenges: Integrated
Approaches to Sustainable Rural Development
in the Era of Climate Change

Editor: Dragan Cvetkovic

Kumanovo, 02-04 April 2026

**SECOND INTERNATIONAL SCIENTIFIC AGRI-BUSINESS
CONFERENCE
"AGRO MAK 2026"**

**"LOCAL RESOURCES AND GLOBAL CHALLENGES: INTEGRATED
APPROACHES TO SUSTAINABLE RURAL DEVELOPMENT IN THE
ERA OF CLIMATE CHANGE"**

**ВТОРА МЕЃУНАРОДНА НАУЧНО АГРО-БИЗНИС КОНФЕРЕНЦИЈА
„АГРО МАК 2026“**

**„ЛОКАЛНИ РЕСУРСИ И ГЛОБАЛНИ ПРЕДИЗВИЦИ:
ИНТЕГРИРАНИ ПРИСТАПИ КОН ОДРЖЛИВ РУРАЛЕН РАЗВОЈ ВО
ЕРАТА НА КЛИМАТСКИТЕ ПРОМЕНИ“**

PROCEEDINGS

ЗБОРНИК НА ТРУДОВИ

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Macedonia, Комора на Органски Производители– КОП, Куманово, РС
Македонија**

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преку истражување, едукација и одржување на биодиверзитет „ЖИВОТ“
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Со особено задоволство и чувство на професионална одговорност го претставуваме овој **Зборник на научни трудови од Втората меѓународна научна агро-бизнис конференција AGROMAK 2026**, одржана во Куманово во периодот од 02 до 04 април 2026 година.

Конференцијата AGROMAK 2026 претставува значајна научна и стручна платформа која ги обединува академската заедница, научноистражувачките институции, носителите на јавни политики, претставниците на бизнис секторот, како и експертите од областа на земјоделството, руралниот развој и агро-бизнисот. Основната цел на оваа конференција е да поттикне интердисциплинарен дијалог, размена на научни сознанија и добри практики, како и создавање нови можности за соработка помеѓу науката, институциите и стопанството.

Во услови на динамични економски, технолошки и климатски промени, современото земјоделство и агро-бизнисот се соочуваат со бројни предизвици, но и со значајни развојни можности. Токму затоа, научните истражувања и иновациите претставуваат клучен фактор за унапредување на конкурентноста на земјоделското производство, одржливото управување со природните ресурси, развојот на руралните заедници и подобрувањето на квалитетот на живот во овие средини.

Во овој зборник се содржани научни и стручни трудови од автори од повеќе земји, кои преку своите истражувања и анализи придонесуваат кон подобро разбирање на современите трендови во агро-бизнисот, одржливото земјоделство, руралниот туризам, климатските предизвици, иновациите и развојните политики. Трудовите опфатени во зборникот се резултат на научна работа, практични искуства и институционални перспективи, што му дава на овој зборник значајна научна и применлива вредност.

Како уредник на овој зборник, изразувам искрена благодарност до сите автори за нивниот научен придонес, до членовите на Научниот и Организацискиот одбор за нивната посветеност и професионална поддршка, како и до сите институции и партнери кои го поддржаа организирањето на конференцијата AGROMAK 2026.

Се надеваме дека трудовите објавени во овој зборник ќе претставуваат значаен придонес кон понатамошниот развој на научната мисла и практичните решенија во областа на агро-бизнисот, како и поттик за нови истражувања, партнерства и иницијативи во насока на одржлив развој на земјоделството и руралните заедници.

Со почит,

Уредник:
Драган Цветковиќ
AGROMAK 2026

Куманово, 02-04. Април 2026 год.



FOREWORD

It is with great pleasure and a strong sense of professional responsibility that we present this **Proceedings of Scientific Papers** from the **Second International Scientific Agri-Business Conference AGROMAK 2026**, held in Kumanovo from **April 2 to April 4, 2026**.

The AGROMAK 2026 conference represents an important scientific and professional platform that brings together the academic community, research institutions, policy makers, representatives of the business sector, and experts in the fields of agriculture, rural development, and agribusiness. The main objective of the conference is to encourage interdisciplinary dialogue, the exchange of scientific knowledge and best practices, and the creation of new opportunities for cooperation between science, institutions, and the business community.

In a time of dynamic economic, technological, and climate changes, modern agriculture and agribusiness face numerous challenges, but also significant development opportunities. Therefore, scientific research and innovation represent key factors for improving the competitiveness of agricultural production, ensuring sustainable management of natural resources, supporting the development of rural communities, and enhancing the quality of life in these areas.

This proceedings volume contains scientific and professional papers authored by researchers and experts from several countries, who through their studies and analyses contribute to a better understanding of contemporary trends in agribusiness, sustainable agriculture, rural tourism, climate challenges, innovation, and development policies. The papers included in this volume are the result of scientific research, practical experience, and institutional perspectives, giving this publication significant scientific and practical value.

As the editor of this proceedings volume, I would like to express my sincere gratitude to all authors for their valuable scientific contributions, to the members of the Scientific and Organizing Committees for their dedication and professional support, as well as to all institutions and partners who supported the organization of the AGROMAK 2026 conference.

We hope that the papers published in this proceedings volume will represent a valuable contribution to the further development of scientific thought and practical solutions in the field of agribusiness, and will serve as an incentive for new research, partnerships, and initiatives aimed at the sustainable development of agriculture and rural communities.

Respectfully,



Editor:
Dragan Cvetković
AGROMAK 2026

Kumanovo, 02-04. April 2026

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DIGI-AGROTOUR CHAT – A DIGITAL PLATFORM FOR CONNECTING AGRICULTURE AND AGROTOURISM THROUGH THE APPLICATION OF CHATBOT TECHNOLOGIES

DIGI-AGROTOUR CHAT – ДИГИТАЛНА ПЛАТФОРМА ЗА ПОВЕЗИВАЊЕ ПОЉОПРИВРЕДЕ И АГРОТУРИЗМА КРОЗ ПРИМЕНУ ЧЕТБОТ ТЕХНОЛОГИЈА

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Abstract: The DIGI-AGROTOUR CHAT project aims to foster the sustainable development of rural areas through the digital integration of agriculture and agritourism. Rural areas of Serbia, such as the City of Kikinda and its surroundings, possess significant agricultural and tourism potential, yet they face challenges including a weak digital presence, limited communication with tourists, and insufficient promotion. Modern tourists increasingly seek authentic experiences, local products, and direct contact with producers, creating opportunities for the application of innovative digital solutions. Field research has shown a high level of interest in participation in agritourism and in the use of simple digital tools. The key barriers identified during the research include a lack of digital skills, limited time for communication, and inadequate promotion. Based on these findings, the project envisages the development of a functional agro-tourism chatbot, the creation of digital content following the "from field to table" concept, user training programs, and promotional activities, with the goal of increasing visibility, economic sustainability, and the overall quality of the tourist experience. The project is innovative as it represents the first integrated application of chatbot technology in agritourism, connects multiple farms into a digital "cooperative," and combines education, tourism, and agriculture into a single multidimensional system. The implementation of this solution is expected to increase tourist visits, farm income, digital literacy, and local identity, with minimal maintenance costs and strong potential for expansion into new areas through public-private partnerships. DIGI-AGROTOUR CHAT represents a sustainable, innovative, and replicable solution for the digital transformation of rural tourism, integrating technology, education, and economic development with the aim of strengthening local communities and enhancing the tourism offer.

Keywords: innovative solutions, chatbot technology, agritourism, sustainable development

Анстракт: Пројекат DIGI-AGROTOUR CHAT има за циљ подстицање одрживог развоја руралних подручја кроз дигитално повезивање пољопривреде и агротуризма. Рурална подручја Србије, попут града Кикинде и околине, располажу значајним пољопривредним и туристичким потенцијалима, али се суочавају са изазовима у виду слабог дигиталног присуства, ограничене

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комуникације са туристима и недовољне промоције. Савремени туристи све више траже аутентична искуства, локалне производе и директан контакт са произвођачима, што отвара простор за примену иновативних дигиталних решења. Истраживање проведено на терену показало је висок интерес за укључивање у агротуризам и примену једноставних дигиталних алата. Кључне препреке идентификоване током истраживања укључују недостатак дигиталних знања, ограничено време за комуникацију и недовољну промоцију. На основу ових налаза, пројекат предвиђа развој функционалног агро-туристичког четбота, креирање дигиталног садржаја „од њиве до стола“, обуке за кориснике и промоцију понуде, са циљем повећања видљивости, економске одрживости и квалитета туристичког искуства. Пројекат је иновативан јер представља прву интегрисану примену четбота у агротуризму, повезује више газдинстава у дигиталну „задругу“ и комбинује едукацију, туризам и пољопривреду у један мултидимензионални систем. Очекује се да имплементација овог решења повећа број туристичких посета, приход газдинстава, дигиталну писменост и локални идентитет, уз минималне трошкове одржавања и потенцијал за ширење на нова подручја кроз јавно-приватна партнерства.

DIGI-AGROTOUR CHAT представља одрживо, иновативно и реплицибилно решење за дигиталну трансформацију руралног туризма, које интегриса технологију, образовање и економски развој у циљу јачања локалних заједница и унапређења туристичке понуде.

Кључне речи: иновативна решења, четбот технологија, агро-туризам, одрживи развој

1. INTRODUCTION

DIGI-AGROTOUR CHAT is an innovative project aimed at enhancing rural development through the digital integration of agriculture and agritourism. By applying modern chatbot technologies, the project seeks to enable easier access to information, improve the promotion of agro-tourism offerings, and strengthen interaction between agricultural holdings and tourists.

Through the development of a digital platform, the project contributes to increasing the visibility of local products and services, educating visitors about agricultural production, and creating authentic tourist experiences. In this way, DIGI-AGROTOUR CHAT fosters the sustainable economic development of rural areas, diversifies farm income, and preserves local traditions in line with national and European development policies.

2. EXPLANATION OF THE PROJECT TYPE IN RELATION TO THE TERRITORY OF THE CITY OF KIKINDA

The DIGI-AGROTOUR CHAT project falls within the field of rural digitalization and agritourism development, with a particular focus on the application of innovative digital tools in agriculture. The territory of the City of Kikinda represents an exceptionally suitable pilot region for the implementation of this type of project, considering its developed agricultural production, significant number of family farms, and the existence of real potential for the development of agritourism activities.

Research conducted in this area has identified several key challenges: limited visibility of the agro-tourism offer, insufficient digital presence of agricultural holdings, and inadequate integration of agricultural production with tourism-related content. Although there is clear interest in generating additional income through tourism, most farms lack access to simple digital tools that would enable effective communication with potential visitors.

Based on the results of field research, the need for an integrated solution was identified—one that would simultaneously support agricultural production, promote local products, and foster the development of agritourism services. For this reason, the project is conceptually oriented toward the development of a chatbot platform that will enable easy access to information, digital presentation of farms, and personalized communication with tourists, tailored to the specific characteristics of the local area.

Through the implementation of this model in Kikinda and surrounding rural settlements, the project aims to test an innovative approach to the digitalization of agritourism, with the potential for successful solutions to be later transferred to other rural areas of the Republic of Serbia.

- Project Type: Rural digitalization / Agritourism / Innovation

- Potential Funders:

- EU Funds (IPARD III, Horizon Europe – Cluster 6)

- National Funds (Ministry of Agriculture, Ministry of Tourism)

- Local governments and development agencies

- Project Duration: 12–18 months.

- Area of Implementation: Republic of Serbia (pilot region: Vojvodina and the territory of the City of Kikinda).

2.1 Project justification

Rural areas of Serbia possess significant potential for the development of agriculture and tourism, which has not yet been fully utilized. These areas are characterized by fertile land, traditional food production, and cultural and historical resources capable of attracting tourists. However, despite these natural and cultural assets, there is a clear need for modernization and digitalization of promotion processes and stronger alignment with tourism demand.

The development of agritourism in rural communities contributes to economic and social progress, but it often faces obstacles such as limited access to digital tools, insufficiently systematized offerings, and restricted market visibility. Modern tourists increasingly seek authentic experiences, local food, and direct contact with producers, creating opportunities for innovative ways to connect agriculture and tourism.

In this context, the application of digital solutions represents a logical and sustainable step forward. Digital channels enable easier access to information, more efficient communication between producers and consumers, and improved promotion of agritourism offerings. Such tools can significantly enhance the visibility of rural farms, increase regional competitiveness, and stimulate the development of new activities that combine production and tourism.

The justification for the project lies in the need to provide rural areas with an accessible, intuitive, and sustainable digital channel that will enable:

- easier access to information and promotion of local products,
- efficient interaction with tourists,
- structured presentation of agritourism offerings,
- improvement of the economic and social position of local communities.

The current situation in rural areas, together with the evolving needs of modern tourists, clearly demonstrates the importance and necessity of developing digital solutions capable of integrating agriculture and tourism, ensuring sustainable development, and fostering the economic growth of local communities.

2.2 Project objectives

The project has a clear and strategically defined objective focused on the development of rural areas through the digital integration of agriculture and agritourism. The overall objective of the project is to contribute to the sustainable development of rural communities by enabling local farms to present their products and services to a wider audience, while offering tourists authentic and educational experiences that combine agricultural production and tourism.

The specific objectives of the project reflect multiple levels of benefits—for farms, tourists, and the broader community:

1. Enhancing the visibility of agritourism offerings

- The project aims to provide rural farms and tourism activities with greater recognition and accessibility through digital channels, enabling better market positioning and attracting a larger number of visitors.

2. Digital support for agricultural holdings

- Through the application of modern digital tools and platforms, the project supports farms in promotion, communication, and the management of tourism activities, facilitating access to new markets and strengthening organizational capacities.

3. Increasing farm income through tourism

- The objective is to create conditions for the economically sustainable integration of agritourism, ensuring that participation in tourism activities directly contributes to the economic stability and income growth of local farms.

4. Educating tourists about agricultural production

- The project seeks to enable tourists to better understand food production processes, the importance of local resources, and the cultural value of agricultural activities, thereby contributing to education and the creation of authentic tourism experiences.

5. Encouraging young people to remain in rural areas

- By creating new economic opportunities and promoting innovative and digital approaches in agritourism, the project encourages young people to stay in rural communities, contributing to demographic sustainability and local development.

The project objectives demonstrate its multidimensional character, linking the economic, educational, and social aspects of rural development. The focus on digitalization enables the implementation of innovative solutions aligned with modern trends in tourism and agriculture, while simultaneously promoting sustainability, economic activity, and social inclusion within local communities.

2.3 Target groups

The project focuses on several target groups that are key to the successful implementation and sustainability of a digital platform connecting agriculture and agritourism. These groups include various participants in the agricultural and tourism value chains, aiming to ensure that all stakeholders benefit from the application of project solutions.

1. Agricultural holdings and rural tourist households

- The primary target group consists of farms producing agricultural products and offering tourism services.
- The project provides them with the opportunity to promote their offerings in a digital, accessible, and intuitive way, increase market visibility, and organize agritourism activities.
- This group directly benefits from digitalization, including easier communication with tourists and more effective management of their resources and activities.

2. Tourists (domestic and international)

- Tourists are the end users of the information and services provided by the platform.
- The project enables them to easily access the offerings, experience authentic rural life, and participate in activities that combine agriculture and tourism.
- Digital tools provide convenience, speed, and clarity when planning visits, making reservations, and interacting with producers.

3. Local communities and associations

- Local communities and associations play an important role in promoting the region and organizing joint activities.
- The project facilitates better coordination and cooperation between farms, associations, and tourism stakeholders, creating synergy that promotes local development and shared economic benefits.

4. Young farmers and entrepreneurs

- This target group represents potential for innovation, modernization, and sustainable development in rural areas.
- Through the use of digital tools, the project creates conditions for developing entrepreneurial skills, establishing new business models, and retaining young people in rural communities.

5. Tourism organizations

- Tourism organizations play a key role in promoting the region and connecting supply with demand.
- The project allows them to integrate individual activities and farms into a single, accessible system, facilitating marketing, management of tourist flows, and monitoring visitor interests.

The project's target groups cover all key actors in the rural tourism and agriculture value chain. The focus on integrating digital solutions enables all groups to achieve tangible benefits—ranging from economic and organizational to educational and social. The project creates conditions for the sustainable development of the region, improves the visibility and competitiveness of local farms, and simultaneously supports tourism development and the retention of young people in rural areas.

2.4 Description of project activities

The project is structured into five interconnected activities that together cover all aspects of developing a digital platform for connecting agriculture and agritourism. The purpose of this division is to ensure a systematic approach, from identifying potentials and needs to implementing the tools and promoting them on the market.

Activity 1: Needs analysis and selection of pilot farms

- This activity forms the foundation of the project, as it maps the agritourism potential of rural areas and defines the pilot farms that will participate in the platform implementation.
- Mapping allows for precise identification of resources, activities, and capacities of each farm, which is essential for adapting the digital solution to real needs.
- The selection of pilot farms provides a focused and manageable sample for testing and final refinement of the solution.

Activity 2: Development of the agritourism chatbot

- The development of the chatbot represents the central technological component of the project.
- Key functions include multilingual support, information on production, accommodation, and activities, as well as booking capabilities and activity calendar tracking.
- This activity enables the creation of a digital interface connecting farms and tourists in a simple and intuitive way, increasing the visibility of offerings and facilitating real-time activity management.

Activity 3: Digital content and “from field to table” stories

- Creating digital content allows tourists to gain a deeper understanding of local agricultural production and cultural traditions.
- Descriptions of local products, traditional recipes, customs, and seasonal agricultural cycles create an authentic experience and contribute to visitor education.
- This activity promotes the region while linking the economic and educational aspects of agritourism.

Activity 4: User training

- Training for farms and other platform users is a critical element for successful implementation.
- Trainings ensure that users understand the chatbot’s functionalities, learn how to apply it in daily operations, and fully exploit the benefits of the digital tool.
- This activity supports project sustainability and ensures long-term application of the solution in rural communities.

Activity 5: Promotion and visibility

- Promotional activities aim to maximize the platform’s visibility and connect the agritourism offer with potential tourists.
- Online campaigns and collaboration with tourism organizations enable outreach to a wider audience, build the region’s brand, and contribute to the economic and tourism promotion of local farms.

All activities are interconnected and designed to provide a fully integrated solution—from identifying needs, creating digital tools and content, through user training, to promotion and visibility. This structure allows the project to simultaneously develop the technological component while enhancing the economic, educational, and tourism aspects of rural areas, supporting sustainable development and long-term application of the results.

2.5 Expected results

The project is designed to deliver concrete and measurable effects in rural areas, with a focus on digitalization, economic development, and the promotion of agritourism. The expected

results are anticipated to have a multidimensional impact on local farms, tourists, and the wider community.

1. Functional agritourism chatbot

- The creation of a digital tool enables easy access to information on products, accommodation, and activities.
- The chatbot will serve as an innovative communication channel that integrates promotion, bookings, and management of tourism activities on a single platform.
- This solution is designed for users with limited technical knowledge, ensuring broad accessibility and long-term use.

2. Increased number of tourist visits

- Digitalization and improved visibility of agritourism offerings make it easier for tourists to plan visits and participate in activities.
- Clear and organized presentation of the offer increases the region's attractiveness and encourages higher tourist engagement, resulting in an economic impact on local communities.

3. Increased farm income

- Integration of agritourism with digital channels allows farms to achieve better market positioning, promote products, and sell directly to consumers.
- More efficient marketing and the possibility of automated booking of services contribute to economic sustainability and revenue growth.

4. Improved digital literacy

- By introducing intuitive tools and providing user training, the project contributes to the development of digital competencies among local stakeholders.
- Enhanced digital literacy enables farms to manage their offerings independently, increasing the efficiency and sustainability of their activities.

5. Strengthening local identity

- Promotion of local products, traditions, and agritourism activities helps create a recognizable regional brand.
- At the same time, it raises awareness of the cultural and natural value of rural areas, contributing to sustainable community development and a positive impact on the local economy.

The project is expected to generate a synergistic effect, where the technological solution not only facilitates communication and promotion but also stimulates economic activity, education, and the strengthening of local cultural awareness. In this way, the project provides an integrated solution that connects digitalization with agritourism development and sustainable growth of rural communities.

2.6 Project innovation

The project stands out for its innovation as it introduces a new approach to connecting agriculture and tourism through digital technologies. The innovativeness is reflected in several key aspects:

1. First integrated application of a chatbot in agritourism

- The project introduces a chatbot as the central tool for digital communication, promotion, and management of tourism activities in rural areas.

- Integrating the chatbot into agritourism is a regional novelty, enabling automated interaction with tourists, surveys, bookings, and providing a comprehensive overview of offerings in a single platform.

2. Combination of education, tourism, and agriculture

- The project combines three key elements: educating tourists about local production and traditions, tourism activities, and economic support for farms.
- This multidimensional integration allows the creation of authentic experiences that simultaneously promote culture, enhance economic value, and foster education.

3. Digital "cooperative" of multiple farms

- The project enables the connection of multiple farms on a single digital platform, creating the effect of a digital cooperative.
- This solution allows for coordinated promotion, easier management of offerings, increased visibility and competitiveness of all participating farms, and creates conditions for collective growth and economic sustainability.

The project's innovation lies in applying modern digital technologies to rural tourism and agriculture in a way that has not been implemented before. The project not only introduces new technological tools but also creates a model for an integrated approach that connects education, tourism, and economic development, providing a sustainable solution to enhance visibility, economic activity, and the competencies of local communities.

2.7 Project sustainability

The project is designed with the goal of long-term sustainability, both technologically and economically, as well as organizationally. Key aspects of the project's sustainability include:

1. Potential for expansion to new areas

- The digital platform is scalable and can be implemented beyond the pilot region, allowing the inclusion of other rural areas in Serbia.
- Such expansion increases the project's impact, contributes to national agritourism development, and enables the transfer of knowledge and best practices to new users.

2. Minimal maintenance costs

- The platform and chatbot are designed to require minimal maintenance and technical support.
- Ease of use and process automation ensure that farms and local organizations can manage the service independently, reducing reliance on external resources and increasing economic sustainability.

3. Potential for public-private partnerships

- The project provides opportunities to establish partnerships between the public sector (local governments, tourism organizations) and private stakeholders (farms, tourism operators).
- Public-private partnerships can support financial and organizational sustainability, enable additional investment in the platform and promotion, and stimulate joint initiatives for rural tourism development.

Project sustainability is ensured through a scalable and cost-effective model that allows expansion to new areas, minimizes costs, and creates conditions for collaboration among diverse stakeholders. The digital solution and innovative approach guarantee long-term application, support local communities, and promote the continuous development of agritourism as a sustainable economic and cultural resource.

2.8 Budget – Framework

The project budget is designed to cover all key aspects of developing a digital platform for connecting agriculture and agritourism, with a focus on efficient and rational use of resources. The budget structure includes four main components:

1. Platform and chatbot development

- This item covers all costs related to the technical development of the digital solution, including design, programming, multilingual support, and functionality testing.
- Platform development is critical to the project's success as it serves as the primary channel for promoting and managing agritourism offerings.

2. Training and workshops

- User training, including for farms and local organizations, is a key part of the budget.
- This includes preparation of materials, conducting workshops, and support for using digital tools.
- Investment in training ensures the long-term sustainability of the project by enabling users to independently manage the platform.

3. Promotion and marketing

- This component includes online and offline promotion, including advertising, marketing campaigns, and collaboration with tourism organizations.
- Promotion is necessary to increase the platform's visibility, attract tourists, and stimulate economic impact for local farms.

4. Project management

- Management costs cover activity coordination, monitoring and reporting, as well as administrative and organizational support.
- Efficient management is essential for implementing the project according to timelines, resources, and objectives.

The project budget is structured to cover all critical elements of implementation, from technological development and user training to promotion and management. This resource allocation ensures rational and efficient use of funds, supports sustainability, and maximizes impact for all target groups. The detailed budget will be adapted to the specific requirements of funders and the actual costs in the field.

The **DIGI-AGROTOUR CHAT** project represents a modern, innovative, and sustainable solution that contributes to the development of agriculture and agritourism, aligned with EU priorities and national rural development strategies.

3. MINI STUDY: POTENTIALS FOR DIGITALIZATION OF AGRITOURISM IN THE CITY OF KIKINDA – BASED ON A SAMPLE OF 40 FARMS

3.1. Research objective

The aim of the research was to gain a detailed understanding of the status and needs of agricultural farms in the city of Kikinda and surrounding rural settlements in the context of digitalization and agritourism. The main focus of the study covered three key areas:

1. Level of digital presence of farms

- The study examined how farms use digital channels to promote their production and tourism offerings.

- Assessing digital presence allows understanding of how ready the community is to adopt modern technologies and where gaps exist.

2. Interest in developing agritourism activities

- The research evaluated farms' interest in participating in activities that connect agriculture and tourism.
- This includes potential activities such as local product tastings, participation of tourists in seasonal farm work, and on-site product sales.

3. Readiness to adopt digital tools for communication with tourists

- The study examined how farms perceive the need for simple digital solutions, such as chatbots or other platforms, enabling automated communication, bookings, and tourist information.
- This component is key to identifying technological barriers and opportunities for the digital transformation of agritourism activities.

The research was designed to provide a comprehensive picture of local farms' readiness, interest, and needs, enabling the creation of targeted, innovative, and sustainable solutions for developing digital agritourism in the region.

3.2 Research methodology – explanation

The research was conducted as a combined qualitative–quantitative field analysis during March–May 2025, aiming to collect comprehensive information on the digital presence of farms, their interest in agritourism, readiness to adopt digital tools, and the potential of local tourism offerings in Kikinda and surrounding suburban and rural settlements.

3.2.1 Quantitative Part

Survey of farms: The survey included 40 farms, selected as a representative sample covering different types of production and locations (village, suburban, and central areas of Kikinda).

The survey aimed to statistically measure:

- Level of digital presence (websites, social media)
- Interest in agritourism activities
- Need for digital tools (chatbot platform)

3.2.2 Qualitative Part

- **Semi-structured interviews:** Interviews were conducted with selected farm owners and representatives of local tourism organizations to gain deeper understanding of:

- Specific problems and challenges in agritourism development
- Perceptions of digital solutions and their application
- Local potentials not visible through quantitative data

- **Analysis of existing tourism and digital offerings:** A systematic analysis of current agritourism offerings in Kikinda and its surroundings was conducted, including online presence, promotional activities, and information available to tourists. This part helped identify gaps and opportunities for digitally connecting agriculture and tourism.

3.2.3 Sample

- **Number of participants:** 40 farms
- **Area:** City of Kikinda and surrounding suburban/rural settlements
- **Selection criteria:**
 - Different types of production (vegetables, fruit, livestock)
 - Existing and potential agritourism development
 - Willingness to cooperate and participate in digital projects

By combining quantitative surveys and qualitative interviews with an analysis of current offerings, the study provided a comprehensive insight into the needs and potentials of farms in Kikinda. This methodology provides a solid foundation for developing the **DIGI-AGROTOUR CHAT** digital platform, as it identifies both the challenges and opportunities the project needs to address.

4. INTRODUCTION AND RESEARCH ANALYSIS

The research on agricultural farms in the city of Kikinda and surrounding suburban and rural settlements was conducted between March and May 2025. The purpose of this study was to provide a detailed insight into the digital habits of farms, their interest in agritourism, and the need for digital tools to facilitate promotion and communication with tourists.

The research approach was combined, incorporating both quantitative and qualitative methods to obtain a comprehensive and accurate picture of the actual situation on the ground. The quantitative part included a survey of 40 farms, selected to cover different types of production, farm sizes, and geographical locations (central Kikinda, suburban, and rural areas). The survey allowed for the collection of structured data on existing digital presence, interest in agritourism activities, and the obstacles farms face in promoting themselves and communicating with potential tourists.

The qualitative part involved semi-structured interviews with farm owners and representatives of local tourism organizations, which enabled a deeper understanding of specific challenges and potentials. These interviews identified critical aspects that cannot be fully revealed through surveys, such as: specific needs for digital tools, challenges in organizing agritourism activities, and the local community's perception of digitalization.

Additionally, a systematic analysis of the existing tourism and digital offerings in the Kikinda region was conducted. This analysis helped identify gaps in the current offerings and potential for implementing digital solutions that would increase farm visibility and attract more tourists.

All collected data were processed and visually presented through tables and charts to provide a clear and comprehensive overview of key findings. The results of this analysis provide the foundation for the design and development of the **DIGI-AGROTOUR CHAT** digital platform, which aims to connect agriculture and agritourism, facilitate communication with tourists, and promote local products.

This section sets the context for the further presentation of data and allows for an understanding of how the findings were obtained, as well as their practical application in developing digital support for agritourism in Kikinda and surrounding areas.

Mini Research – Kikinda City Area

Table 1: Key Research Findings

Research Indicators	Percentage of respondents (%)
Farms without a website or digital presence	65
Farms interested in developing agritourism	70
Farms reporting a lack of digital skills as an obstacle	60
Farms interested in a simple digital tool (chatbot)	75

Source: Author

Table 1 presents the key indicators obtained from a survey conducted among 40 agricultural farms in the city of Kikinda and surrounding suburban and rural settlements. The data highlight three important areas that affect the development of digital presence and agritourism:

1. Digital Presence of Farms

- More than half of the surveyed farms (65%) do not have their own website or digital presentation.
- This indicates a significant gap in online visibility and insufficient internet presence, which limits the promotion of products and tourism activities.
- The lack of a digital platform to showcase local products and services reduces the possibility of direct communication with potential tourists.

2. Interest in Agritourism Development

- A large number of farms (70%) show interest in developing agritourism.
- This indicates the existing potential of the region to connect agriculture with tourism and create new sources of income.
- However, interest alone is not enough — tools, support, and knowledge are needed for successful implementation of these activities.

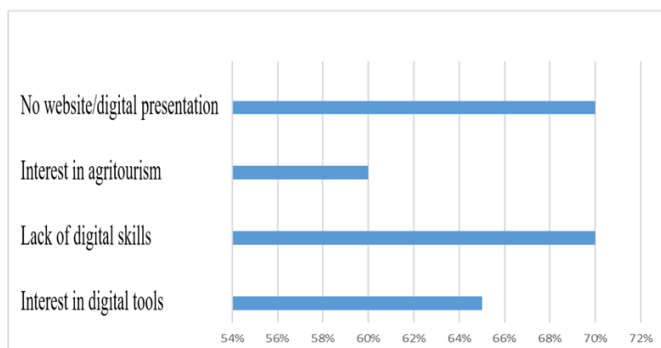
3. Issues with Digital Skills and Need for Tools

- About 60% of respondents indicate that a lack of digital knowledge is an obstacle to promoting and developing agritourism.
- At the same time, 75% of farms are interested in a simple digital tool (chatbot) that could assist them in communication and promotion.
- This reveals a clear need for intuitive and practical solutions that can be applied without advanced technical knowledge.

Summary of Findings: The results show that digitalization and the connection between agriculture and agritourism in Kikinda and its surroundings are still at an early stage, but there is significant interest and readiness to adopt new tools. The data indicate two main barriers:

1. Lack of a personal digital presence.
2. Insufficient digital literacy.

Chat 1. Research indicator



Source: Author

At the same time, the high level of interest in using simple digital tools, such as a chatbot platform, represents a promising opportunity for developing digital solutions that can directly connect farms with tourists, facilitate product promotion, and accelerate the growth of agritourism.

Table 2: Identified problems and needs

Area	Perceived problem	Identified need
Digital presence	Weak or non-existent online visibility	Unique digital platform
Communication with tourists	Lack of time and capacity	Automated communication
Agritourism offer	Insufficiently structured offer	Packaged agro-tourism activities
Knowledge and skills	Insufficient digital literacy	Simple and intuitive tool

Source: Author

Table 2. systematically presents the key problems and needs of agricultural farms in the city of Kikinda, identified through surveys and semi-structured interviews. These findings provide the foundation for developing digital solutions and targeted measures within the DIGI-AGROTOUR CHAT project.

1. Digital Presence

- Problem: Weak or non-existent online visibility of farms.
- Need: A unified digital platform that allows each farm to present its products, services, and agritourism offerings online in one place.
- Comment: Lack of online visibility limits the ability to attract tourists and promote local products. A centralized platform would enable easier presentation and increase accessibility of information for potential visitors.

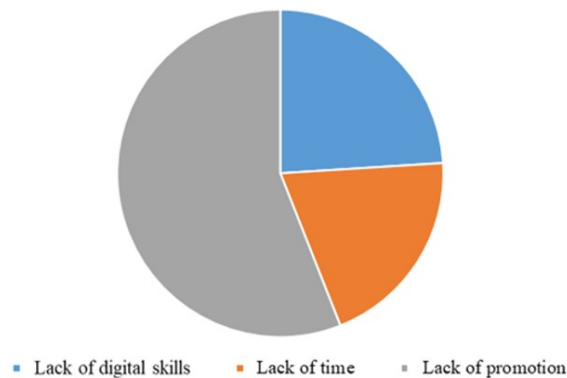
2. Communication with Tourists

- Problem: Lack of time and capacity for direct communication with tourists.
- Need: Automated communication enabling quick responses to inquiries, visit requests, or bookings.

- Comment: Farms often lack resources to respond to every tourist request in real time. A chatbot or other digital tools can significantly improve efficiency and information accessibility.
3. Agritourism Offerings
- Problem: Insufficiently structured offerings that do not clearly present tourist activities.
 - Need: Packaged agritourism activities combining production, tastings, educational, and recreational content.
 - Comment: Tourists often cannot understand what is available or how to use the offerings. Structuring and packaging activities helps promotion and creates an attractive and unique experience.
4. Knowledge and Skills
- Problem: Insufficient digital literacy among farm owners.
 - Need: A simple and intuitive tool enabling quick and easy use without requiring advanced technical knowledge.
 - Comment: There is a need for tools adapted to users with limited digital experience. An intuitive interface and simple functionality allow higher adoption rates and effective use of digital solutions.

These findings clearly highlight four key areas where farms face challenges: digital visibility, communication, structured offerings, and digital skills. At the same time, each area has a clearly defined need, allowing for targeted solutions through a digital platform. By introducing a centralized and intuitive system for presentation, communication, and packaging of agritourism activities, significant improvements in farm visibility and increased tourist interest in visiting Kikinda and its surroundings are expected.

Chart 2. Categories of obstacles



Source: Author

Chart 2 illustrates the main obstacles faced by agricultural farms in developing agritourism and digital promotion:

- Lack of digital skills (60%) – the most common barrier, indicating that the majority of farms are not sufficiently familiar with using digital tools.
- Lack of time (50%) – half of the respondents reported limited capacity for communication with tourists and managing activities.

- Lack of promotion (40%) – a significant number of farms are unable to effectively promote their offerings, which affects visibility and visitor numbers.

Interpretation:

- The primary obstacle is insufficient knowledge of digital tools, highlighting the need for simple and adaptable digital solutions, such as a chatbot.
- Lack of time and promotional capacity indicates that farms need tools that save time and automate communication and marketing.
- The pie chart visually emphasizes the relative importance of each obstacle, helping to prioritize project measures and interventions.

Table 3: Linkage between research and project activities

Research findings	Project Solution
Lack of digital presentation	Development of an agri-tourism chatbot
Limited communication with tourists	Automatic responses and reservations
Untapped agritourism potential	Digital promotion "from field to table"
Need for simple tools	Custom interface for farms

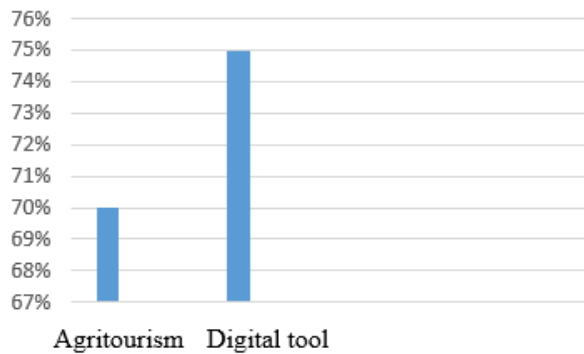
Source: Author

Table 3. clearly shows the direct link between field research findings and the project solutions planned through the DIGI-AGROTOUR CHAT platform. This provides a clear overview of how specific problems faced by farms can be addressed using digital tools.

1. Lack of digital presence → Development of an agro-tourism chatbot
 - 65% of respondents do not have their own digital visibility.
 - Addressing this issue through the chatbot platform allows for a centralized and accessible presentation of products and services, without the need for a separate website or complex web solutions.
2. Limited communication with tourists → Automated responses and bookings
 - Farms do not have enough time or capacity to respond to tourist inquiries in real time.
 - Automated responses and booking systems enable efficient interaction with tourists, reducing the workload for owners and increasing accessibility of information.
3. Untapped agritourism potential → Digital promotion “from farm to table”
 - A large portion of the offering is under-promoted or unstructured.
 - The goal of the digital platform is to highlight specific activities and products, presenting a unique experience that tourists can enjoy from production to consumption.
4. Need for simple tools → User-friendly interface for farms
 - Not all farms are digitally literate, which can be a barrier to using complex systems.
 - A tailored interface enables easy navigation and use of the chatbot without deep technical knowledge, ensuring high usability of the platform.

Table 3 demonstrates how concrete research findings can be directly transformed into solutions. Each obstacle has a clear strategy for overcoming it, making the project plan precise and practical. This linkage between research results and project activities ensures that the DIGI-AGROTOUR CHAT platform addresses the real needs of local farms.

Chart 3. Compared interest



Source: Author

The chart shows the percentage of surveyed farms interested in two key areas:

1. Agritourism (70%) – the number of farms expressing willingness or interest in participating in agritourism activities.
2. Digital tool (75%) – the number of farms showing interest in using a simple digital tool (chatbot) to assist in promotion, communication with tourists, and management of activities.

Interpretation:

- The bar for agritourism (70%) indicates that most farms recognize the importance of engaging in tourist activities and are willing to develop them.
- The bar for the digital tool (75%) shows that an even greater number of farms see the benefits of applying digital solutions that facilitate communication and promotion.
- The 5-percentage-point difference suggests that while interest in agritourism is high, there is an even stronger awareness of the need for digital support to successfully implement these activities.

The chart visually demonstrates that digitalization, through a simple and functional tool, is a critical factor in promoting and facilitating the development of agritourism. It emphasizes that the digital aspect is nearly as important as the agritourism activities themselves, justifying the development of platforms like **DIGI-AGROTOUR CHAT**.

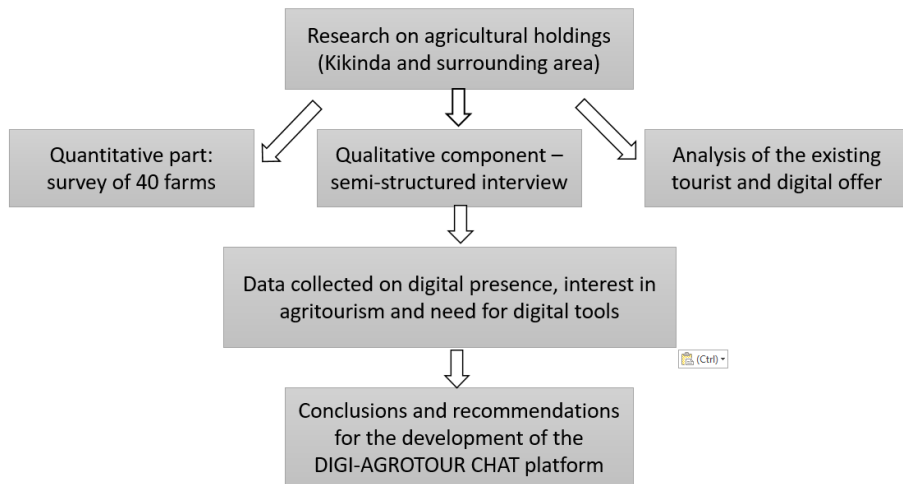
4.1 Analysis of the graphical representation of the research methodology

To present the study of agricultural farms in Kikinda and its surroundings in a clear and organized way, a graphical representation of the methodology (flowchart) was created. This visual representation allows for an immediate understanding of the structural and logical connections between all research steps – from defining the sample, through data collection using various methods, to processing results and formulating concrete recommendations for the development of the **DIGI-AGROTOUR CHAT** digital platform.

The flowchart illustrates the integration of quantitative and qualitative approaches. The quantitative component, based on surveys of agricultural farms, provides statistical data on digital presence, interest in agritourism, and obstacles in the use of digital tools. The

qualitative component, based on semi-structured interviews, enables a deeper understanding of specific challenges, needs, and potentials that surveys alone cannot fully reveal. In addition, the existing tourism and digital offerings were analyzed, allowing the identification of gaps in the current system and the introduction of new solutions that will enhance the visibility and promotion of local farms.

Figure 1. Systematic presentation of steps during field research



Source: Author

Flowchart represents a systematic overview of the steps followed during field research of agricultural farms in the city of Kikinda and its surrounding areas. This visual representation allows a clear understanding of the structure and logic of the research process, as well as how the collected data were processed for the purposes of the DIGI-AGROTOUR CHAT project.

1. Research of agricultural farms (top square in the flowchart)
 - This step defines the sample of 40 farms in Kikinda and the surrounding areas, including urban, suburban, and rural locations.
 - It establishes the basic context of the research: which groups of respondents are included and in which areas.
2. Quantitative part – Surveys
 - The aim of the surveys is to collect structured data on farms' digital presence, interest in agritourism, existing problems, and potential needs for digital tools.
 - This step enables statistical analysis and forms the basis for charts and tables illustrating the results.
3. Qualitative part – Semi-structured interviews
 - Interviews with farm owners and local tourism organization representatives provide a deeper understanding of specific problems and needs.
 - Qualitative data give context and explanation for the survey findings and allow identification of practical obstacles and potential opportunities.
4. Analysis of existing tourism and digital offerings
 - This step identifies gaps in the current offerings and highlights where the digital platform can provide added value.
 - The results help define platform functionalities and promotional strategies.

5. Collected data on digital presence, interest in agritourism, and need for digital tools
 - All data from the quantitative and qualitative parts, along with the results of the existing offerings analysis, are combined at this stage.
 - A complete set of findings is formed, enabling the creation of tables, charts, and further analysis.
6. Conclusions and recommendations for the development of the DIGI-AGROTOUR CHAT platform
 - Based on the collected data, concrete recommendations are defined for the development of the digital platform.
 - Solutions are created for identified problems: digital visibility of farms, automated communication, structuring agritourism offerings, and simple tools adapted for users.

The purpose of this graphical representation is to show how different research methods are interconnected and how the collected data lead to concrete conclusions and recommendations. It forms the basis for creating tables and charts that visually illustrate the findings while providing the reader with a clear overview of the logic of the research process, which is essential for planning and implementing the digital platform in practice.

The flowchart presents a systematic and organized overview of all steps followed during the field research of agricultural farms. This visual representation allows clear understanding of the research structure and logic, identifying how data were collected and processed for the **DIGI-AGROTOUR CHAT** project.

The methodology flowchart precisely and systematically illustrates the research process – from defining the sample and choosing data collection methods, through integrated analysis of quantitative and qualitative results, to formulating conclusions and recommendations. Such visualization emphasizes the complexity and interconnection of the process, showing how the combination of surveys, semi-structured interviews, and analysis of existing tourism and digital offerings allows the creation of a platform fully adapted to the actual needs and capacities of local farms.

The flowchart also serves as a guide for further interpretation of results, as it allows at a glance to see which data lead to which conclusions and how each methodological component contributes to the development of concrete solutions within the project.

5. KEY RESEARCH FINDINGS

Field research conducted on a sample of 40 agricultural farms in the city of Kikinda and its surrounding suburban and rural areas revealed significant trends and needs regarding digital presence, agritourism potential, main challenges, and the readiness of farms to adopt digital solutions. These findings provide the basis for developing the strategy for the **DIGI-AGROTOUR CHAT** digital platform.

5.1 Digital presence

The research shows that over 65% of farms do not have their own website or any digital presentation, indicating a significant gap in online visibility. Existing social media presence is irregular and often unprofessional, making it difficult to attract tourists and promote products. The lack of a systematic and standardized way of presenting offerings significantly

limits tourism visibility and reduces the possibility of direct communication with potential visitors.

These findings highlight the need for a single, centralized digital platform that would allow each farm to present its products, services, and activities in one place, easily and clearly.

5.2 Agritourism potential

The research also revealed that around 70% of respondents expressed interest in participating in agritourism activities. The most frequently mentioned activities include:

- Local product tastings – allowing tourists to experience the authentic flavors of the region.
- Participation in seasonal agricultural work – providing an interactive and educational experience for visitors.
- On-site product sales – stimulating direct purchases, promoting local products, and supporting the local economy.

These data indicate significant potential for agritourism development in Kikinda, while also emphasizing the need for structured and clearly presented offerings so that tourists can easily access information and participate in activities.

5.3 Main challenges

Respondents identified several key obstacles that hinder the development of digital presence and agritourism activities:

- Lack of time to communicate with tourists – preventing fast and efficient interaction, often resulting in missed opportunities.
- Insufficient knowledge of digital tools – creating a barrier for independently creating online content or managing platforms.
- Absence of a unified promotion platform – resulting in disorganized and hard-to-access offerings for both tourists and farm promotion.

These findings show that although there is interest in agritourism development, without adequate digital tools and support, the region's potential remains underutilized.

5.4. Readiness for digital solutions

Most respondents (over 75%) showed interest in adopting simple digital tools, such as a chatbot platform. Respondents emphasized that the tool should:

- Be easy to use, with an intuitive interface.
- Require no technical knowledge, making it accessible for owners with limited digital experience.
- Enable automated communication with tourists, including answering inquiries, registration for visits, or reservations.

These findings indicate a clear readiness among farms for digitalization and a need for tools that integrate promotion, communication, and offer management in one place. Implementing such a solution would overcome existing obstacles and stimulate the development of agritourism in Kikinda.

6. BACKGROUND AND PROJECT JUSTIFICATION

Rural areas of Serbia, including the region around the city of Kikinda, possess significant potential both in agricultural production and in the development of agritourism. However, field research results indicate that this potential is not yet fully realized due to a range of structural and technological limitations.

Key problems and obstacles identified in the research include:

1. Lack of digital tools and online visibility
 - Over 65% of surveyed farms do not have their own website or regular digital presentation.
 - Social media presence is irregular and often unprofessional, making it difficult to promote products and services and limiting access to tourists.
2. Limited communication with tourists
 - Farms lack sufficient time or capacity for direct interaction with tourists, resulting in missed opportunities for bookings or on-site sales.
 - The absence of automated communication channels further slows processes and reduces the attractiveness of the offerings.
3. Insufficiently structured and promoted agritourism offerings
 - Although 70% of respondents show interest in agritourism, activities are often scattered and poorly highlighted, making it difficult for tourists to find and engage with them.
 - The lack of a unified channel for presentation and packaging of offerings reduces the commercial potential of the farms.
4. Limited digital literacy
 - Over 60% of respondents report insufficient knowledge of digital tools as a barrier to developing and promoting agritourism.
 - There is a clear need for simple and intuitive solutions, as most farms do not have the technical knowledge to operate complex systems.

At the same time, modern tourists increasingly seek authentic and personalized experiences, local food, and direct contact with producers. These trends indicate a growing demand for services that combine agriculture and tourism in a new, digitally supported way.

In this context, the application of **chatbot technology** represents an effective solution to overcome the identified challenges. A simple, accessible, and user-friendly digital channel enables:

- Centralized presentation of agritourism activities and products.
- Automated communication with tourists.
- Easy management of offerings without requiring advanced digital skills.
- Integration of agriculture and tourism in a single, sustainable framework.

The project background confirms a clear need for the digitalization of rural areas and the development of tools that allow farms to effectively and efficiently promote their products and agritourism activities. The **DIGI-AGROTOUR CHAT** project addresses these specific field needs and represents an innovative and sustainable approach that enhances the competitiveness of local farms, increases the region's visibility, and stimulates the development of agritourism in Serbia.

7. CONCLUSION

The **DIGI-AGROTOUR CHAT** project represents an innovative and strategic approach to rural development, linking agriculture and agritourism through digitalization. Field analysis and research conducted in the city of Kikinda and surrounding areas reveal significant potential for the development of agritourism activities, while also identifying concrete barriers such as limited digital presence, insufficient knowledge, and restricted communication with tourists.

The research identified the key needs of local farms – a digital platform that enables easy promotion, automated communication, and efficient management of offerings. Based on these findings, the project was designed to integrate a technological solution (chatbot), digital content, user training, and promotional activities, aiming to ensure visibility, economic sustainability, and long-term strengthening of rural communities.

All project activities are interconnected and support multiple specific objectives: improving the visibility of agritourism offerings, increasing farm income, educating tourists about agricultural production, and encouraging young people to remain in rural areas. The implementation of a digital tool and the promotion of authentic agritourism experiences are expected to increase visits, improve the economic position of local farms, and reinforce the local identity.

The project also emphasizes innovation – it is the first integrated application of a chatbot in agritourism, with the potential to connect multiple farms into a digital “cooperative” and a focus on a multidimensional impact that includes tourism, education, and agriculture. Long-term sustainability is ensured through minimal maintenance costs, the potential for public-private partnerships, and the possibility of expansion to new regions.

In summary, the project provides a concrete response to identified needs and challenges, integrating research results into the development of solutions that contribute to sustainable rural development, economic strengthening of local farms, and improved quality of tourist experiences. It sets a model that can be replicated and adapted to other rural regions, creating a long-term and multidimensional impact.

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POSTOPERATIVE NUTRITION AND LONG-TERM ANTHROPOMETRIC CHANGES FOLLOWING LAPAROSCOPIC SLEEVE GASTRECTOMY

ПОСТОПЕРАТИВНА ИСХРАНА И ДОЛГОРОЧНИ АНТРОПОМЕТРИСКИ ПРОМЕНИ ПО ЛАПАРОСКОПСКА SLEEVE ГАСТРЕКТОМИЈА

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Abstract: *This study aims to investigate changes in body mass index, body fat percentage, and excess weight loss following a weight loss program. Results show that there is a rapid improvement in anthropometric parameters during the first year, with maximum improvement noted when body mass index ranges between 45 and 32 kg/m², body fat percentage is reduced to 36%, and excess weight loss is maximized at 69%. There is then a stabilization phase where there is a small increase in body mass index, body fat percentage, and a decline in excess weight loss, indicating metabolic adaptation. This study emphasizes the importance of distinguishing between total weight loss and changes in body composition, emphasizing fat-free mass preservation. In addition, the concept of metabolic surgery is discussed, showing that not only is there a benefit to obesity surgery, there is also a benefit to metabolic disorders such as type 2 diabetes. Nutritional management is essential following laparoscopic sleeve gastrectomy. A structured dietary program, progressing from liquids to solids, is recommended to promote gastric healing, ensure adequate intake of proteins, which is >60–80 g/day, and minimize postoperative complications. A high-protein diet is essential to ensure metabolic health, preventing nutritional deficiencies.*

Key words: *Obesity, body mass index (BMI), bariatric surgery, long-term weight loss, body composition*

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Апстракт: Оваа студија има за цел да ги испита промените во индексот на телесна маса, процентот на телесни масти и процентот на губиток на вишок телесна тежина по програма за намалување на телесната тежина. Резултатите покажуваат брзо подобрување на антропометриските параметри во текот на првата година, со максимален ефект кога индексот на телесна маса се намалува од 45 на 32 kg/m², процентот на телесни масти се редуцира на 36%, а губитокот на вишок телесна тежина достигнува 69%. Потоа следува фаза на стабилизација со мало зголемување на индексот на телесна маса и процентот на телесни масти, како и намалување на губитокот на вишок телесна тежина, што укажува на метаболичка адаптација. Студијата ја нагласува важноста од разликување помеѓу вкупното намалување на телесната тежина и промените во телесната композиција, со акцент на зачувување на безмасната телесна маса. Дополнително, се разгледува концептот на метаболичка хирургија, при што се покажува дека придобивките не се ограничени само на лекување на дебелината, туку опфаќаат и подобрување на метаболички нарушувања како дијабетес тип 2. Нутритивниот менаџмент е од суштинско значење по лапароскопска sleeve гастректомија. Се препорачува структуриран диететски режим со постепен премин од течна кон цврста исхрана, со цел да се овозможи заздравување на желудникот, да се обезбеди адекватен внес на протеини (>60–80 g/ден) и да се минимизираат постоперативните компликации. Високопротеинската исхрана е клучна за одржување на метаболичкото здравје и превенција на нутритивни дефицити.

Клучни зборови: Дебелина, индекс на телесна маса (BMI), баријатриска хирургија, долгорочно намалување на телесната тежина, телесна композиција

1. INTRODUCTION

Obesity has been described as “an abnormal or excessive fat accumulation that presents a risk to health” according to the World Health Organization (WHO), but in reality, excessive fat is seldom directly measured (Blundell et al., 2014). Instead, body mass index (BMI), which is calculated as weight divided by height squared, is commonly utilized to categorize overweight (25.0-29.9 kg/m²) and obese (≥ 30.0 kg/m²) individuals. Though it is a useful tool that is also inexpensive to measure, it does not measure fat distribution, which limits its precision as a tool in the new era of personalized medicine (Gómez-Ambrosi et al., 2011, 2012a). For instance, an individual classified as having class I obesity can have a visceral fat index and total adiposity comparable to those of an individual classified as having a much higher BMI (Gómez-Ambrosi et al., 2014). However, it has been shown to be a strong predictor of overall mortality, where excess mortality at a BMI of 30 kg/m² or greater is due to vascular causes (Flegal et al., 2013, 2015). Increased BMI values have been associated with decreased life expectancy by 2-4 years at 30-35 kg/m² and by 8-10 years at 40-45 kg/m², which is comparable to the impact of smoking (Kitahara et al., 2014). In addition, even increased BMI values within the high-normal percentiles have been associated with long-term cardiovascular and all-cause mortality in adolescence (Twig et al., 2016). The study by Morina & Brestovci, 2022 revealed a high prevalence of overweight and obesity in adults in Kosovo, which is in accordance with trends observed in other ethnic groups in Eastern Europe (Blundell et al., 2017; Stepaniak et al., 2016). In this study, 46.5% were overweight and 21.5% were obese, which is in accordance with previous reports that suggested that more than half of European adults were overweight and obese (Berghöfer et al., 2008; Peytremann-Bridevaux et al., 2007). In this study, it was observed that women were more obese than men, which is in accordance with previous reports that suggested that gender differences exist in body composition and fat distribution (Manios et al., 2005; de Salas et al., 2016). In this study, it was observed that older adults (>60 years) were more overweight and obese than younger adults, which is in accordance with previous reports that suggested that weight gain

increases with age due to a decrease in metabolic rate and physical inactivity and alterations in body composition that occur with age (Ng et al., 2014; Guh et al., 2009). Socio-economic factors such as education, employment, place of living, and marital status were found to have a significant association with weight status, thus confirming previous studies indicating that lifestyle, occupation, and urbanization play a role in obesity risk (Sarlio-Lähteenkorva et al., 2006; de Salas et al., 2016). Significantly, individuals living in urban areas were found to have higher levels of overweight and obesity compared to those living in rural areas, which could be related to differences in dietary intake, sedentary lifestyle, and availability of processed foods (Murtagh & Murphy, 2015; Blundell et al., 2017). In addition, retirees and those with lower levels of education were found to have high levels of obesity, thus emphasizing the role of socio-demographic factors. Therefore, there is a need to develop strategies to address overweight and obesity, especially in Kosovo, where such factors could have a significant impact on health outcomes. This could lead to reduced economic burden in the future (Wilkinson et al., 2014; NCD Risk Factor Collaboration, 2016). Therefore, this study affirms that socio-demographic factors are statistically significant to weight status, thus providing a foundation for future prevention programs targeting the Kosovar community.

The objective of this study is to assess the long-term alterations in anthropometric parameters such as BMI, body fat percentage, and excess weight loss after a weight reduction program for a period of 3-5 years. Moreover, the present study also aims to assess the association between weight loss and alterations in body composition, as well as the dynamic role of bariatric and metabolic surgery in the treatment of obesity and metabolic disorders beyond the traditional BMI parameters.

2. MATERIALS AND METHODS

The study is based on a descriptive longitudinal approach for anthropometric results over a period of 3-5 years, using adapted secondary data from published sources (Engin, 2017) and existing data on bariatric and metabolic surgery. The study population is defined as a group of people with severe obesity, with a BMI of 45 kg/m² and a percentage of body fat of 52%. The study results are based on BMI, percentage of body fat, and EWL, measured over a period of time from baseline up to 3-5 years. A descriptive study was conducted to determine the trends for weight loss, peak weight loss, and weight stabilization. Furthermore, a narrative study of existing evidence-based guidelines from ASMBS and ESPEN was conducted, focusing on postoperative nutritional management, dietary phases, and clinical recommendations.

3. RESULTS AND DISCUSSION

3.1 Long-term changes in body mass index, body fat percentage, and excess weight loss following weight-loss intervention

The results shown in Table 1 indicate significant long-term changes in body mass index (BMI), body fat percentage, and excess weight loss (EWL) after a period of 3-5 years. A major improvement in anthropometric parameters is seen in the first year after intervention. This is followed by a period of stabilization with minimal variations in the following years. This is consistent with the weight loss studies conducted in the long term by Buchwald et al. (2004) and Sjöström et al. (2007). At baseline, the subjects exhibited severe obesity as

indicated by a BMI of 45 kg/m² and a body fat percentage of 52%. This is consistent with severe obesity in subjects who are candidates for bariatric or metabolic surgery (Ng et al., 2014). A significant reduction in BMI is seen in the first month, reducing to 40 kg/m². At the same time, there is a minimal reduction in body fat. This is consistent with the metabolic responses seen in the early stages after intervention (Adams et al., 2007). A major reduction in BMI is seen in the third month, reducing to 38 kg/m². At the same time, there is a significant reduction in body fat to 45%. At the same time, EWL increased to 45%, reflecting rapid weight loss. This period is characterized as the most dynamic period in weight loss (Courcoulas et al., 2013). At the end of the sixth month, BMI decreased to 36 kg/m², and body fat decreased to 38%. At the same time, EWL increased to 62%, reflecting the effectiveness of the intervention. The most significant weight loss outcomes were noted after the first year. At this time, BMI decreased to 32 kg/m², and body fat decreased to its lowest value of 36%. At the same time, EWL increased to its peak value of 69%. This is in agreement with the literature that indicates that the greatest weight loss is noted in the first year after the intervention (Angrisani et al., 2015). At the long-term follow-up period, minimal changes were noted in the weight loss outcomes. At two years after the intervention, BMI decreased to 29 kg/m², but body fat increased to 38%. At the same time, EWL decreased slightly to 66%.

Table 1. Changes in body mass index, body fat percentage, and excess weight loss during a 3–5 year follow-up period

Time	BMI (kg/m²)	Body Fat (%)	EWL (%)
Baseline	45	52	0
1 month	40	51	22
3 months	38	45	45
6 months	36	38	62
1 year	32	36	69
2 years	29	38	66
3–5 years	30	39	64

(Adopted from: Engin, 2017)

These observations indicate metabolic adaptation and behavioral changes (Magro et al., 2008). The BMI increased slightly to 30 kg/m² at 3-5 years, while the body fat increased to 39%. The EWL reduced to 64%. However, the clinical outcomes were significantly improved compared to the baseline values. The maintenance of the BMI near 30 kg/m² is a significant clinical improvement. The reduction in body fat from 52% to 39% is a significant clinical improvement. The clinical improvement observed in the outcomes leads to the reduction of obesity-related comorbidities (Hruby & Hu, 2015). It is important to highlight the difference between total weight loss and changes in body composition. The BMI does not distinguish between fat mass and fat-free mass (Frühbeck, 2015). The initial weight loss may include a significant loss in fat-free mass. This is clearly observed in the first month of the study. Preservation of fat-free mass is critical to metabolic stability. Muscle is critical to glucose metabolism and insulin sensitivity (Blundell et al., 2012). Excessive loss of muscle mass could have a negative impact on metabolic stability. Conversely, adipose tissue is metabolically active, thus playing a role in inflammation. This tissue secretes adipokines, which affect metabolic processes. Gains in adiposity could have a negative impact on metabolic stability. Chronic inflammation, together with hormonal imbalances, is associated

with fat accumulation. This is related to cardiovascular disease and cancer risk. White adipose tissue is considered an endocrine organ, thus affecting disease progression.

The long-term trends also emphasize the significance of lifestyle changes. Dietary control, physical activity, and medical attention are all significant. Behavioral and psychological issues are also important for long-term success (Wing & Phelan, 2005). Without the implementation of lifestyle recommendations, the patient may regain weight. In conclusion, the study has shown that the intervention is extremely effective. EWL was above 60% after six months. It has been observed that EWL has been above this limit for 3–5 years. This suggests that the long-term outcome has been successful (Buchwald et al., 2004).

3.2 From bariatric to metabolic surgery: Expanding indications beyond BMI-based criteria

The recognition of the fact that the benefits of bariatric surgery go beyond the reduction of body weight has prompted the emergence of metabolic surgery, whose primary objective is the treatment of T2D, even in patients with BMI levels lower than those of bariatric surgery (Rubino et al., 2014). This is a move towards a new concept of treatment that is different from the conventional bariatric surgery concept (Rubino et al., 2016). Although the population undergoing metabolic surgery tends to have lower BMI levels than those of bariatric surgery, their body composition in terms of total and visceral adiposity tends to resemble that of bariatric surgery (Frühbeck, 2015). This has raised questions about the BMI levels that separate the two concepts of surgery.

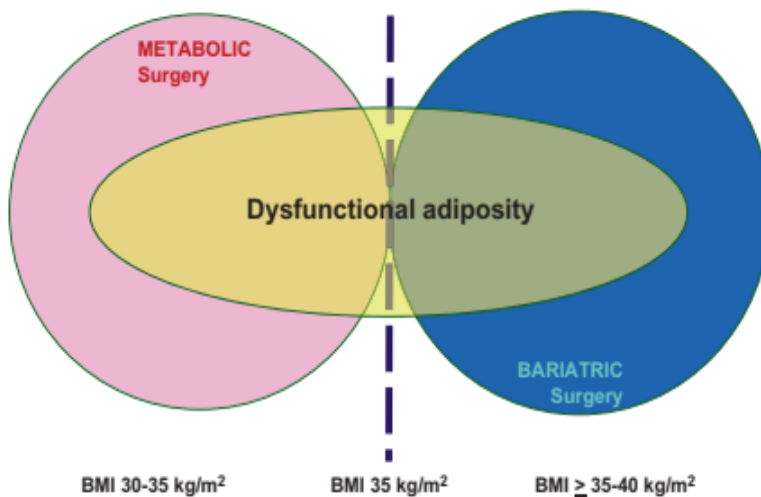


Figure 1. Relationship between metabolic surgery, bariatric surgery, and dysfunctional adiposity according to body mass index (BMI).
(Adopted from: Engin, 2017)

Figure 1 demonstrates the conceptual overlap of metabolic surgery and bariatric surgery with regard to dysfunctional adiposity and BMI. Metabolic surgery is usually recommended for patients with a BMI ranging from 30-35 kg/m², especially when there is the presence of metabolic complications of obesity, such as type 2 diabetes. On the other hand, bariatric

surgery is conventionally recommended for patients with a BMI of ≥ 35 -40 kg/m². The overlap of the two areas represents dysfunctional adiposity, emphasizing the fact that metabolic complications of obesity cannot be fully explained by BMI but also by the distribution and function of adipose tissue. Notably, bariatric surgery is characterized by both weight loss effects and metabolic effects, thus creating a somewhat artificial boundary between metabolic surgery and bariatric surgery. Patients undergoing metabolic surgery have considerable adipose tissue dysfunction and cardiometabolic disorders similar to those found in patients with morbid obesity. Weight loss is a common consequence of metabolic surgery, thus creating difficulties in separating the effects of gastrointestinal anatomical changes from those of weight loss. Differences in the objectives of therapy may also be a factor in the patient population. Patients seeking metabolic surgery may be older, more likely to be male, and have more severe metabolic comorbidities, including T2D, hypertension, dyslipidemia, and cardiovascular disease (Cefalu et al., 2016; Moncada et al., 2016). Patients with BMI < 35 may also have osteoarthritis and other metabolic disorders associated with obesity that impair their ability to move and lose weight (Frühbeck, 2015). In these patients, surgery may relieve the mechanical and inflammatory aspects of the disease. Thus, bariatric and metabolic surgery may be applicable to a wider population than is currently defined by BMI. The strict semantics may not capture the complex pathophysiology of the disease and may not allow a wider population to benefit from a multidisciplinary treatment modality.

3.3 Nutritional dietary plan after laparoscopic sleeve gastrectomy

The significance of the findings of the study lies in the emphasis placed on the role of nutritional dietary plans in the postoperative period in achieving positive outcomes in the process of laparoscopic sleeve gastrectomy surgery. The findings of the study show that the implementation of the nutritional dietary plan by gradually increasing the texture of the diet from liquid to pureed and finally to a normal diet facilitates the healing of the stomach and minimizes complications after the surgery. In the first week after the surgery (1-2 weeks), the liquid diet with a high concentration of water and protein is important for the replenishment of fluids and the initiation of the intake of protein for the healing of the stomach tissues (Table 2) (Cederholm et al., 2021). In the second week after the surgery (2-4 weeks), the nutritional focus is the intake of protein with a minimum of 60-80 g per day. This stage is important in maintaining anabolic states and ensuring that nutritional deficiencies are avoided in the early stages. In the long-term stage (>6-8 weeks), the consumption of food in small, frequent meals in the form of solids and slow eating and mastication will help in adapting the digestive system and managing weight in a sustained manner. A high-protein diet with low carbohydrate content is still the cornerstone in long-term success (>6-8 weeks) (Busetto et al., 2022). Moreover, it has been observed from the results that adherence to clinical guidelines by individuals will lead to better metabolic outcomes and weight management in a sustained manner. It is important to ensure that individuals are well-hydrated (>1.5 L/day), and it is important to provide supplements in a sustained manner and avoid carbonated drinks and high-fat and high-sugar content food and drinks. From a general perspective, it is important to integrate nutritional care with surgery. Even though LSG is effective in bringing about significant weight loss, long-term success is largely dependent upon patient compliance with dietary advice and lifestyle modifications. The phased nutritional model not only aids in physiological recovery but also leads to long-term dietary habits that result in better body composition and metabolic well-being.

Table 2. Postoperative nutritional dietary plan after LSG

Nutrition Phase	Duration	Recommended Intake and Nutritional Goals	Example Foods
Phase 1 – Liquid Diet	1–2 weeks post-surgery	Clear and protein-enriched liquid diet aimed at healing the gastric staple line, preventing dehydration, and ensuring minimal protein intake (≥ 60 g/day). Frequent, small fluid intake is recommended.	Water, unsweetened herbal teas, clear broth (fat-free), protein shakes (whey or plant-based), diluted lactose-free milk, sugar-free electrolyte solutions
Phase 2 – Pureed Diet	2–4 weeks post-surgery	Gradual introduction of pureed and soft foods with high protein content. The goal is to maintain protein intake ≥ 60 –80 g/day and avoid concentrated sugars and saturated fats.	Pureed cooked chicken or turkey, pureed fish, low-fat yogurt or kefir, pureed boiled eggs, cottage cheese, pureed lentils or beans, pureed cooked vegetables
Phase 3 – Soft and Solid Diet	6–8 weeks post-surgery and beyond	Introduction of solid foods in small portions (3–5 meals/day), with slow eating and thorough chewing. Long-term recommendations include a high-protein, nutrient-dense diet with limited refined carbohydrates and processed foods.	Baked or boiled lean meat, fish, eggs, low-fat dairy products, legumes, soft peeled fruits, cooked vegetables, whole grains in small quantities

4. CONCLUSION

Weight loss interventions, including bariatric and metabolic surgeries, are effective in producing considerable weight loss in terms of BMI, body fat, and excess weight loss, particularly in the first year, which is considered to be a critical period to attain maximum weight loss results. However, stabilization of weight loss and a small amount of weight gain suggest that long-term lifestyle modifications, including dietary intake and physical activity, are essential. The results of this study also suggest that reduction in BMI does not entirely account for alterations in body composition, indicating that maintenance of fat-free mass, as well as prevention of regaining adiposity, is essential to maintain a state of health. Moreover, the shift from bariatric to metabolic surgeries indicates that a more holistic approach to managing obesity is necessary. In this regard, dietary regimens are essential in managing long-term health.

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ETHNOBOTANICAL AND PHYTOCHEMICAL ACTIVITIES OF *Rosa canina* L. FROM R.N. MACEDONIA

ЕТНОБОТАНИЧКА И ФИТОХЕМИСКА АКТИВНОСТ НА *Rosa* *canina* L. ОД МАКЕДОНИЈА

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Abstract: *Rosa canina* L. has a significant ethnobotanical importance with a rich history of traditional uses across various cultures. The goal of this study was to determine the potential of *Rosa canina* L. as a source of bioactive compounds for use in the pharmaceutical, cosmetic and food industries. This study provides a comprehensive ethnobotanical analysis of the utilization of *Rosa canina* L. across different regions from R.N. Macedonia, especially in traditional medicine, food and for other purposes. The research methodology involved a review of ethnobotanical literature and interviews with local residents. Rosehip is a nutritionally valuable fruit containing substantial amounts of bioactive compounds. Fruits with a mass of 1.147 g, a length of 18.88 mm and a width of 11.00 mm contain 356 mg/100 g vitamin C, 38 799 mg/kg total phenols, 73 mg/kg total anthocyanins, 615 mg/kg flavan-3-ols and have high antioxidant activity (89.2% inhibition). In traditional medicine, *Rosa canina* L. is used as a remedy for colds, flu, inflammation and for improving immunity, against anemia, for better functioning of the heart and blood vessels, against diarrhea, for reducing high blood pressure, for stomach diseases and gastritis. This plant has antiviral and immune-boosting, antioxidant, anti-inflammatory, antibacterial, anti-aging, anticancer, antiproliferative, antidiabetic, cardioprotective, hepatoprotective and protective effect against kidney diseases. The fruits are used dried (for tea) and processed into syrups, juices, jams, liqueurs and wines. Roasted fruits and seeds are used as raw material for coffee. Teas, preparations and lotions are made from leaves and flowers. This research consolidates existing ethnobotanical knowledge and highlights the need for sustainable conservation efforts to ensure the continued availability of this valuable botanical resource.

Key words: *Rosa canina* L., rosehip, ethnobotanical, phytochemical activities.

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Апстракт: *Rosa canina* L. има значајно етноботаничко значење со богата историја на традиционална употреба во различни култури. Целта на оваа студија беше да се утврди потенцијалот на *Rosa canina* L. како извор на биоактивни соединенија за употреба во фармацевтската, козметичката и прехранбената индустрија. Оваа студија обезбедува сеопфатна етноботаничка анализа на употребата на *Rosa canina* L. во различни региони од Р.С. Македонија, особено во традиционалната медицина, храната и за други цели. Методологијата на истражување вклучуваше преглед на етноботаничката литература и интервјуа со локалните жители. Шипката е хранливо вредно овошје кое содржи значителни количини на биоактивни соединенија. Плодовите со маса од 1,147 g, должина од 18,88 mm и ширина од 11,00 mm содржат 356 mg/100 g витамин Ц, 38 799 mg/kg вкупни феноли, 73 mg/kg вкупни антоцијанини, 615 mg/kg флаван-3-оли и имаат висока антиоксидантна активност (89,2% инхибиција). Во традиционалната медицина, *Rosa canina* L. се користи како лек за настинки, грип, воспаленија и за подобрување на имунитетот, против слабокрвност, за подобра работа на срцето и крвните садови, против дијареа, за намалување на висок крвен притисок, за стомачни заболувања и гастритис. Ова растение има антивирусно и имуно-засилувачко, антиоксидативно, антиинфламаторно, антибактериско, антистареешко, антиканцерогено, антипролиферативно, антидијабетско, кардиопротективно, хепатопротективно и заштитен ефект против бубрежни заболувања. Плодовите се користат сушени (за чај) и преработени во сирупи, сокови, џемови, ликери и вина. Печеното овошје и семките се користат како сировина за кафе. Чаеви, препарати и лосиони се прават од лисја и цветови. Ова истражување ги консолидира постојните етноботанички знаења и ја истакнува потребата од одржливи напори за зачувување за да се обезбеди континуирана достапност на овој вреден ботанички ресурс.

Клучни зборови: *Rosa canina* L., шипка, етноботаничка, фитохемиска активност

1. INTRODUCTION

Rosehip (*Rosa canina* L.) commonly known as dog rose, wild rose, “ship” is a perennial deciduous ornamental plant of the *Rosaceae* family. It blooms in May and June, depending on climatic conditions and altitude. The fruits are small, red, with an ovoid or elliptical shape. Growing wildly around the globe in areas such as Asia, North America, Europe, Middle East. In R.N. Macedonia *Rosa canina* L. is found on all mountains up to 1600 m altitude. It is found in places exposed to the sun, most often on southern slopes, on hill and mountain pastures, forest clearings, along rivers and streams, along roads, fences, etc. It grows on all types of soils (Micevski, 1998).

Rosehip is a nutritionally valuable fruit containing substantial amounts of bioactive compounds, such as vitamins, minerals, antioxidants, and phenolic compounds, which contribute to its health-promoting properties. The main bioactive compounds of rosehip are phenolic acids, anthocyanins, tocopherols, tannins (Kubczak et al., 2020; Tabaszewska and Najgebauer-Lejko, 2020) and flavonoids (flavan-3-ols) (Dabic Zagorac et al., 2020). Phenolic acids, including ellagic acid and gallic acid, along with anthocyanins such as cyanidin-3-glucoside, further enrich this complex phytochemical profile (Butkeviciute et al., 2022). The main carotenoids found in rosehips are lutein, zeaxanthin, β -carotene and lycopene, also responsible for the characteristic red color (Winther et al., 2016; Medveckiene et al., 2020). Rosehip contains tocopherols and essential fatty acids, sterols (Grajzer et al., 2015; Topkafa, 2016).

The content of these bioactive compounds allows this plant to have antiviral and immune-enhancing, antioxidant, anti-inflammatory, antibacterial, anti-aging, anti-cancer, anti-

proliferative, anti-diabetic, cardioprotective, hepatoprotective and protective effects against kidney diseases. *Rosa Canina* have a rich ethnobotanical history. Its significance in traditional cultures spans various regions across the globe and it has been used for numerous purposes, including medicinal, culinary and cultural.

Due to the increasing pollution and industrialization on the one hand and the development of the concept of organic production and the new trends in nutrition aimed at so-called "healthy food" on the other hand, there has recently been an increased interest in wild fruit species and their use for the production of ecologically healthy food in many countries around the world. As such, they have great potential in the sustainable development of rural areas and their use and popularization are in line with sustainable resource management. Due to their adaptability and resilience, the promotion of wild fruit species can be considered as one of the most promising efforts to mitigate climate change. On the other hand, by collecting fruits and other plant parts and processing them, significant economic gains can be achieved, especially for people in rural areas. They are an important raw material for the cosmetic, pharmaceutical, chemical, food, wood, textile industries, etc.

2. MATERIAL AND METHODS

The results of the studies are part of the scientific research project "Ethnobotanical research of wild fruit species", which included an ethnobotanical and analysis of the polyphenolic composition of *Rosa canina* L.

The information about traditional knowledge of *Rosa canina* was gathered by direct interviews with 278 respondents from different regions of R.N. Macedonia. North Macedonia is situated in the central part of the Balkan Peninsula and is divided into eight statistical regions. The survey was conducted with the assistance of agricultural advisors of the National Extension Agency in the eight regions: 1-Skopje region (with the municipalities Saraj, Chucher Sandevo, Butel, Gjorce Petrov, Aerodrom, Petrovec, Kisela Voda, Gazi Baba, and Ilinden), 2-Northeastern region (with municipalities Kumanovo, Kriva Palanka, Rankovce, Lipkovo and Kratovo), 3-Eastern region (with municipalities Shtip, Vinica, Makedonska Kamenica, Pehchevo, Berovo, Karbinci and Kochani), 4-Southeastern region (with municipalities Strumica, Valandovo, Radovish and Konche), 5- Pelagonia region (with municipalities Bitola, Demir Hisar, Resen and Krushevo), 6-Southwestern region (with municipalities Ohrid, Kichevo, Centar Zhupa, Struga, Debarca and Debar), 7- Polog region (with municipalities Tetovo, Brvenica, Mavrovo-Rostushe and Gostivar) and 8-Vardar region (with municipalities Veles, Kavadarci, Negotino, Rosoman and Chaska), covering the entire territory of the R.N. Macedonia, in the period from January to March 2026. During the interview, respondents shared their knowledge and experience about using rose hips as food and medicine. The collected data were processed using descriptive statistical methods. Frequencies, percentages and mean values were calculated to summarize the socio-economic characteristics of respondents, the regional distribution of collectors, and the purposes of use and sale of *Rosa canina* fruits. The results were comparatively analyzed by regions and presented in tables.

The chemical analyses included determination of the content of vitamin C and selected phytochemicals (anthocyanins, flavan 3-ols, total phenols) and antioxidant activity of the fruits. The fruits were taken from rural areas in the Skopje region. The Skopje region is located at 41°57'N and 21°28'S and belongs to the continental-mediterranean climate-

vegetation-soil region. In recent decades, global climate changes have been observed in this area, expressed through reduced annual precipitation, increased aridity, altered pluviometric regime, reduced temperature, especially in winter and periodic occurrence of heavy frosts.

Chemical analyses were performed in the oenological laboratory of the Institute of Agriculture in Skopje. The content of vitamin C was examined by volumetric method (Sadasivam and Balasubramanian, 1987). Total phenols in the samples are determined according to the Folin-Ciocalteu method (Slinkard and Singleton, 1977). The content of total anthocyanins was determined according to the acid-ethanol method (Somers and Evans, 1977) and p-dimethylaminocinnamaldehyde (p-DMACA) is used for the quantification of flavan-3-ols in the samples (Di Stefano *et al.*, 1989). Determining of the antioxidant activity was performed as an anti-radical activity against the stable product DPPH (2,2-diphenyl-1-picrylhydrazil).

3. RESULTS AND DISCUSSION

Ethnobotanical survey and socio-economic characteristics of collectors: The study included a total of 278 respondents who are collectors of wild fruits from different regions in the R.N. Macedonia. The data presented in Table 1 on the socio-economic structure show that this activity is dominated by men (73.8%), while the participation of women is significantly lower (26.2%). The highest representation of men in the collection of wild fruits is recorded in the Vardar region (96.8%), while the most balanced gender structure is in the Southwestern region, where women participate with 44.7%. The largest share of older collectors is in the Polog region (90%) and the Southwestern region (89.5%).

According to age, the data show that the majority of collectors are older than 40 years (82.4%), while only 17.6% are younger than 40 years, which indicates that this activity is more often performed by people with greater life and work experience. According to employment status, more than half of the respondents are unemployed (57.3%), which also includes retirees, while 42.7% are employed, which shows that collecting wild fruits is a significant source of income, especially for the population that does not have permanent employment.

According to work experience, the majority of respondents have more than 10 years of experience in collecting wild fruits (52.8%), while 35.8% have 3 to 10 years of experience and 11.4% have less than 3 years of experience, indicating that this activity is often practiced long-term and it is a traditional practice in certain regions. The largest share of collectors with more than 10 years of experience is in the Pelagonia region (78%), as well as in the Eastern and Polog regions (70%), indicating a long-standing tradition of collecting wild fruits in these regions.

Table 1. Socio-economic characteristics of wild fruit collectors by regions according to gender, age, employment and work experience (Source: own research)

Regions	Gender (%)		Age (%)		Employment (%)		Years of experience (%)		
	Male	Female	Below 40	Above 40	Employed	Unemployed	1-3	3-10	Above 10
Skopje	66.7	33.3	20.5	79.5	56.4	43.6	25.6	17.9	56.4
Northeastern	67.4	32.6	19.6	80.4	43.5	56.5	8.7	41.3	50.0

Eastern	72.5	27.5	20.0	80.0	42.5	57.5	5.0	25.0	70.0
Southeastern	76.9	23.1	23.1	76.9	61.5	38.5	23.1	61.5	15.4
Pelagonia	87.8	12.2	14.6	85.4	29.3	70.7	2.5	19.5	78.0
Southwestern	55.3	44.7	10.5	89.5	42.1	57.9	13.1	39.5	47.4
Polog	66.7	33.3	10.0	90.0	46.7	53.3	6.7	23.3	70.0
Vardar	96.8	3.2	22.6	77.4	19.3	80.7	6.4	58.1	35.5
Total share	73.8	26.2	17.6	82.4	42.7	57.3	11.4	35.8	52.8

The respondents are collectors of various wild fruits present in the regions. Only 27.7% of them collect rosehip fruits (Table 2). The most rosehip fruits are collected in the North-East (58.7%) and Skopje (41.0%) and the least in the Vardar region (6.4%). Most of them collect rosehip fruits, while very few collect other plant parts. In some regions, such as the Skopje and Southeastern region, the flowers and leaves of the rosehip are collected and used, most often for tea. In the Southwestern region they use the root, most often for tea. 47.7% of the respondents use rosehip for their own use and 60.3% for sale. Some respondents reported both personal consumption and sale of collected fruits. They make various preparations from the fruits (juice, jam, marmalade and wine), from the dried fruits they make tea that is most often used in the prevention and treatment of colds, to improve immunity due to the high content of vitamin C, against anemia, for better functioning of the heart and blood vessels, against diarrhea, to reduce high blood pressure, for stomach diseases and gastritis. The leaves, flowers and root are used for tea. Regarding the placement of the collected fruits, respondents most often sell the fruits through buyers (60-70%), on local markets (40.2%), through buyers (38.1%) and through acquaintances (33.5%). The largest part of the fruit is sold in the Eastern (87.5%), Pelagonia (82.9%) and Northeastern regions (73.9%) (Table 2). The largest quantities of fruits are purchased in the Pelagonia (73.5%) and Eastern region (60.0%).

Table 2. Structure of forest fruit collectors by region, proportion of pickers and distribution methods (%)

Regions	Total number of wild fruit collectors by regions (%)	Rosehip collectors by regions (%)	Aim		Sale		
			Own use (%)	Sale (%)	Buyers (%)	Local market (%)	Acquaintances (%)
Skopje	14.0	41.0	66.7	56.4	9.1	36.4	54.5
Northeastern	16.5	58.7	34.8	73.9	55.9	32.3	23.5
Eastern	14.4	27.5	35.0	87.5	60.0	22.8	22.8
Southeastern	4.7	15.4	69.2	30.8	25.0	50.0	25.0
Pelagonia	14.8	17.1	26.8	82.9	73.5	8.8	17.6
Southwestern	13.7	28.9	73.7	26.3	20.0	50.0	30.0
Polog	10.8	26.7	33.3	66.7	45.0	55.0	50.0
Vardar	11.1	6.4	41.9	58.1	16.7	66.7	44.4
Total average	12.5	27.7	47.7	60.3	38.1	40.2	33.5

Phytochemistry properties: Rosehip is a nutritionally valuable fruit containing substantial amounts of bioactive compounds, such as vitamins, minerals, antioxidants, and phenolic compounds, which contribute to its health-promoting properties. The main bioactive compounds of rosehip are phenolic acids, anthocyanins, tocopherols, tannins (Kubczak et al., 2020; Tabaszewska and Najgebauer-Lejko, 2020) and flavonoids (flavan-3-ols) (Dabic Zagorac et al., 2020). Accordingly, an examination of the vitamin C content and content of select phytochemicals of *Rosa canina* L. fruits was performed.

According to our study, fruits with an average mass of 1.147 g, length 18.88 mm and width 11.00 mm, contain 356 mg/100 g vitamin C, 38 799 mg/kg total phenols, 73 mg/kg total anthocyanins, 615 mg/kg flavan-3-ols and have 89.2 % inhibition antioxidant activity. The percentage of vitamin C in total antioxidant activity is 399 % (Table 3).

Table 3. Content of selected phytochemicals of *Rosa canina* L. fruits

Fruit mass g	Fruit length Mm	Fruit width Mm	Vitamin C mg/100 g	Total phenols mg/kg	Total anthocyanins mg/kg	flavan-3-ols mg/kg	Antioxidant activity (% inhib)
1,147	18,88	11,00	356	38 799	73	615	89,2

The content of chemical materials of *Rosa canina* depends on different factors, such as genotype, species and cultivars, ripening stage, geographical location, altitude, climatic conditions and according Ghazghazi et al. (2010) depends on the methods which are used to store and extract it. The amount of vitamin C is 6.0 to 8.2 mg/g FW (fresh weight) (Peña et al., 2023).

Rose hips that grow in colder climates contain more vitamin C than those that grow in warmer climates. (Pyke and Melville, 1942; Stamberg, 1945). The highest concentration of vitamin C is typically found in mature, hardened rosehips ranging from 400 to 1500 mg/100 g (Bilgin et al., 2020; Harrison et al., 2014; Ermolaev and Fedorov, 2022). Ripe, red fruits contain a higher amount of vitamin C (417.5 mg/100 g), compared to the green fruits (18.0 mg/100 g) and orange fruits (175.0 mg/100 g) (Nojavan et al., 2008). Fruits of *Rosa canina* collected from higher altitudes contain more vitamin C than fruits collected from lower altitudes (Pyke and Melville, 1942). The amount of efficient compounds varies in different parts of rose hip. This plant contained a considerable amount of vitamin C, especially in the peel, while the seeds contained the greatest amount of oil (Georgieva et al., 2014).

The content of total polyphenols in rose hip fruits is from 10.89 mg GAE/g (gallic acid equivalent/g) to 26.49 mg GAE/g (Butkeviciute et al., 2022), 12.07 to 37.17 mg GAE/g DW (dry weight) (Mihaylova et al., 2015). According to Fascella et al. (2019) *Rosa canina* and *Rosa sempervirens* have the highest total polyphenol contents (6784.5 and 6241.2 mg GAE/100 g DW, respectively) and the highest antioxidant activities than *Rosa corymbifera*, *Rosa micrantha* species.

According to the content of anthocyanins, rosehip fruits have a lower content than some fruit species like blackberry 58.61 mg/100 g FW, red raspberry 14.69 mg/100 g FW, strawberry 16.03 mg/100 g FW, blueberry 29.72 mg/100 g FW, sweet cherry 26.72 mg/100 g FW (de Souza et al., 2014). In terms of flavanol content, rosehip fruits contain more flavanols than strawberry 38.17 mg CE/100 g FW (Catechin Equivalents/100 g), blueberry 47.53 mg CE/100 g FW, sweet cherry 59.92 mg CE/100 g FW (de Souza et al., 2014). Butkeviciute et al. (2020) in the fruits of *Rosa canina*, revealing the presence of flavan-3-ol group compounds such as catechin ranging from 26.30 to 522.48 µg/g, epicatechin ranging from 2.12 to 20.66 µg/g, procyanidin B1 ranging from 1.65 to 40.89 µg/g, and procyanidin B2 ranging from 5.54 to 86.95 µg/g.

Medical uses: Various parts of *Rosa canina* have been traditionally used for medicinal and culinary purposes for centuries. More than 2 000 years ago, people used rosehip for medicinal purposes. Pliny the Elder (23–79 AD) was the first person who described the medicinal properties of *Rosa canina* L. Its use in treating dog bites earned it the name dog rose. In the Canons of Medicine written by Avicenna, rosehip was suggested for treating headaches and some stomach ailments (Khazaei et al., 2020). In folk medicine, the fruits of *Rosa canina* are used as a universal remedy for colds and viral infections, fever (Lustrup and Winther, 2022), as well as exerting a positive influence on the osteoarthritis, anxiety, depression, recognition memory, urinary and reproductive systems disorders, and neutrophil respiratory burst (Khazaei et al., 2020), for reducing cholesterol and high blood pressure, for better appetite and strengthening the immune system (Selahvarzian et al., 2018). During World War II, rosehip syrup was used in the UK as a food and to prevent scurvy. In folk medicine, the oil is used to treat skin burns, treat wrinkles, remove scars and tone the skin. Fruit tea is recommended for women who have given birth, as well as for people who have kidney problems and whose body has a tendency to form kidney stones. It helps to excrete harmful substances from the body and against arthritic pain. In R.N. Macedonia, rosehip is most often used to improve immunity, against colds and flu.

With a rich ethnobotanical history and documented phytochemical profile, rosehip has garnered attention for its therapeutic potential across various health domains.

Antiviral and immune-boosting effect: One of the most well-known benefits of rosehips is their ability to boost the immune system. This is due to their high content of vitamin C, which has been shown to enhance immune function by increasing the production of white blood cells and antibodies (Medveckienė et al., 2021).

Rosehip fruits are rich in antioxidant compounds, especially vitamin C (30–1 300 mg/100 g), more than other fruits and vegetables (Ziegler et al., 1986). *Rosa canina* fruits contain more vitamin C than blackberry (52.41 mg/100 g FW), red raspberry (92.17 mg/100 g FW), strawberry (90.13 mg/100 g FW), blueberry (73.21 mg/100 g FW), sweet cherry (62.42 mg/100 g FW) (de Souza et al., 2014), black currant 216.0 mg/100 g, white mulberry 29.9 mg/100 g, black chokeberry 24.2 mg/100 g (Selamovska et al., 2024), some indigenous varieties of apple (*Malus domestica*) 9.37 mg/100 g, pomegranate (23.67 mg/100 g FW), cherry (12.83 mg/100 FW), grape 9.00 mg/100 g FW, tomato 38.25 mg/100 g FW and pepper 51.25 mg/100 g FW (Selamovska et al., 2021–2022).

Antioxidant activity: Rosehip is known to contain the highest amount of vitamin C among other fruits, which could be explanatory for their antioxidant activity. Furthermore, rosehip is rich in carotenoids (lycopene, β -carotene, zeaxanthin) (Pena et al., 2023), tannins, flavonoids, and phenolic acids, bioactive compounds bounded to the antioxidant activity (Kunc et al., 2023). Along the years, it was mentioned that the high antioxidant activity values of rosehip extracts are due to a strong interaction between polysaccharides and organic acids, and most important with phenolic antioxidants (flavonoids and phenolic acids) (Ognyanov et al., 2022). The authors Mihaylova et al. (2015), Butkevičiūtė et al. (2022), determined a positive correlation between total polyphenol and antioxidant activity in *Rosa canina* fruits. This indicates that in *Rosa canina* fruits, total phenols have a large share in the antioxidant activity.

Rosa canina L. fruits contain more total phenolics than blackberry (850.52 mg GAEs/100 g FW), red raspberry (357.83 mg GAEs/100 g FW), strawberry (621.92 mg GAEs/100 g FW), blueberry (305.38 mg GAEs/100 g FW and sweet cherry (314.45 mg GAEs/100 g FW) (de Souza et al., 2014).

Compared to the other fruit species, *Rosa canina* fruits have higher antioxidant activity than some indigenous fruit varieties of pomegranate 81.58%, indigenous varieties of apple 60.37%, indigenous varieties of cherry 43.36% (Selamovska et al., 2021–2022), *Ribes nigrum* 86.2 %, *Morus Alba* 71.6 %, *Aronia melanocarpa* 76.4 %, *Rubus fruticosus* 78.6 %, *Punica granatum* 86.3 % (Selamovska et al., 2024).

Anti-Inflammatory effect: The phenolic compounds present in rosehips have shown anti-inflammatory properties (Medveckiene et al., 2020; Ozdemir et al., 2022). Flavonoids are an example of a polyphenolic compounds that can block transcription factors or regulatory enzymes involved in the inflammatory process (Maleki et al., 2019). The presence of phenolic compounds in rosehip represents the main reason why rosehip has an anti-inflammatory effect. In our study, fruits with a mass of 1.147 g, length 18.88 mm and width 11.00 mm contained 615 mg/kg flavan-3-ols (Table 3). Some strawberry cultivars contain more flavanols 38.17 mg CE/100 g FW, blueberry 47.53 mg CE/100 g FW, sweet cherry 59.92 mg CE/100 g FW. (de Souza et al., 2014).

Antibacterial effect: The fruit ethanol extract of *Rosa canina* has antimicrobial activity against *E.coli*. Rose hip flower ethanol extract had the best antibacterial activity against *Pseudomonas aeruginosa* and against *Escherichia coli* (Rovná et al., 2015).

Anti-aging effect: The phenolic compounds present in rose hips have anti-aging effects on the skin. (Sallustio et al., 2023). Furthermore, the presence of antioxidants in rose hips confers protective effects against inflammation, a key factor implicated in the onset and progression of chronic diseases like cancer, diabetes, and cardiovascular ailments.

Anticancer and antiproliferative effect: The results of the study showed that the ethanol extract of rosehip had a cytotoxic effect on the MCF-7 and MDA-MB-468 cancer cell lines depending on the dose of exposure without affecting normal cells (Berkoz et al., 2019). Rosehip extracts have been shown to have antiproliferative and antioxidant properties in Caco-2 human colon cancer cells. Rosehip extracts are a potent antioxidant that inhibits cell proliferation in Caco-2 cells (Jiménez et al., 2016).

Antidiabetic and antihyperlipidemic effect: Rosehip extract's beneficial effects in diabetes management are linked to its ability to modulate cell signaling pathways involved in glucose metabolism and insulin sensitivity, ultimately influencing the overall metabolic state and reducing the risk of diabetes progression (Taghizadeh et al., 2016).

Protective effect against kidney diseases: In the traditional medicine rosehip extract could prevent and possibly eliminate preexisting kidney stones (Tayefi-Nasrabadi et al., 2012).

Cardioprotective effect: Rosehip is an effective dietary supplement for preventing the formation of atherosclerotic plaques by modulating systemic blood pressure and the expression of RCT and inflammatory genes (Cavalera et al., 2017). The conclusion of the study shows that they found that blood pressure and atherosclerotic plaques, as well as oxidized LDL, total cholesterol, and fibrinogen levels, are lower when consuming rosehip fruits. In the study by Nasrolahi et al. (2020), the cardioprotective effects of rosehip methanolic extract were evidenced by its ability to modulate the expression of critical markers related to ER (endoplasmic reticulum) stress.

Hepatoprotective effect: The rosehip qualifies as a hepatoprotective herb (Ghanbari-Niaki et al., 2022). The alcoholic extract of rosehip had a protective effect on liver tissue (Banan Khojasteh et al., 2017).

Culinary delights: Rosehip emerges as a potential candidate due to its wide- ranging functionalities. The increasing focus on sustainability and eco-friendly practices in industries has sparked interest in rose hip's potential in applications beyond traditional medicine. Rosehip is utilized in various culinary preparations. The fruits, leaves and flowers are useful for humans. The fruits are consumed raw, dried (for tea) and processed into syrups, juices, jam, marmalade, liqueur, wine, vitamin concentrates, etc. Roasted fruits and seeds are used as a raw material for coffee. The flowers are used as an additive in salads, for the preparation of sweets, etc. The potential applications of rosehips in the food industry make them a promising ingredient for the development of functional products that promote health and wellness. In this regard, both the rose hips and their by-products offer a wide range of potential applications in functional foods and dietary supplements, for obtaining probiotic drinks, yogurts and soups, in addition to the production of conventional products. Its inclusion in functional foods, nutraceuticals, cosmetics and pharmaceuticals has been explored, showcasing its versatility and economic potential. As a result, value-added foods, or functional foods with higher levels of dietary fiber and antioxidants have evolved, especially in bakery and cereal products like cookies, gingerbread or noodles. Moreover, by-products of rosehip are valorized in cereal products such as noodles. In Turkish noodles, flours from seed of rosehip, grape and pomegranate were added in concentrations of 10, 20 and 30 %. The addition of 10 % of these seed flours presented significant antioxidant activity (Koca et al., 2018). Substitution of flour in a standard cookie recipe with 15 % rosehip powder and 25 % hibiscus powder showed to increase total phenolic content, antioxidant capacity all along high acceptance when it comes to sensory evaluation (Antarkar et al., 2019). The incorporation of rosehip flour in bread dough has led to a significant increase in the bread's nutritional value and improved its rheological properties, with a positive correlation observed with the amount of rosehip flour used (Gül and Sen, 2017). The rosehip could be a potential substitute for synthetic ascorbic acid in the bakery industry (Vartolomei and Turtoi, 2021). By adding 5% and 10% rosehip puree, the physicochemical properties of the extrudates are improved and they are enriched with flavonols, carotenoids, vitamin C and folates (Igual et al., 2021). Moreover, rosehip presents applications in meat industry as well, where was most added to products such as sausages. Polyphenols extracted from rosehip added to pork sausages at a concentration of 0.005 %, along with 0.01 % sodium nitrite, can delay lipid oxidation, protein degradation, microbial growth, and preserve the bright red color, flavor, and taste of smoked pork sausages for up to 20 days of refrigeration storage (Nicorescu et al., 2018). Also, Armenteros et al. (2013) showed that natural antioxidants from strawberry and rosehip in frankfurter sausages in combination with traditional additives (sodium ascorbate and nitrite) enhanced the oxidative stability without modifying the color and texture properties of sausages. Rosehip can act as a natural antioxidant in meat sausages, but not as a full replacer for traditional additives (Vossen et al., 2012). The eggs that come from hens fed with rosehip and flaxseed presented high essential amino acids, antioxidant amino acids, and sulfur amino acids contents (Vlaicu et al., 2022).

The leaves and flowers are used to make teas, various preparations and lotions for skin treatment. Regarding rosehip, studies have primarily focused on the valorization of its seeds and pomace. Cold-pressed rosehip seed oil is a valuable source of bioactive compounds, including mono/polyunsaturated fatty acids (oleic and linoleic acids) (Franco et al., 2007).

Furthermore, the diverse bioactivities exhibited by rosehips render them a highly promising ingredient for the formulation and development of nutraceuticals, cosmetics, and pharmaceutical products (Negrean et al., 2024). Moreover, Darie-Nita et al. (2021) research focused on developing an ecological packaging PLA-based containing bio-plasticizers and chitosan modified with rosehip seed oil. Accordance with the obtained results, the elaborated formulations had tensile strength and flexibility depending on whether their composition is rigid or flexible, as well as antibacterial and antioxidant activity, which may allow for prolonged use for food packaging. The created biocomposites made of PLA, chitosan modified, and additives (rosehip seed oil) displayed enhanced processability as well as physical-mechanical, thermal, water vapor barrier, antioxidant and antibacterial characteristics suited for application in food packaging (Darie-Nița et al., 2021).

4. CONCLUSION

Rosehips is a widely distributed plant species in R.N. Macedonia. It is found in all regions. The fruits are used dried (for tea) and processed into syrups, juices, jams, liqueurs and wines. In the past, roasted fruits and seeds are used as raw material for coffee. Teas, preparations and lotions are made from leaves and flowers.

Rosehip is a nutritionally valuable fruit containing substantial amounts of bioactive compounds, vitamin C, total phenols, flavan-3-ols, total anthocyanins, and have high antioxidant activity (89.2% inhibition). In traditional medicine, *Rosa canina* L. is used as a remedy for colds, flu, inflammation and for improving immunity, against anemia, for better functioning of the heart and blood vessels, against diarrhea, for reducing high blood pressure, for stomach diseases and gastritis.

Rosehips and their by-products have gained significant attention in recent years due to their abundance of bioactive compounds which are linked to a wide array of health benefits. Despite the promising health benefits of rosehips, there is still a lack of research on their bioactive compounds and potential applications in functional products.

From the total number of respondents who collect fruits from wild fruit species, only 27.7% of them collect rosehip fruits. The most rosehip fruits are collected in the Northeastern (58.7%) and Skopje region (41.0%) and the least in the Vardar region (6.4%). 47.7% of the respondents use rosehip for their own use and 60.3% for sale. They most often sell the fruits in local markets (40.2%), through buyers (38.1%) and through acquaintances (33.5%).

Despite its high nutritional value, good adaptability to environmental conditions and climate change, as well as the possibilities for its use in various industries and for various purposes, we believe that there is not enough awareness of its importance, which is why more attention needs to be paid to this plant species.

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IMPACT OF ECONOMY, ENERGY AND ECOLOGY ON SUSTAINABLE DEVELOPMENT

UTICAJ EKONOMIJE, ENERGETIKE I EKOLOGIJE NA ODRŽIVI RAZVOJ

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Abstract: The implementation of sustainable development involves defining a sustainable development policy and using adequate economic, energy, environmental and other instruments for the implementation and control of strategic solutions. By adopting sustainable development strategies, the governing bodies of countries in the modern world order should promote the use of economic instruments in financing the environment and ensuring the implementation of the basic principles of sustainability. Respect for the principles of sustainable development, at the national, regional, local and enterprise levels, implies the application of economic instruments in the field of environment, general and sectoral policies. The connection of quality management systems, new technologies and environmental and energy management systems are the basic conditions for sustainable development, which is based on enterprise management ready to find a compromise between economic, energy and environmental requirements. Their connection is direct and mutually conditioned, and is therefore the subject of simultaneous consideration from the standpoint of causes, consequences, and possible overcoming.

Key words: Economy, Energy, Ecology, sustainable development, environment.

Анстракт: Примена одрживог развоја подразумева дефинисање политике одрживог развоја и коришћење адекватних економских, енергетских, еколошких и других инструмената за примену и контролу стратегијских решења. Органи руковођења, у државама савременог светског поретка, усвајањем стратегија одрживог развоја требало би да унапреде коришћење економских инструмената у финансирању животне средине и обезбеђивању спровођења основних начела одрживости. Поштовање начела одрживог развоја, на националном, регионалном, локалном и нивоу предузећа, подразумева примену економских инструмената у области животне средине, опште и секторских политика. Повезивање система управљања квалитетом, нових технологија и система управљања заштитом животне средине и енергетиком, основни су услови одрживог развоја, који је заснован на менаџменту предузећа спремном да нађе компромис између економских, енергетских и еколошких захтева. Њихова веза је директна и међусобно условљена, па је због тога предмет истовременог сагледавања са становишта узрока, последица и могућих превазилажења.

Кључне речи: Економија. Енергетика. Екологија, одрживи развој, животна средина.

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1. INTRODUCTION

The living and working conditions of modern generations can be said to be characterized by a general state of crisis and uncertainty. In fact, old problems related to insufficient energy, food and water supplies have not yet been resolved. However, new problems have emerged: general exposure to terrorist acts, mass migration of the population from war-torn areas, etc.

Classical theorists of economic growth emphasize several of its economic policy factors, such as: the importance of savings and investment, education, technological innovation – research and development, population growth and free trade. Today, a new economic paradigm – sustainable development – is increasingly dominant, encompassing economic growth but also important aspects of environmental protection and corporate responsibility.

The concept of sustainability is not new. Its roots can be found in the works of classical economics, in early attempts to answer the question of what the prospects for the development of human society are. An extensive overview of the development of economic thought on the environment was given by E. Kula (1998). Smith and Ricardo, and especially Malthus, sought answers to questions related to the limitation of natural resources, primarily land, then to demographic growth, and to diminishing returns to production.

The main goal, in this regard, is to point out the unequivocally strong correlation between the economics of ecology and energy.

The interaction of the three main branches in terms of resolving the accumulated contradictions should lead to the goal that is being pursued – sustainable development, in the sense of the imperative that today's economic prosperity is not based on the ruthless exploitation of nature and its capacities for the benefit of contemporary generations, but rather to leave to future generations at least that part of the natural resources that today's generations inherited from their ancestors. The green economy aims, therefore, to solve the main identified problems of today: shortages of food, drinking water and energy, along with drastic environmental pollution. Of course, solutions are offered in the form of sustainable agriculture and the food industry, which should reduce negative impacts on the environment.

Events in the environmental and energy sectors, both locally and globally, simply require every country and every individual to act in a way that saves energy, while protecting the environment at all levels, while actively participating in the fight against climate change. The ever-increasing need for energy, which practically drives the world, but also the growing problems of environmental protection, require environmentally and economically efficient energy production. The areas of energy production, distribution and consumption have been identified as the main environmental pollutants. The explanation lies in the fact that every business is made up of energy flows that are directed towards material production and the provision of services, and focused on energy that opens up new possibilities.

Because, if energy is the main driver of economic activities, then the economy should be viewed as an energy system consisting of energy flows and conversions that culminate in the production of goods and services, and energy as a key source of economic growth, industrialization and urbanization (Ayres, Warr, 2010).

2. ECONOMY AND SUSTAINABLE DEVELOPMENT

The neoclassical growth theory, which emerged in the 20th century, completely denies any need for a stationary state, and the issue of depletion of natural resources loses its importance.

Scientific and technological progress becomes the main factor in the development of the economy and society, and it also occupies a central place in the theory. The decades-long period of stable growth of the world economy after World War II supported the belief in the unlimited possibilities of scientific and technological progress. The capitalist world believed that Keynesian economic theory and policy provided answers to the challenges of economic instability. On the other hand, the socialist world firmly believed in the correctness of the fundamental assumptions of scientific socialism that would ensure a secure future for humanity. On the other hand, Milton Friedman, an economist and Nobel Prize winner, believes that the main responsibility of a manager is to run a business in the best interests of shareholders, which is actually financial profit (Robbins, Coulter, 2005). If funds are spent for social good, the costs of doing business increase. Friedman does not believe that it is not necessary to be socially responsible, but rather reduces responsibility to making a profit for the benefit of shareholders.

The crisis of the 1970s, which manifested itself through unemployment, inflation, oil shocks, and rising energy prices, created the need for a new way of thinking about economic policy. A new era was beginning, inspired by the achievements of the natural sciences, primarily physics, as well as the achievements of biology, primarily genetics and ecology. Robert Solow (1974) was the first to emphasize the demand for intergenerational equality in the enjoyment of natural goods. In his famous work from 1974, Solow sets out the demand that each generation of people must have an equal right to reap the benefits of nature, i.e. the environment, and that only a pattern of economic development that enables this over an unlimited period of time can be considered sustainable.

The environment is threatened by human intervention in nature, rapid industrial and technological development, nuclear and other programs. Pollution can cause environmental toxicity. High levels of gas emissions cause air pollution and negatively affect people who suffer from asthma or other respiratory problems, including cancer. Waste materials of organic and inorganic origin have been dumped directly into rivers, lakes or seas for years, which endangers plant and animal life, but also impairs the quality of drinking water. Chemical pesticides, herbicides and other chemicals used in agriculture, as well as the addition of hormones and antibiotics to the food of many animals, can have a detrimental effect on the normal functioning of the human body. Global warming is one of the most serious environmental challenges of our time. Deforestation - unplanned or commercial, threatens the ecosystem. This means that the regulation of water reserves is disrupted, oxygen release into the atmosphere is reduced, and soil erosion is accelerated. The habitats of plant and animal species are put at risk.

Economists and other thinkers increasingly base economic development on intellectual capital (human capital, technology and social capital), and thus knowledge becomes the leading factor of production in relation to physical labor and natural resources (Albijić, 2011). Numerous activities of state and non-governmental organizations around the world led to the holding of the *UN Conference on Environment and Development*, UNCED, in Rio de Janeiro in 1992. Many important documents were adopted at this conference. In August 2002, the World Summit on Sustainable Development was held in Johannesburg. At this summit, the participating countries agreed to begin developing and adopting national sustainable development strategies as soon as possible. **Today, the concept of sustainable development can be understood as the achievement of three goals:** (1) sustainability through economic growth without inflation and increasing external debt; (2) social

sustainability through poverty reduction; and (3) sustainability in terms of the use of natural resources and environmental protection. The concept of sustainability is widely accepted as a roadmap for human development. There are strong moral reasons for today's generation to leave the planet and the possibility of development to posterity as a legacy, at least at the current level. This means that planet Earth, with its potential, must not be degraded by existing people. This position is based on the theory of equity, which emphasizes the fundamental principle of moral justice, contained in the equal right of every person to the broadest basic freedoms, which do not contradict the freedom of others. Therefore, the right of the current generation to exploit resources and the environment must not threaten the same right of future generations. This is analogous to the Golden Rule in economics that current generations cannot consume more than future generations. **The basis of sustainable development is ecologically ethical because nature represents a value in itself and man is only a part of nature and it is unacceptable for his activity to destroy the diversity of the living world and the wealth of resources.** The economic argument for sustainable development is also important because it is on the side of efficiency against the waste of resources and energy, if we want long-term stability and progress of society as a whole. Hence, it can be concluded that pollution is not a consequence of selfish, frivolous, or short-sighted human behavior, but an inevitable companion of economic activity. The only imperative that humanity can face is that the pace of environmental pollution be optimal, i.e. in line with the possibility of restoring balance in nature and with the principle of economic efficiency (Harris, Jonathan, 2009, p. 456).

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Harris, Jonathan, 2009, p. 458). Sustainable techniques for agricultural production (organic soil restoration, organic healthy food), energy consumption, natural resource management, and industrial production have significant potential but have not yet found widespread application.

Energy is a fundamental input for economic systems. Production depends on fossil fuels, primarily oil, coal, and natural gas. Alternative (renewable) energy sources, such as hydropower, solar power, and wind power, could become significant. The second law of thermodynamics states that in isolated systems, the amount of useful energy and matter decreases over time. This law, known as the law of entropy, has far-reaching significance. The concept of entropy itself refers to the level of organization of matter and energy. The higher the organization of matter and energy, the greater their utility, i.e., the lower the entropy. The opposite is also true; the lower the level of organization, i.e., the higher the entropy, the lower the utility. In order for matter and energy to be biologically and economically useful, they must be organized in highly structured forms. The law itself states that in isolated systems, entropy increases over time, i.e., the level of organization decreases.

2.1 Knowledge economy and ecology

The most important development resource of the world economy of the 21st century is knowledge. The efficient use of knowledge is achieved through an effective business strategy of knowledge management. Knowledge management is the basis for directing the learning and knowledge of an organization towards the realization of set goals and the development of modern society. Accordingly, if environmental protection is a goal that enables the satisfaction of the needs of current and future generations, then knowledge management is a significant opportunity for its realization. In this regard, we especially emphasize the

characteristics of a learning organization (LO) and its possible contribution to the improvement and modernization of education for sustainable development and environmental protection.

The modern economy, the knowledge economy, is based on knowledge, which is the basis for creating added value for the organization and prosperity of society as a whole. What characterizes the modern economy is certainly the development of technology, globalization and the creation of a world economy, the emergence of new political and social challenges that are changing society and the economy of today, and, of course, knowledge at the center of the new economy with all its implications for work, leadership and society as a whole (Đorđević Boljanović, 2009). As the intellectual component of products and services is increasingly gaining importance, the possibility of knowledge management is becoming increasingly important in today's business economy.

The creation and dissemination of knowledge within a modern organization is becoming a decisive factor in achieving and maintaining its competitive advantage. In fact, the only sustainable advantage of a modern organization comes from how much a company knows, how effectively it uses what it knows, and how quickly it acquires and uses knowledge (Davenport, and Prusak, 2000, p. xv). In this sense, in order to emphasize the importance of knowledge as their strategic orientation, national economies are increasingly using terms such as the knowledge economy, the ecology of knowledge, smart buildings, and smart cities. This orientation also indicates the necessity of connecting the knowledge-based economy with the environment in which the market competition takes place. With this in mind, and explaining the modern economy, the author Peter Drucker also introduces the concepts of "ecological vision" and "social economy". Namely, in his book *Ecological Vision* (Drucker, 2000, p. 442) Drucker speaks of the social dimension of the economy, the social function of management, and organizations as social institutions. In this context, according to Drucker, periods of great social change reveal a tension between the need for continuity and the need for innovation. In order to understand this imbalance of these changes as historical, on the one hand, and a roadmap for the future, on the other, Drucker introduced a discipline that he called "social economics", which includes the study of the environment with the idea of its innovation and change, but also active efforts to maintain a balance between change and preservation of that same environment.

Namely, in order for companies to develop their knowledge-based competitiveness, they need to manage knowledge in an optimal and efficient manner, but while respecting the rules of green business. Although knowledge management, as a management concept, is most often associated with the availability of knowledge at all times, or, which is the shortest definition of knowledge management – the right knowledge in the right place at the right time, in itself, the knowledge management program is ecological and focused on sustainability and sustainable development as a whole (Lamonth, 2012). Of course, successful examples of "green" business speak in favor of the fact that this way of thinking of modern organizations is justified and necessary, which leads to sustainability (Čajka, and Jovanović, 2015, pp. 87-89).

Companies that operate in this way certainly reduce costs, increase their positive impact on the environment and its preservation, improve their public image, increase productivity, create a healthier working environment for their employees and create potential business opportunities. Unlike the once-popular view that environmental protection reduces business

opportunities, reality speaks in favor of the fact that both the environment and business can win at the same time (Kostić, Knežević, Vukadinović, 2014, pp. 93-95). Doing business "green" is not a cost, but an investment and a catalyst for innovation, new market opportunities and wealth creation. The question arises: how to achieve this? The answer lies in ecology as a strategy and the organization of business systems as ecosystems.

Also, ecological intelligence brings the functioning of ecological systems and its factors closer together. Ecological intelligence enables managers to learn from existing experience and to deal effectively with their environment, i.e. to apply everything learned about how human activity threatens ecosystems, as well as to work with less damage and once again live in harmony not only with their immediate environment, but also with the entire planet (Đoković, 2008, pp. 383-385).

The basic idea of a business or management ecosystem is that each organization influences and is influenced by other elements of the ecosystem, developing mutual relationships in which it must be flexible and adaptable in order to survive – as in a biological ecosystem, and in the aforementioned goal of achieving a comparative advantage that is the result of their symbiosis, and which they could not achieve individually (Lansiti, and Levien, 2004, pp. 67-78).

With all of the above in mind, business ecosystems indicate the dynamics of relationships between their elements. Ecosystems indicate the importance of the way people collaborate, share, trust each other, and grow together. When an ecosystem develops, it also indicates the free flow of ideas, talents, and capital. For these reasons, the term "business ecosystem" is fully justified because it indicates how and in what way a society views economic values, values the individual, and his or her power to bring about change and make a difference in cooperation with others, which is the ultimate goal of modern management (Hwang, 2014).

2.2 Economic perception of the environmental crisis

The modern era of accelerated scientific and technological changes has confirmed the unsustainability of the quantitative growth model, i.e. the civilizational growth model, which is based on the endless depletion of natural resources. The need to find sustainable paths of social development is being initiated again. The essence of the ecological crisis of modern industrial society and civilization consists in the productivist logic, according to which the production of material goods exists for the purpose of gaining profit and accumulation, and not for the purpose of satisfying authentic human needs; then, obsessive consumption in which the value of "having" (things) takes precedence over "being" (realization of human potential) of a one-dimensional (technical) process that turns both nature and man into its instruments. "The blame for the eruption of the ecological crisis cannot be attributed exclusively to industry, science and politics. Namely, it is necessary to put the entire social consciousness under the microscope of criticism. It is not a question of rejecting all the previous civilizational-social (and technical) tradition as extremely hostile, but rather of the necessity of changing man's established relationship with nature. Successfully overcoming the accumulated ecological problems implies the emergence of a completely new social context, which creates space for mutual rapprochement between man and nature, but also between man and man, which eliminates and mitigates the consequences of the moral and physical decline of the contemporary Ecumene" (Bose, 1985, pp. 479-486).

The modern concept of society originated from the mechanistic vision of the world, accepted for centuries, on whose model modern society is founded, which has continued the further degradation of the environment. André Gorz reveals the connection between the ecological crisis and the crisis of contemporary society. Criticizing the profiteer logic, he claims that both social scenarios (Western and Eastern), by accepting the idea of growth, have condemned themselves only to the persistent accumulation of ecological problems. Although left-wing, Gorz clearly states: "The ecological demand is based on fundamental assumptions. Therefore, it is not subject to bargaining, guessing. Socialism is not worth more than capitalism if it uses the same tools. The complete rule of man over nature inevitably entails that the technique with which this rule is exercised dominates man. In the absence of any other choice, nuclear capitalism is still worth more than nuclear socialism" (Vasović, 2006, pp. 13-15).

A radical critique of the ecological crisis of Western civilization requires a strong critique of its economy because, as Branković argues, "the reason for man's destruction of nature in Western civilization should certainly be sought in the economy. Namely, liberated spirits are precisely in the vortex of the economic perpetuum mobile of that civilization. Nature is an object there because the subject has caused the dizzying acceleration of the economic flywheel and can no longer stop it." (Gorz, 1982).

According to Danilo Z. Marković (1991), "in fact, as is often pointed out, ecology, with its knowledge, should contribute to the creation of more humane living conditions by overcoming the appropriative attitude of society towards nature, which does not take into account the basic ecological principle that there is ecological conditioning, interconnectedness in nature" (Branković, 1989).

3. ENERGY AND SUSTAINABLE DEVELOPMENT

One of the tasks of environmental economics is to identify those economic activities that contribute to sustainability, as well as those that undermine it (Perman, Ma & McGilvray, 1996). To illustrate the content of the basic principles of sustainability, we will use the codified set of norms and goals provided by the Ontario Round Table on Environment and Economy (ORTEE) of the Canadian state of Ontario and the Dutch National Environmental Action Plan (NEPP). According to ORTEE, a sustainable society can be considered one that (Edwards, 2008): (1) recognizes that economic growth has limits and that these are determined by the carrying capacity of resources in the environment; (2) values cultural diversity; (3) cultivates respect for all forms of life and encourages the diversity of the living world; (4) expands the system of social values through education about sustainability; (5) involves environmental experts in making all development decisions; (6) makes balanced development plans, respecting social, health, economic and environmental needs; (7) uses local resources and capacities in the best long-term way; (8) uses renewable and reliable energy sources; (9) minimizes environmental damage, and (10) strengthens activities in which materials are recycled.

As a result of the application of these principles, a sustainable social community does not undermine the sustainability of other communities, nor does it undermine the sustainability of the lives of future generations (Edwards, 2008).

A similar set of sustainable development principles is provided by the Dutch National Environmental Action Plan NEPP. The Dutch NEPP is one of a series of "green" national

documents, first created in 1989, with the aim of linking sustainable development at the local, regional and national levels, primarily through a presentation of planned activities to improve the state of the environment. It is envisaged that this action plan will be updated every four years. NEPP 4 is currently in the advanced implementation phase, and NEPP 5 is being prepared, with a time horizon extending to 2030.

The basic principles of the NEPP are: (1) intergenerational equity, in the sense that the current generation must not reduce the development opportunities of future generations; (2) the precautionary principle, in conditions of global environmental uncertainty; (3) the principle of conservation of natural resources with minimal environmental damage; (4) pollution control at source; (5) the polluter pays principle, through internalization of environmental costs, through fees, taxes and permits; (6) use of best available technologies (BAT); (7) prevention and elimination of unnecessary waste generation; (8) isolation and control of waste that cannot be recycled and reused; (9) inclusion of environmental analyses and assessments in any decision-making in the economy; (10) integral management of the product life cycle, and (11) respect for the capacity of the environment and eco-space.

The above does not represent a complete or definitive content of the principles of sustainable development. Rather, it can be said that the concept of sustainable development is still in the process of being developed and supplemented, and that it is gaining not only relevance but also breadth of scope every day. For example, the "Earth Charter", as a declaration of the basic moral principles of human progress in the 21st century, has been adopted by over 4,500 international organizations, including UNESCO, as well as over 250 universities around the world. After more than ten years of work on its formulation, with extensive support from the Netherlands, the Charter was adopted in March 2000 by UNESCO in Paris.

The Earth Charter (2000) includes key principles grouped into four areas. These are: (I) *Respect and Care for Life*; (II) *Ecological Integrity*; (III) *Social and Economic Justice*; (IV) *Democracy, Nonviolence and Peace*.

All of the above suggests that, today, sustainable development is not just a political slogan or a scientific paradigm. In fact, it is a value orientation based on the view that the primary task of humanity is to preserve life on Earth, which is a prerequisite for its survival and further development.

According to a sustainable economy, *energy is the most important factor of production and the main polluter of the environment*. On a global scale, the situation is such that developing countries are less rich in natural resources, of course with existing exceptions, while in some regions there are not enough natural resources. How to balance the existing differences in the world and preserve natural goods? Ecology deals with the preservation of natural resources, while economics deals with the highest possible profit. Ecological economics represents a new direction in which ecology and economics go hand in hand, with the harmonization of opposing interests. Profit is important, but only to the extent that it does not become destructive to the environment, to humans and to sustainable development (Guy McPhearson, 2002).

Energy, in classical economic doctrines, therefore, did not play an important role as a factor of economic prosperity. This is understandable, because nature and natural resources were treated as an inexhaustible source of input for economic activities. At the same time, with such an exploitative attitude towards nature and its total resources, the theory was developed that people could take everything they needed from nature, in unlimited quantities, and at the same time consider that nature has the capacity for self-renewal of resources. Nature was

considered an inexhaustible reservoir of raw materials, necessary for man for survival and further development.

To this should be added the lack of concern regarding the disposal of waste, i.e. residues from economic activities, supported by the view that nature itself is able to neutralize the harmful effects of human activities. Therefore, in economic theory, it was long believed that the amount of energy available to a given economy was endogenously determined, of course under the influence of biophysical and economic constraints (Stern, 2010, pp. 1-13). However, time has shown that such a theory in economic science is simply unsustainable. The first energy crisis, in the early 1970s, showed in its true light the unsustainability of classical theory in economics. Namely, at that time, energy appeared as an important, if not the most important factor of economic growth and development, in all its forms. Economic theory, in accordance with the requirements and problems of practice, finally introduced energy into its research as an important factor of economic activities. Energy is no longer marginalized in modern economic theory.

On the contrary, an increasing number of scientific researches in the field of economic sciences are related precisely to the examination of the impact of energy, forms of energy and energy resources on the economy, not only at the regional and national level, but also worldwide. In this sense, out of the need to solve practical problems, **modern economic theory has included in its research the direct connection that actually exists between energy, economy and ecology** (the so-called 3E). It has even gone a step further, in the direction that the modern economy, still based largely on non-renewable energy sources, is increasingly seen as the main cause of harmful impacts on the environment, and thus on sustainable development. The need to base future economic development on the principles of sustainability has given rise to a new economic doctrine called the "green economy" (Stern, 2010, pp. 1-13).

4. ECOLOGY AND SUSTAINABLE DEVELOPMENT

Environmental management is a modern system of environmental management. The main goal of such a system is to eliminate negative impacts and trends that affect human health. The concept of sustainable development implies balanced economic, social and cultural development without endangering the environment.

Given the fact that the modern world is already largely faced with the need for global, shared responsibility for development in accordance with the needs of people and nature, the moral reasons of today's generation must be strong in terms of adequate chances for future development and survival of offspring. In this way, future generations could be enabled to develop at the same or higher level. Therefore, it can be stated that the essence of the concept of sustainable development is the correlation of economic development and the environment while respecting the legality of ecological systems. This concept is aimed at the rational use of the country's natural wealth and, accordingly, at raising the quality of the environment and the quality of life. *In order to achieve sustainable development, it is also necessary to establish new social values based on knowledge, creativity and human resource capabilities, in a word, on creating quality management with a tendency to transform the current society into a learning society.*

It is necessary to form a Sustainability strategy. An extremely important step in the implementation of a Sustainable Development Strategy is the implementation of a process of continuous data and information collection to measure the process of its success, i.e. timely signaling to responsible institutions about the "points" of success (34). This way of thinking is based on the fundamental principle of moral justice, i.e. that all people have equal rights to the broadest basic freedoms that do not contradict the freedom of others. The right of the current generation to exploit resources and to a healthy environment must not endanger the same right of future generations. Responding to the demands of the current generation without destroying the opportunities for future generations to respond to their demands is sustainable development (30).

Ecomanagement can be defined as the process of allocating natural and artificial resources, but in such a way as to achieve optimum use of the environment in meeting basic human needs at a minimum and, if possible, on a sustainable basis. It also represents a form of control of all human activities that have a significant impact on the environment. In other words, environmental management encompasses the process of making decisions that regulate the impact of human activities on the living space.

At the core of the concept of sustainability, the central place is occupied by the use of the capacity of the environment for human progress and development, but in such a way that it is not damaged and completely exhausted (Milutinović, 2009). Environmental quality management is a complex multidisciplinary task whose strategic basis is the principles of sustainable urban development and which can be successfully achieved if there is a well-conceived eco-management in the environment itself. Environmental protection and management are an integral part of governance - management at all organizational levels and in all business functions.

To this end, management should introduce a continuous process that must be coordinated with social and economic processes (employee safety, health protection, etc.). **The principles and elements of environmental management may include the following strategies** (Milutinović, 2009): (1) environmental policy; (2) planning; (3) implementation and control; (4) monitoring and corrective action, and (5) review, improvement and continuous improvement.

In each of the listed environmental management strategies, or ecological management, there are four basic phases (Milutinović, 2009): (1) identification phase – obtaining information on the basis of which knowledge about the potential effects of pollution would be gained; (2) monitoring phase – direct monitoring and measurements of pollutants, their distribution and localization; (3) valorization phase – ends with the sum of all environmental information obtained in earlier phases and (4) regulation phase – application of various instruments and measures for the purpose of effective environmental management.

To direct the desired state of the environment in the future, prognostic and planning methods and models must be used in order to bring management to an exact level. Therefore, it is necessary to influence the development of environmental management methods, both at the theoretical level and at the level of regulations, standards and instructions. The management model must demonstrate a good relationship between the subjects (competent state bodies) and the object of management (environmental elements), management tools (laws and plans), as well as the position of management instruments (regulations, standards, norms, criteria and information) (Mihajlović, Stošić Mihajlović, 2009). The implementation of planning

solutions is based on the coordinated application of instruments and measures in various areas of directing development, construction and use of space and environmental protection.

Strategic planning of environmental management integrates the potential for managing changes in space, but also the long-term time horizon, taking the position of a catalyst for harmonizing public, social and private interests. The concept of environmental management in the function of sustainable socio-economic development, with the goals it seeks to achieve in modern business and living conditions. The basic goals that are at the base of environmental management are the following: (1) prevention and resolution of environmental problems; (2) establishment of boundaries; (3) establishment and maintenance of institutions that effectively support environmental research, monitoring and management; (4) warning of dangers and identifying opportunities for overcoming them; (5) maintenance and, if possible, improvement of existing resources; (6) improvement of the "quality of life", and (7) identification of useful new technologies or policies.

Each of these goals can be discussed in detail, but what they all have in common is their essence, which can be expressed as the desire to preserve the environment. Table 1 shows the so-called "golden rules of ecomanagement", as well as the consequences of not respecting them.

From Table 1, it can be seen that the important rules are substitution, reduction and assimilation. In other words, it is necessary to replace non-renewable resources with renewable ones, to consume natural resources in a planned manner so that they are not exhausted, that is, it is necessary to monitor the period of their regeneration. Finally, the rule of assimilation obliges all participants in economic and other activities to reduce the emission of harmful substances into the environment, that is, to ensure that the rate of environmental pollution does not exceed the optimal level.

Table 1. Golden rules and consequences of environmental management

Golden rules of environmental management	Consequences
RULE OF SUBSTITUTION Non-renewable resources can be consumed to the extent that they can be replaced by equivalent (renewable) substitutes.	If the consumption of non-renewable resources is not drastically reduced within the next generation, many will disappear or exist in very limited quantities.
REDUCTION RULE The amount of renewable resources used should not exceed their renewability.	If the growth of renewable resources exceeds regeneration growth, species extinction will follow.
ASSIMILATION RULE Emissions of harmful substances should not exceed the absorption capacity of the environment, i.e. exceed the burden on ecological systems.	If environmental burdens are not drastically reduced, absorption capacity will be exceeded locally and globally.

Source:

https://www.google.rs/search?q=http://sewa.sewaweather.com/~ambassadors/new_site/srp/images/stories/Papers+/08-01.pdf&ie=utf-8&oe=utf-8&client=firefox

Environmental management is an increasingly common topic that relates to various areas of organization management, which see it as a way to improve their position in the market. It is related to growth and development, procurement, production, marketing, investments, personnel, etc., or in short, it is related to all areas of business. Miller (2007) defines environmental management as "the shaping, management and development of companies and organizations with responsibility towards the environment". This responsibility means that in all functions of a company or organization, interaction with the natural environment is taken into account when making business decisions. Environmental management is the science and skill of effective and efficient behavior and achieving goals in the right way, but also the true knowledge and practice of achieving the right goals, i.e. goals that concern human survival and the quality of their life. Here, more than in other areas of management application, the dominance of the principle of effectiveness over the principle of efficiency is confirmed, i.e. the inability to compensate for the lack of effectiveness with efficiency. Therefore, environmental management must become a kind of management infrastructure for successful management practices in all sectors, because poorly chosen non-ecological goals cannot be compensated for even by the greatest efficiency.

The main objective of an ecologically protected area is to ensure the quality of life and long-term livelihood of the local population. All areas should be managed in a way that will enable the protection of all natural and cultural resources, while preserving the interests of the owners in achieving appropriate profits, as well as the interests of the local population. Such management is complex and requires different knowledge and skills. Due to increasing public pressure, as well as the potential for cost reduction, legal restrictions and ethical reasons, it is necessary to develop appropriate ecomanagement strategies to create "environmentally friendly" processes and products in the function of sustainable development. Therefore, modifying existing and developing new strategies in the direction of environmentally responsible business is an imperative of modern business in the field of sustainable development.

Sustainable development encompasses three dimensions: environmental sustainability, economic efficiency, and social responsibility. This concept is known as the "three-pillar model" (Giddings, Hopwood, & O'Brien, 2002, p. 190).

The ecological dimension refers to the preservation of biodiversity, the conservation and rational use of natural resources, the reduction of environmental pollution, the care of endangered species, their habitats, ecosystems, and the like (Milojević, 2011, pp. 639-653).

The social dimension refers to social relations, respect for human rights, the achievement of social well-being, the transparency of social activities, and the involvement of people in decision-making, and is monitored through five areas: health, social justice, education, population, security, and housing.

The economic dimension of sustainable development is based on the principles of harmonization of economic development with resources and production capacities and is observed through two areas: production and economic structure and consumption (Milojević, 2011, pp. 639-653).

In the 1980s, Dutch statisticians (Konning, 2015) argued that their national development strategy consisted of four dimensions of sustainable development: social, cultural, economic

and environmental. According to their thinking, the social dimension requires answering the following questions (Konning, 2015): (1) "how satisfied are we now; (2) to what extent is there safety and security in our environment and social structure; (3) what has been done about people's social connections between the society to which we belong and people outside our society".

When thinking about the social dimensions of sustainable development, we think about a satisfactory level of social sustainability that includes: employment that provides decent living conditions, equitable income, social stability and equitable access to resources. Social sustainability implies social equality and the reduction of social exclusion, as well as the development and inclusion of: equality, social justice and quality of life. Indicators of social sustainability include access to information, connectivity, physical, psychological and reproductive health, availability of activities important for sustaining life, which means: nutrition, household formation, employment, the possibility of accessing land and resources, as well as security inside and outside the home (Becker, E., Jahn, T., Stiess, I., & Wehling, P., 1997).

Social stability as an element of social sustainability is defined as the ability of a human being (individual, household, family) to achieve and maintain adequate living conditions (Becker, et al., 1997). Everything that applies to sustainable development at the macro level (the level of a country's economy) also applies at the micro level when we talk about social enterprises.

4.1. Sustainable and unsustainable development – parallels

Today, the term *sustainable development* is used too often, in different meanings, and the key factors of the concept of sustainable development itself are: the economy, social relations viewed as the degree of realization of freedom and social justice and equality for all people, as well as environmental protection.

In the broadest sense, sustainable development refers to the interdependence of the environment, social and economic systems, as well as the promotion of equality and fairness through the strengthening of public power and a sense of global belonging. It is a concept based on the idea of combining the best aspects of different perspectives and harmonizing the development of humanity with the protection of nature.

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." This definition was formulated by the WCED - World Commission on Environment and Development (38), led by the Norwegian Prime Minister Gro Harlem Brundtland, in 1987. The word "development" in this definition introduces two important aspects of this concept: it is multidisciplinary, because development cannot be limited to a certain number of disciplines or areas, but is applicable to the whole world, everyone and everything in it, now and in the future. The second aspect is that there is no set goal, but the continuity of development is the goal of development. The definition is based on two principles: (1) the principle of "needs", including the conditions for maintaining an acceptable standard of living for all people, and (2) the principle of "limits" of the capacity of the environment to meet present and future needs, determined by technological development and social organization. **Any development should help meet needs and should not increase restrictions** (Government of Serbia, 2005).

Sustainable development is a harmonious relationship between ecology and economy, in order to preserve the natural wealth of our planet for future generations. It can be said that sustainable development represents a direction, a striving to create a better world, balancing social, economic and natural factors of environmental protection.

Table 2. Comparative presentation of the advantages and disadvantages of two opposing concepts in the relationship of society to the conditions of its own existence

Sustainable development	Unsustainable development
Quality of life improvement goals - are based on a general definition including social and environmental factors, as well as monetary ones.	The goals are only to raise the standard of living - they are based on finances which are the foundation of our well-being and happiness
There is an interconnectedness between economic, social and environmental problems. They are addressed in such a way as to achieve lasting solutions based on harmony.	Economy, society, and environment are three distinct, separate groups of problems, and it is held that a healthy economy automatically leads to a healthy society and a safe environment.
It views the needs of future generations as the needs of today's generations and seeks to avoid problems in the future by working on their solutions today.	Things improve in the short term. It's mostly left to future generations to sort them out.
Sustainable development	Unsustainable development
The environment and its capacity to support human action are taken into account in all decisions,	The environment is seen as a luxury – it should only be protected if we can afford it.
Balancing the importance of individual rights with collective responsibility.	The focus is mainly on individuals and individual rights.
Collaboration between experts and ordinary people is planned so that plans and proposals meet people's needs.	Experts and specialists plan.

Source: (Bachun, 2005).

Sustainability, as interpreted in Germany, requires an inextricable link between ecology, economy and social security. Sustainable development requires that progress in economic and social living conditions be consistent with the long-term process of preserving the natural foundations of life.

5. CONCLUSION

The ecological crisis implies a crisis of the existing matrix of industrial society in relation to the natural conditions of life. The ecological crisis manifested through various degrees: what kind of pollution, threats, destruction are, in essence, a burning civilizational problem, the solution of which depends on the very future. The developed part of the Planet is faced with the problem of depletion and pollution of resources due to the expansion of energy needs. We now live in a time when renewable energy sources cannot cover all of humanity's energy needs, the use of classical energy sources is unsustainable, because it pollutes the

environment to the maximum, and all this is manifested in economic collapses, which seem inevitable, the only question is under what scenario economic collapses will occur.

The meaning of sustainable development policy at all levels of social organization lies in the need to maintain a balance between demand, saving and renewal of natural resources, as an expression of concern for future generations.

Regardless of the evident weakening of the state as an organizer, coordinator and arbiter of social relations in modern society, the key issue of sustainable development, and thus environmental protection, is posed as a relationship between the state and the market. This relationship should be viewed in interaction and should result in meeting people's needs in a way that does not endanger the environment and the right of future generations to live in a preserved environment.

Environmental protection problems are primarily problems of economic societies, or in the broader sense of the word, of the country's economy; with the economy as the material basis, as a condition for the survival and progress of a human community that exists in a certain more or less compact area. Environmental protection is an ambivalent category and has another face. It is about the state having a monitoring and supervisory, control role and the right to intervene in the field of environmental protection. Intervention is usually directed towards the economy and economic organizations that do not respect the established "rules of the game".

The state, also, within its role as the organizer of global society, not only establishes a certain environment through coercive measures and laws that is a prerequisite for a quality environment, but also appears in the role of an investor in infrastructure, where this is not the obligation of the economic sector, with the aim of providing a healthy environment for the population, plant and animal species.

Market mechanisms and state intervention are complementary in terms of providing the conditions for sustainable development. If the market is allowed to develop, the economic effects will be positive. If market mechanisms do not produce the expected results, similar effects can be ensured through state intervention. But only if the market and state policy form an integral whole can a very positive effect and accelerated and sustainable development in accordance with the principle of environmental protection be expected.

Industrialization, in addition to the benefits it has brought to modern man, also brings with it unwanted consequences for the *areal* - the environment in which man lives and works.

Environmental indicators show the quality of the environment, the quantity and quality of natural resources. The state of the environment is the result of environmental pressures and means the quality of different parts of the environment (lithosphere, pedosphere, hydrosphere, atmosphere), basic elements (water, air, soil, surface, etc.) as well as the quality of individual ecosystems (Radej, 1992). Changes in the state of the environment affect the quality and prosperity of humans. Changes in the state of the environment cause ecological and/or economic impacts on ecosystem functions and human health (Plut, 2002). These indicators include the concentration of heavy metals in rivers, exposure of the population to polluted air, and the like. The difference between indicators of environmental pressures and indicators of environmental status and sustainable development is that environmental status indicators show environmental conditions and changes in status over time, rather than

pressures. Indicators of environmental pressures can be used in practice as a substitute for status indicators, the collection of which may be difficult and uneconomical.

The changes in today's society, which have occurred in the technical and technological sphere, require a new and fundamentally changed approach in many domains and areas of human life and work, including in the field of environmental protection. Environmental issues have increasing consequences for economic entities and the economy in general. Depending on the reaction of economic entities or organizations, environmental interests can have a positive or negative impact on the extent to which set economic goals are achieved. Economy and ecology have opposing interests, but these interests must be harmonized for the sake of environmental protection and living space. Environmental protection presents risks, but also opportunities. Energy is fundamental for economic development, but at the same time it must serve the function of environmental preservation. Only this approach to energy leads to a sustainable energy system, a more efficient economy and greater social well-being, with sustainable balances and capacities of natural resources and as low levels of pollution as possible.

A new scientific discipline that emerged within the synthesis of social and natural sciences, called *ecological economics*, pays special attention to the importance of the laws of thermodynamics in the process of economic activity, thus ensuring economic activity while preserving the environment within the realistic framework of sustainable development. Energy management is a way and support for reducing environmental threats and economic costs while increasing the quality of life and economic progress.

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COMPARATIVE ANALYSIS OF CIRCULAR BUSINESS MODELS IN AGRICULTURE

КОМПАРАТИВНА АНАЛИЗА НА ЦИРКУЛАРНИТЕ БИЗНИС МОДЕЛИ ВО ЗЕМЈОДЕЛСТВОТО

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Abstract: *This paper examines circular business models (CBMs) in agriculture through a comparative analysis of six domestic and international cases.¹⁴ Using an inductive exploratory approach, models are assessed across technological characteristics, economic viability, environmental effects, and scalability potential. Findings indicate that CBMs in agriculture function as context-dependent configurations rather than universally transferable templates, and that circular effectiveness does not require high technological sophistication.*

Key words: *circular economy, circular business models, agriculture, sustainability, comparative analysis*

Анстракт: *Трудот ги испитува циркуларните бизнис модели (ЦБМ) во земјоделството преку споредбена анализа на шест домашни и меѓународни случаи.⁴ Со индуктивен истражувачки пристап, моделите се оценуваат според технолошки карактеристики, економска одржливост, еколошки ефекти и потенцијал за реплицирање. Резултатите покажуваат дека ЦБМ функционираат како контекстуално зависни конфигурации, а не како универзални шаблони.*

Клучни зборови: *циркуларна економија, циркуларни бизнис модели, земјоделство, одржливост, споредбена анализа*

1. INTRODUCTION

Agriculture is increasingly confronted with structural and environmental pressures, including resource depletion, soil degradation, biodiversity loss, and climate instability. Conventional linear production models, based on extract-produce-dispose logics, are progressively inadequate for ensuring long-term sustainability and resilience. In this context, the circular economy (CE) has emerged as a framework aimed at closing material loops, reducing waste,

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and enhancing resource efficiency across sectors, including agriculture (Geissdoerfer et al., 2017; Ellen MacArthur Foundation, 2019).

Within agricultural systems, circular principles are operationalized through practices such as composting, nutrient recycling, anaerobic digestion, agroecological diversification, and the valorisation of organic waste (FAO, 2021). These practices are embedded in circular business models (CBMs), which integrate environmental objectives into value creation logic rather than treating sustainability as an external constraint (Bocken et al., 2016; Lüdeke-Freund et al., 2019). However, CBMs in agriculture are not uniform. Their technological configuration, economic structure, and scale vary significantly depending on resource availability, production structures, and broader development conditions.

Existing literature suggests that circular initiatives in more industrialized contexts are often characterized by higher technological intensity, advanced system integration, and significant capital investment, while less developed or transition economies tend to rely on simpler, locally embedded circular solutions aligned with available resources and incremental innovation pathways (Kirchherr et al., 2018; Murray et al., 2017). This variation does not imply a hierarchy of effectiveness but rather reflects different structural constraints and development trajectories. Despite growing conceptual work on circular agriculture, comparative empirical research examining how diverse CBMs function across such contexts remains limited.

The Republic of North Macedonia represents a case of a small agricultural system characterized by fragmented farm structures, limited mechanization, and constrained investment capacity. In such settings, circular initiatives are more likely to emerge in forms that are technologically moderate or simple yet closely aligned with local resource loops and production practices (Daniloska and Boshkovska, 2025). This context provides a relevant empirical setting for exploring how circular business models operate under structural constraints.

Accordingly, this paper adopts an inductive and exploratory comparative approach to examine selected domestic and international examples of circular business models in agriculture. The selection deliberately combines simpler, locally embedded initiatives from North Macedonia with more technologically advanced and system-integrated models from other countries. This heterogeneity is intentional and designed to illuminate differences in technological characteristics, economic viability, environmental effects, and scalability potential across diverse contexts. By comparing these models, the paper seeks to identify recurring patterns and trade-offs rather than to prescribe a single optimal pathway for circular agriculture.

The paper proceeds with the methodological framework and selection criteria, followed by a comparative analysis of the selected examples and a synthesis of the main findings.

2. MATERIAL AND METHODS

This paper adopts an inductive and exploratory comparative case-study approach to examine selected circular business models in agriculture across different contexts. The analysis relies on illustrative cases in order to identify recurring patterns and trade-offs across different

contexts rather than to test predefined hypotheses (Yin, 2018). The objective is analytical generalization through structured comparison, not statistical representativeness.

The study draws on six selected examples: three domestic cases from the Republic of North Macedonia and three international models. The cases were deliberately chosen to reflect variation in technological configuration, scale of operation, and business orientation. This heterogeneity is methodologically intentional, as it allows for comparison across different levels of complexity and development conditions (Ridder, 2017).

In selecting the cases, attention was given to their relevance for comparative analysis rather than to representativeness. The domestic examples illustrate locally embedded and structurally constrained circular initiatives, while the international cases reflect more technologically integrated and system-level configurations. Together, they enable cross-contextual examination of circular business models under diverse structural conditions.

The analytical framework combines descriptive case attributes and four formal analytical dimensions. Descriptive attributes include the type of business model, resource inputs, and final outputs, which provide contextual understanding of each case. Comparative assessment is structured around four key dimensions:

(1) Technological characteristics, referring to the degree of technological integration and process complexity; (2) Economic viability, including value creation logic, revenue streams, and cost-efficiency; (3) Environmental effects, encompassing resource efficiency, waste reduction, and ecological impact; (4) Scalability potential, referring to the capacity for replication, adaptation, or expansion in comparable agricultural contexts. These dimensions are adapted from established circular economy evaluation frameworks (Kirchherr et al., 2017; Ellen MacArthur Foundation, 2019) and provide a consistent basis for systematic comparison across cases.

The analysis relies primarily on secondary data derived from publicly available sources, including official company documentation, organizational reports, media coverage, project materials, and relevant academic literature. All case descriptions are based on verifiable sources, which are cited accordingly in the text and listed in the reference section. While the depth of available information varies across cases, particularly for smaller domestic initiatives, triangulation of sources was applied where possible to enhance analytical reliability and consistency.

3. RESULTS AND DISCUSSION

3.1 Case Descriptions and Analytical Framing

This section presents six selected case studies that illustrate diverse configurations of circular business models (CBMs) in agriculture. Three cases originate from the Republic of North Macedonia and represent locally embedded initiatives operating under structural constraints, while three international examples reflect more technologically advanced and system-integrated models. The cases are intentionally heterogeneous in order to enable comparative analysis across different levels of technological complexity, economic structure, environmental impact, and scalability potential.

Veze Shari-Tetovo, North Macedonia. Veze Shari represents a biogas-based circular model built on the conversion of poultry manure into renewable energy and organic fertilizer (Veze Shari, 2024; ETF UGD, 2021). Through anaerobic digestion, organic waste is transformed into biogas used for electricity generation, while digestate is processed into value-added fertilizer. The model demonstrates moderate technological integration, relying on automated fermentation systems and energy conversion infrastructure. Economically, it benefits from diversified revenue streams, including energy production and fertilizer sales (Club Economy, 2022). Environmentally, it contributes to methane reduction and improved nutrient cycling. Its scalability is contingent on access to feedstock and capital investment but remains viable in contexts with concentrated livestock production.

Kompostara Resen-North Macedonia. Kompostara Resen illustrates a low-technology municipal composting initiative based on the recycling of apple-processing waste into agricultural compost (Prespa Razbudi Se, 2020; Prizma, 2019). The model operates through basic composting techniques with limited mechanization, reflecting low technological complexity. Its economic viability is moderate, primarily linked to reduced waste management costs and potential compost distribution. Environmental effects are significant at the local level, particularly in terms of organic waste reduction and nutrient recovery. Due to its modest investment requirements, the model demonstrates strong replication potential in small municipalities with similar biomass availability. The facility ceased operations around 2017-2018, primarily due to institutional and financing constraints rather than technical infeasibility. This trajectory illustrates a recurring challenge for low-technology circular initiatives in structurally constrained contexts: technical viability does not guarantee operational continuity in the absence of sustained institutional support.

Orizova Bratimka-Cheshinovo-Obleshevo, North Macedonia. Orizova Bratimka represents a hybrid circular model combining resource-efficient rice production with eco-oriented market positioning (ARNO, 2019; Faktor, 2020). The model relies on rational water use, reduced chemical inputs, and environmentally conscious packaging. Technological complexity remains relatively low, centered on agronomic knowledge and irrigation management rather than advanced automation. Economic viability stems from differentiated market access and eco-branding strategies. Environmental benefits are moderate, particularly in biodiversity preservation and input reduction. The model shows considerable scalability potential within rural regions oriented towards sustainable or organic production.

Ÿnsect-Amiens, France. Ÿnsect exemplifies a high-technology circular model based on insect-based bioconversion of agricultural by-products into protein feed and organic fertilizer (Ÿnsect, 2022). The company operates vertically integrated facilities utilizing automation, robotics, and AI-based monitoring systems. Technological complexity is high, reflecting advanced process optimization and industrial-scale production. Economic viability is supported by substantial investment and access to premium feed markets. Environmental benefits include waste valorization and reduced reliance on conventional protein sources such as fishmeal and soy. The modular design of production units enhances scalability across suitable regulatory and market environments.

Hengelo Integrated Anaerobic Digestion-Composting Plant, Netherlands. This composting plant represents a hybrid circular model combining anaerobic digestion and composting within a decentralized regional framework (BioCycle, 2014). The model integrates farmers, energy producers, and local stakeholders in the conversion of biomass

into renewable energy and soil-enhancing fertilizer products. Technologically, it reflects a medium-to-high level of integration, incorporating digestion tanks, energy recovery systems, and compost stabilization processes typical of advanced anaerobic treatment systems in Europe (Baere and Mattheeuws, 2012). Economically, the model relies on diversified revenue streams, including renewable energy production, fertilizer sales, and policy-supported green incentives. Environmentally, it contributes to greenhouse gas mitigation, improved manure management, and reduced dependency on fossil-based inputs. Its scalability is supported by modular infrastructure and regional coordination mechanisms, allowing gradual expansion within comparable agricultural systems.

Kalundborg Symbiosis-Denmark. Kalundborg Symbiosis represents an advanced example of industrial symbiosis, where multiple actors exchange waste streams, heat, and by-products to optimize resource use (Kalundborg Symbiosis, 2020; European Circular Economy Stakeholder Platform, 2025). Although not limited to agriculture, the model includes agricultural resource loops within a broader industrial ecosystem. Technological complexity is high, supported by integrated logistics and coordinated process management. Economic viability arises from cost savings and secondary revenue streams. Environmental benefits are substantial due to systematic waste reuse and heat recovery. Scalability depends on coordination capacity and spatial proximity among participating actors but has demonstrated replicability in similar industrial clusters.

Table 1. Key characteristics of the selected case studies across four analytical dimensions

Model	Technological Characteristics	Economic Viability	Environmental Effects	Scalability Potential
Veze Shari (MK)	Moderate	High	Significant	Strong
Kompostara Resen (MK)	Low	Moderate	High	Strong
Orizova Bratimka (MK)	Low	Moderate to High	Moderate	High
Ÿnsect (FR)	High	High	High	Very High
Hengelo Anaerobic Digestion (NL)	Medium to High	Moderate to High	Significant	High
Kalundborg Symbiosis (DK)	High	High	Very High	High

Source: Authors' own elaboration based on case study analysis.

The table provides a structured overview of the relative positioning of the selected models across the four analytical dimensions. While the domestic cases are generally characterized by lower technological intensity, they demonstrate notable environmental and replication potential within constrained contexts. The international examples reflect higher technological integration and capital intensity, combined with broader system-level scalability. This structured differentiation provides the empirical basis for the comparative analysis developed in the following section.

3.2 Comparative Analysis Across Analytical Dimensions

Technological Characteristics and System Configuration. Comparison across the selected cases confirms that technological intensity significantly shapes the operational configuration of circular business models, but does not determine their circular effectiveness per se. The Macedonian cases are characterized by low to moderate technological integration. Kompostara Resen and Orizova Bratimka rely primarily on basic infrastructure, agronomic expertise, and incremental process optimization. Circularity in these models emerges through improved resource management and the reintegration of organic flows rather than through advanced digitalization or automation.

In contrast, Ÿnsect and Kalundborg Symbiosis represent high-technology and system-integrated configurations. Ÿnsect's model depends on controlled production environments, automation, and vertically integrated processing chains, enabling high material throughput and process standardization. Kalundborg operates through coordinated exchanges of energy and by-products among multiple actors, relying on advanced logistics and infrastructure. In these cases, technology functions as an enabler of systemic circularity across broader production networks.

Configurations characterized by moderate technological integration, including the Hengelo integrated anaerobic digestion-composting plant and the Veze Shari biogas system, illustrate a transitional technological profile. These models incorporate technical infrastructure for energy recovery and nutrient management while remaining operationally manageable. The comparison indicates that technological complexity should be interpreted as a configuration variable that influences scale and integration, rather than as a normative benchmark of circularity.

Economic Viability and Value Creation Logic. Economic viability across the examined cases is achieved through diverse value creation mechanisms. The domestic models rely primarily on hybrid and context-sensitive economic logics. Kompostara Resen generates economic value largely through cost avoidance and internal resource recovery, while Orizova Bratimka leverages product differentiation and eco-market positioning to enhance revenue stability. In both cases, circularity supports economic sustainability through incremental efficiency gains and niche market access rather than through scale expansion.

The international high-technology models exhibit more capital-intensive and market-integrated economic structures. Ÿnsect operates within premium protein markets, where technological efficiency and product standardization underpin revenue generation. Kalundborg Symbiosis creates economic gains through resource efficiency and cost-sharing mechanisms across interconnected actors. In these cases, circularity strengthens competitiveness by reducing dependency on virgin inputs and improving system-wide efficiency.

Intermediate models combine energy production, input substitution, and diversified outputs, which enhances resilience against market volatility. A central insight emerging from the comparison is that economic stability depends more on diversification of value streams than on operational scale alone. Models integrating multiple forms of economic benefit (energy recovery, waste reduction, premium pricing) or cost savings, demonstrate greater adaptive capacity across different agricultural contexts.

Environmental Effects and Regenerative Potential. All analyzed models generate positive environmental outcomes, though the scope and intensity of these effects vary considerably. The Macedonian low-technology initiatives demonstrate strong localized regenerative impacts. Composting enhances nutrient cycling and soil organic matter, while eco-oriented crop production reduces chemical inputs and supports biodiversity preservation. These environmental benefits are embedded within local agroecosystems and contribute to cumulative improvements in resource efficiency.

High-technology models extend environmental effects beyond immediate production sites. Ýnsect contributes to reduced reliance on conventional protein sources, thereby lowering pressure on land and marine ecosystems. Kalundborg achieves substantial waste reuse and emission reductions through integrated material exchanges across sectors. These configurations illustrate how advanced coordination can amplify environmental gains at regional or cross-sectoral levels.

However, the comparison also highlights trade-offs. High-technology systems require significant infrastructure and energy inputs, whereas low-technology initiatives operate with smaller ecological footprints but generate more localized impacts. Intermediate models, such as biogas systems, combine emission reduction with nutrient recovery, illustrating how mitigation and regeneration can be jointly achieved. Environmental performance therefore varies along a continuum shaped by system boundaries, resource inputs, and operational scale.

Scalability and Context Compatibility. Scalability emerges as a context-dependent characteristic rather than an inherent property of any specific model. Low-technology initiatives display strong horizontal replication potential due to modest capital requirements and reliance on locally available resources. Their simplicity facilitates adaptation in small-scale agricultural systems and supports incremental expansion.

High-technology models demonstrate vertical scalability through capacity expansion and system integration, yet their transferability depends on financial resources, infrastructural readiness, and stable operational conditions. While replicable in suitable environments, such models are not universally transferable as standardized solutions.

Intermediate systems benefit from modular design principles that allow gradual capacity expansion and integration into existing agricultural structures. Across cases, scalability is most effective when models align with prevailing production structures, resource availability, and market conditions. The findings indicate that compatibility with structural conditions is more decisive for scaling than technological sophistication alone.

Cross-Case Synthesis. The cross-case comparison reveals patterns that extend beyond the individual case descriptions. First, neither technological sophistication nor simplicity guarantees operational sustainability. Kompostara Resen ceased operations despite low investment requirements, while Ýnsect encountered significant financial difficulties notwithstanding advanced technological integration and substantial capital backing. This parallel suggests that circular effectiveness depends less on technological tier and more on the alignment between model design and the structural conditions in which it operates.

Second, a tension emerges between environmental ambition and economic resilience. Models generating the broadest environmental benefits such as Kalundborg Symbiosis and Ynsect, are also the most capital-intensive and context-dependent, limiting their transferability. Conversely, the most replicable models tend to generate more localized and modest environmental impacts. This trade-off is not a deficiency but a structural feature of circular agriculture that policy frameworks should explicitly account for.

Third, scalability and sustainability do not necessarily align. Several cases demonstrate strong replication potential in theory while facing practical constraints in implementation. Taken together, the evidence suggests that circular business models should be evaluated not only on their performance within favorable conditions but on their resilience under structural and market pressures.

Table 2. Comparative patterns across analytical dimensions

Dimension	Low-Technology configurations	Intermediate configurations	High-Technology configurations
Technological characteristics	Basic infrastructure; knowledge-driven processes	Integrated energy and nutrient recovery systems	Automated, digitally managed, system-integrated operations
Economic logic	Cost avoidance; niche differentiation	Diversified revenue streams; energy and input substitution	Capital-intensive; premium markets; system efficiency gains
Environmental effects	Localized nutrient cycling; soil regeneration	Combined mitigation and regeneration	Broad system-level emission reduction and material efficiency
Scalability	Horizontal replication in small-scale systems	Modular expansion under stable conditions	Vertical scaling in capital-intensive environments

Source: Authors' own elaboration based on comparative analysis.

Table 2 systematizes the comparative patterns identified across the four analytical dimensions and highlights structural differences between low, intermediate, and high-technology configurations. The differentiation does not imply a linear hierarchy of performance, but rather illustrates distinct circular strategies shaped by resource conditions, operational scale, and value creation logic. Importantly, the table also reflects a cross-cutting finding that no technological tier is inherently immune to sustainability challenges, that is operational failure and financial vulnerability are distributed across configurations, suggesting that structural alignment rather than technological choice is the primary determinant of circular model resilience.

4. CONCLUSION

This paper examined selected circular business models in agriculture through a structured comparative analysis across four analytical dimensions: technological characteristics,

economic viability, environmental effects, and scalability potential. The findings demonstrate that circularity in agriculture does not follow a single technological or organizational pathway. Instead, circular business models function as context-dependent configurations shaped by resource availability, production structures, and market conditions. A structured cross-context comparison of domestic and international cases provides empirical grounding for these conclusions.

The comparative analysis indicates that technological sophistication is neither a prerequisite nor a guarantee of circular effectiveness. Low-technology models can generate meaningful local environmental and economic benefits when aligned with existing resource flows, while high-technology systems enable broader integration and increased material throughput. Similarly, economic resilience depends more on diversified value creation than on scale alone, and environmental performance varies in scope according to system boundaries and operational intensity. Scalability emerges as a function of structural compatibility rather than technological advancement.

Taken together, these findings reinforce the argument that circular business models should not be approached as universally transferable templates. Their effectiveness depends on the coherence between technological design, value creation logic, environmental objectives, and operational scale within specific agricultural contexts.

Several limitations must be acknowledged. The analysis relies on a limited number of illustrative cases and on secondary data sources, which constrains the depth of empirical verification and quantitative assessment. Differences in data availability across cases introduce asymmetry in the level of detail. Moreover, the study focuses on qualitative comparative patterns rather than on measurable performance indicators.

Future research could expand the empirical base through quantitative evaluation of environmental and economic outcomes, longitudinal analysis of model performance, and broader comparative studies across additional regional contexts. Further investigation into performance metrics and impact measurement would strengthen the analytical foundations of circular agriculture research.

The findings carry practical implications for rural development policy in the Republic of North Macedonia. Given the structural constraints of the domestic agricultural sector, fragmented farm structures, limited mechanization, and constrained investment capacity, low-technology circular models such as composting and eco-oriented production represent the most immediately replicable pathways. Scaling such initiatives require targeted public support in the form of advisory services, co-financing mechanisms, and simplified access to rural development funds. Intermediate models, such as biogas systems, offer viable upgrading pathways where livestock concentration provides adequate feedstock. Policy frameworks should therefore prioritize structural compatibility over technological ambition, supporting circular transitions that align with existing resource endowments and local production conditions.

Overall, the paper contributes to a differentiated understanding of circular business models in agriculture as adaptable configurations whose success depends on strategic alignment with contextual conditions rather than on replication of technologically advanced examples.

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THE CONTRIBUTION OF ANXIETY IN THE PREDICTION OF CLIMATE CHANGE AMONG THE SERBIAN RURAL POPULATION

ДОПРИНОС АНКСИОЗНОСТИ У ПРЕДИКЦИЈИ КЛИМАТСКИХ ПРОМЕНА КОД СРПСКЕ РУРАЛНЕ ПОПУЛАЦИЈЕ

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Abstract: The aim of this online research was to identify the relative influence of predictors (general anxiety, relatedness to nature and perception of proactive pro-ecological behaviors) in explaining the criteria of anxiety due to climate change. The average age of respondents of both sexes ($N = 282$) of the rural population was $M_{\text{years}} = 45.62$, $SD = 2.31$. Four measurement instruments were applied: Climate Change Anxiety Scale, Nature Relatedness Scale, Anxiety Subscale and Proactive Environmental Behavior Questionnaire. The results of hierarchical regression analysis suggested that the predictor variables predict 19% of the total variance of the criteria. Statistically relevant influence on anxiety due to climate change showed two partial predictors: general anxiety ($\beta = 0.40$, $p \leq 0.01$) and relatedness to nature ($\beta = 0.22$, $p \leq 0.05$), while the predictor proactive environmental behavior is not statistically significant. The positive beta coefficients obtained suggested that higher levels of general anxiety and correlations with nature contribute to higher values of climate change anxiety. In this quantitative cross-sectional study, the theoretical and practical implications of the results on an online Serbian sample are discussed.

Key words: rural population, relatedness to nature, proactive ecological behavior, climate change

Абстракт: Циљ овог онлине истраживања је био идентификовање релативног утицаја предиктора (генералне анксиозности, корелације с природом и перцепције проактивних проеколошких понашања) у објашњавању критеријума анксиозности због климатских промена. Просечна старост испитаника оба пола ($N = 282$) руралне популације износила је $AS_{\text{godine}} = 45.62$, $SD = 2.31$. Примењена су четири мерна инструмента: Скала анксиозности због климатских промена, Скала повезаности с природом, Субскала анксиозности и Упитник проактивног еколошког понашања. Резултати хијерархијске регресионе анализе сугерисали су да предикторске варијабле предвиђају 19% од укупне варијансе критеријума. Статистички релевантан утицај на анксиозности због климатских промена, показала су два парцијална предикторија: генерална анксиозност ($\beta = 0.40$, $p \leq 0.01$) и корелација с природом ($\beta = 0.22$, $p \leq 0.05$), док предиктор проактивно еколошко понашање није статистички значајан. Добијени позитивни бета-кофицијенти су сугерисали да виши ниво генералне анксиозности и корелације с природом доприносе вишим вредностима анксиозности због климатских промена. У овој

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квантитативној трансверзалној студији дискутоване су теоријске и практичне импликације резултата на онлине српском узорку.

Кључне речи: сеоско становништво, корелација с природом, проактивно еколошко понашање, климатске промене

1. INTRODUCTION

Climate change on Earth is defined as a change in climate that has arisen as a direct or indirect result of human activity and is caused by changes in the atmosphere over periods of time (Coffé et al., 2026). Its main characteristics are an increase in average temperature, extreme weather events, and changes in ecosystems and biodiversity. Climate change is an increasingly pronounced generator of psychological stress, with significant implications for human mental health. In the last two decades of the twenty-first century, climate change represents a major problem of contemporary society, as well as a subject of research in applied environmental and climate psychology. Climate change is a negative consequence of the global ecological crisis and a threat to human health, given that global warming is 1.5° higher than in the pre-industrial period (Roopesh, 2026). The mentioned author considers that the burning of fossil fuels in industrial processes, the automotive industry, modern agricultural production, and deforestation contribute maximally to climate change; human behavior significantly influences the shaping of the climatic future, as its negative impact on nature generates adverse consequences of climate change, primarily affecting mental health status.

Climate change as a threat manifests itself negatively in the health context (Loc, 2026); for example, the dimension of *anxiety* – an emotional state of discomfort and worry accompanied by the expectation of an unfavorable outcome (extreme weather conditions and natural disasters, such as floods and tornadoes), is becoming increasingly prevalent among people due to climate change. Therefore, researchers (Bhakuni, Saxena, 2026; Shymko, Babadzhanova, 2024) emphasize that if people do not undertake more activities aimed at reducing the negative consequences of climate change, such as storms, droughts, or fires, this may negatively affect their mental health. Concern about climate change is to some extent acceptable when an individual understands the objectivity of events resulting from climate change. However, when concern about climate change transforms into frequent behaviors that deviate from socially acceptable ones, it then generates increased emotional, mental, or somatic stress as a reaction (Sobirjonov, 2026). Researchers (Ágoston et al., 2022) concluded that two forms of anxiety – cognitive – emotional impairment and functional impairment of people due to climate change – affect their ability to normally perform everyday activities.

The construct of *relatedness to nature* – cognition, affect, and experience encompassing people's connectedness with all living beings in nature is also a predictor of anxiety due to climate change (Moulavinafchi et al., 2026). In the study by Alshammari (2025), it was found that individuals who achieved higher scores on the relatedness to nature scale exhibited higher levels of stress, anxiety, and concern for pro-environmental behaviors in natural settings. This reciprocity is explained by the fact that individuals are oriented toward practical activities and therefore think more about the negative characteristics of climate change. The study by Wilson et al. (2026) emphasizes that a high percentage of respondents behave in an environmentally friendly manner in everyday life, for example, through lower consumption of energy and water and reduced use of automobiles in order to mitigate climate change.

The interrelationship between general anxiety, relatedness to nature, and the perception of proactive pro-environmental behaviors in predicting the criterion variable of anxiety due to climate change occupies an important place in research. Taking into account the findings of previous studies and the indisputable significance of the research problem, as well as the fact that identical studies on the relationships between the constructs of anxiety and climate change have not been conducted in the Republic of Serbia, the aim of this research is to examine the relative quantitative contribution of different predictors (general anxiety, relatedness to nature, and perception of proactive pro-environmental behaviors) in explaining the criterion variable of anxiety due to climate change in the rural population. Based on the cited previous findings, this study tested the alternative *hypothesis* (H): a statistically significant positive correlation is expected between general anxiety, relatedness to nature, pro-environmental behaviors, and the perception of climate change anxiety among the rural population.

2. MATERIAL AND METHODS

2.1 Respondents

The quantitative research was conducted on a non-probabilistic Serbian rural sample of 282 respondents of both sexes ($M = 45.62$, $SD = 2.31$). The age range was from 18 to 65 years, comprising 147 women (52.12%) and 135 men (47.87%). The basic criteria for participation in this online research design were the respondents' residence in rural, spatially dispersed areas on the territory of Serbia, as well as knowledge of the Serbian language. The educational structure of the respondents was as follows: incomplete primary education (3.14%), primary education (35.37%), secondary education (58.22%), and higher education and university degree (3.27%). According to marital status distribution, the largest number of respondents were married (63.10%), followed by divorced individuals and widows/widowers (24.06%), and those who had never been married (12.84%).

2.2 Procedure

The *online* measurement instruments used were administered in the form of a Google Forms platform and shared with respondents via a link on the social networks WhatsApp, Instagram, Facebook, and LinkedIn. In the instructions, respondents were informed that participation in the study was entirely voluntary and anonymous, that they could withdraw at any time without any consequences, and that the data would be analyzed at the group level exclusively for scientific purposes. After providing consent to participate, which was recorded by clicking "next," the completion of the measurement instruments began in February 2026 and lasted approximately 20 minutes. Prior to conducting the research, approval was obtained from the Scientific Council of the Serbian Academy of Innovation Sciences in Belgrade (approval no. 20/2026), based on the ethical standards of the Declaration of Helsinki.

2.3 Climate Change Anxiety Scale (CCAS)

The CCAS scale (Climate Change Anxiety Scale; Clayton & Karazsia, 2020) examines the impaired psychological state of individuals resulting from climate change. The measurement instrument comprises 13 items that assess the level of thinking about climate change in

relation to sleep (“Thinking about climate change makes it difficult for me to sleep”), socialization (“My concern about climate change makes it difficult for me to enjoy myself with my family and friends”), and emotion regulation and concentration at work (“Thinking about climate change makes it difficult for me to concentrate”). Respondents rate the extent to which each statement applies to them on a five-point Likert-type scale (from 1 = *never* to 5 = *almost always*). The total score is calculated as the arithmetic mean of responses across all items, with higher scores indicating a higher level of anxiety due to climate change. The coefficient of internal consistency (Cronbach’s alpha coefficient) in this study is $\alpha = 0.82$.

2.4 Nature Relatedness Scale (NR-6)

The NR-6 scale (Nature Relatedness Scale; Nisbet et al., 2009) consists of six items. Respondents assess personal identification with nature, a sense of relatedness to nature, spirituality, awareness, and subjective knowledge of the human natural environment, for example: “My relationship to nature is an important part of who I am,” “I always think about how my actions affect the environment,” “I feel very related to all living beings and the planet Earth.” The task of the respondents is to rate their agreement with each statement on a Likert-type scale ranging from 1 = *strongly disagree* to 5 = *strongly agree*. The total score is formed as the arithmetic mean of all statements. A higher score on the scale indicates a greater level of people’s relatedness to nature. The internal consistency (Cronbach’s alpha) of the scale on the examined sample is $\alpha = 0.79$.

2.5 Anxiety Scale (DASS)

The DASS subscale (Anxiety Scales; Lovibond & Lovibond, 1995) measures symptoms of anxiety. It comprises 14 items that describe symptoms of more intense physiological activation of the organism, as well as the perception of panic and fear. The symptoms are classified into four categories: autonomic arousal (e.g., “I experience heart problems—rapid heartbeat or skipping—even when I am not physically active”), skeletal-muscular experience (e.g., “My hands tremble”), situational anxiety (e.g., “I worry about situations in which I might panic or embarrass myself”), and the subjective experience of anxiety (e.g., “I feel like I am going to faint”). Respondents rate how often each item applied to them during the past week on a Likert-type scale ranging from 1 (*does not apply to me at all*) to 3 (*applies to me completely*). The total score on the scale is obtained by summing the responses to the corresponding items. A higher score suggests a higher level of anxiety. The obtained alpha coefficient value in our sample is $\alpha = 0.80$.

2.6 Proactive Environmental Behavior (PEB)

The PEB questionnaire (Proactive Environmental Behavior; Huang, 2016) consists of 10 items on the basis of which respondents individually manifest the level of recycling—reprocessing waste into new products, composting—a natural process of decomposition of organic waste resulting in fertilizer-compost, energy saving, reduction of transportation use, and purchasing local products (e.g., “I turn off or unplug electronic devices when they are not needed,” “I compost kitchen waste,” “I recycle newspapers/paper, plastic, cans, and glass”). The task of the respondents is to evaluate the listed behaviors on a five-point Likert scale ranging from 1 (*never*) to 5 (*almost always*). The total score is calculated by summing the responses to the corresponding items, with a higher score indicating more pronounced

proactive environmental behavior. The reliability of the questionnaire in this study is acceptable, as the obtained Cronbach's alpha value is $\alpha = 0.77$.

3. RESULTS AND DISCUSSION

The calculated basic statistical parameters of central tendency in Table 1 show that most of the distributions of perceived variables are close to the arithmetic means, which suggests a uniform level of variability and moderate individual differences in a homogeneous sample of respondents.

Table 1. Descriptive statistics of the used variables

Variables	<i>M</i>	<i>SD</i>	<i>Sk</i>	<i>Ku</i>	<i>SkSE</i>	<i>KuSE</i>
Anxiety due to climate change	1.23	0.72	0.46	0.91	0.10	0.12
Relatedness to nature	3.16	0.77	0.25	0.67	0.10	0.12
Proactive environmental behaviors	2.95	0.68	0.54	0.43	0.10	0.12
General anxiety	0.75	0.70	0.49	1.05	0.10	0.12

Legend: *Sk* = skewness; *Ku* = kurtosis; *SkSE* = standard error of the skewness; *KuSE* = standard error of the kurtosis; * $p \leq 0.05$. ** $p \leq 0.01$.

The calculated parameters of shape, standardized skewness and kurtosis, indicate that the distributions of the examined variables do not deviate from the normal hypothetical Gaussian distribution (range ± 2), which, according to the criteria proposed by (Kline, 2023), makes them acceptable for use in parametric statistical procedures.

Inspection of the Pearson correlation coefficients (*r*) in Table 2 shows that they range from weak to moderate linear correlations.

Table 2. Correlation coefficients between the examined variables

Variables	1	2	3	4	5	6	7
Age	–	0.03	-0.20*	-0.06	-0.10	0.02	-0.07
Gender		–	0.01	0.32**	0.06	0.30**	0.01
Financial status			–	-0.03	-0.06	-0.05	0.02
General anxiety				–	0.10	0.13	0.29**
Relatedness to nature					–	0.50**	0.18*
Proactive environmental behaviors						–	0.13*

Annotation. * $p \leq 0.05$, ** $p \leq 0.01$

The maximum statistically significant correlation with a negative direction was manifested between the variables proactive environmental behavior and relatedness to nature and age ($r = -0.90, p \leq 0.01$), whereas the minimal and negative linear association was found between general anxiety and proactive environmental behavior ($r = -0.90, -0.13, p \leq 0.01$), which is consistent with empirical research by Asbrand et al. (2026).

In order to check the influence of predictors in interpreting the variance of anxiety due to climate change, a hierarchical regression analysis was conducted. Before implementing this multivariate method, the independence of residuals, i.e. the difference between the actual (observed) value and the value predicted by the statistical model, was checked using the Durbin - Watson test, whereby a satisfactory value of 1.986 was obtained (Field, 2013), which shows that the prerequisite for the independence of residuals was met. Also, for the purpose of checking, the variance inflation factor –VIF (*Variance Inflation Factor*) was calculated to determine the degree of connection between the predictors and the *reciprocal value (Tolerance)* of the unexplained part of the variance of other predictors. The calculated VIF values are less than 10, and the reciprocal values are greater than 0.1, and it is concluded that there is no multicollinearity phenomenon between the predictors (Field, 2024).

The applied regression model consisted of three steps (Table 3). The variable of general anxiety was entered in Step 1, the variable of relatedness to nature was included in Step 2, while the variable of proactive environmental behavior was introduced in Step 3 of the model.

Table 3. Results of hierarchical regression analysis for the criterion anxiety due climate change

Predictors	Model 1	Model 2	Model 3
	β (SE)	β (SE)	B (SE)
General anxiety	0.40** (0.05)	0.29** (0.10)	0.40** (0.09)
Relatedness to nature		0.19** (0.07)	0.22* (0.06)
Proactive environmental behaviors			0.20* (0.08)
ΔR^2	0.14**	0.03**	0.00
R^2	0.13	0.19	0.19

Legend. β = standardized regression partial coefficient Beta; R^2 = Coefficient of multiple determination; SE = standard error of estimate of the regression coefficient; ΔR^2 = changed delta coefficient of multiple determination. ** $p \leq 0.01$, * $p \leq 0.05$.

The finding in the first regression model, which included the predictor general anxiety, suggests that it partially explains 14% of the variance of the criterion variable of anxiety due to climate change. The control variable relatedness to nature, entered in the second model, additionally explains 3% of the variability, while in the third model the control predictor proactive environmental behavior does not contribute quantitatively in a statistically significant manner to the prediction of variation in the criterion variable. In addition, it is observed that no mediation or suppression effects were found in the conducted regression – that is, no influence of the independent variables on the dependent variable through a third variable. It should also be emphasized that the set of all predictor variables explained a total of 19% of the proportion of variance in the criterion of anxiety due to climate change.

Analysis of the obtained standardized beta coefficients showed that in the first regression model, general anxiety emerged as a positive and statistically significant predictor ($\beta = 0.40$, $p \leq 0.01$). In the second model, in addition to general anxiety, perceived relatedness to nature stood out as a particularly relevant predictor ($\beta = 0.20$, $p \leq 0.01$). In the third model, the predictors general anxiety and relatedness to nature, with an additional 2% of explained variance, were the only significant positive determinants of the criterion variable. Specifically, the obtained regression parameters indicate that with an increase in the level of general anxiety and relatedness to nature, the level of anxiety due to climate change also increases. Based on the calculated beta coefficients, it is concluded that the hypothesis (H) was partially verified, that is, the significance of the constructs of general anxiety and relatedness to nature in explaining the variability of anxiety due to climate change was confirmed.

4. DISCUSSION

The aim of this online study was to examine the quantitative contribution of the perceived predictors (general anxiety, relatedness to nature, and proactive pro-environmental behaviors) in predicting the variability of the criterion variable of anxiety due to climate change. The obtained correlational–regression findings partially confirm the initial hypothesis that the constructs of anxiety and relatedness to nature represent significant generators of variability in anxiety due to climate change, which is consistent with theoretical models of anxiety and relatedness to nature that contribute to anxiety due to climate change.

In the earlier studies of applied psychology, that is, environmental and climate psychology, it has been established that there is a significant correlation between the variables of concern about climate change and general anxiety (Barrett, 2026). However, despite the fact that more than one half of the Serbian rural population believes that climate change is a major problem, this study found a low level of linear association between general anxiety and climate change anxiety. A likely generator of their low level of climate change anxiety is that the consequences of climate change are exposed to the negative influence of personal understanding; therefore, individuals to a large extent do not perceive the negative consequences of climate change. In addition, Serbian rural residents do not view the problem of climate change at a personal level, but rather expect state authorities to undertake measures to reduce the negative impact of climate change.

The findings of this study suggest that symptoms of anxiety are manifested to a lesser extent among respondents than concern, as it has probably not yet reached a quantitative level that would interfere with their everyday functioning. Identical results were found in the study

(Pohl et al., 2026), where concern about climate change was in a significant correlation with pathological worry. The phenomenon of climate anxiety is not a clinical diagnosis; therefore, the scale does not assess clinical use, but is applied to define the prevention of climate change anxiety over a period of time (Beron et al., 2024). However, in this study, climate change anxiety was more pronounced among some individuals who have general anxiety, higher relatedness to nature, and who manifest proactive environmental behaviors, which was expected and confirmed by the hypothesis. On the other hand, no statistically significant correlation was obtained between the variables of age and climate change anxiety. Thus, the identified positive correlation between general anxiety and climate change anxiety indicates that respondents with higher levels of general anxiety also have higher scores on the climate change anxiety scale, which is congruent with the findings of the study (Åskaree et al., 2026). This finding suggests that individuals with general anxiety are at greater risk of perceiving climate change anxiety, as they often experience emotions of fear and worry. Likewise, the predictor relatedness to nature is positively correlated with climate change anxiety, which is consistent with the results of the study (Kapoor and Rishbeth, 2026). Conversely, relatedness to nature may also have an opposite effect, that is, time spent in nature reduces stress and therefore people do not perceive climate change anxiety, which indicates that this interdependence should be further examined.

The predictor variable of proactive environmental behaviors in our sample is positively correlated with climate change anxiety, as rural respondents who behave proactively in an environmentally friendly manner on a daily basis think about reducing their negative contribution to the natural environment due to concern for the future climate and the environment in which they will live. However, the authors (Akhtar et al., 2026) did not find a statistically significant interaction between proactive environmental behaviors and climate change anxiety. In this study, proactive environmental behaviors did not emerge as a determinant of the criterion of climate change anxiety. Conversely, in previous studies, pro-environmental behaviors have been shown to be strong predictors of climate change-related stress, which draws attention to the fact that people who behave proactively in an environmentally friendly way are at greater risk of perceiving climate anxiety (Wang et al., 2026), which may increase stress and generate climate change anxiety. According to researchers (Ágoston et al., 2024), the reason for these differing results likely lies in the level of cognitive and emotional impairment correlated with an individual's ability for climate anxiety to serve as a motivation for behavioral transformation and the formation of proactive environmental behaviors, that is, saving energy, purchasing second-hand products, and similar actions. Interestingly, such behaviors require greater effort, whereas behaviors for which climate anxiety was not a determinant are those that do not require greater effort, such as avoiding food waste and purchasing fewer products. Accordingly, a possible interpretation of why proactive environmental behaviors in this study did not prove to be a statistically significant determinant of climate change anxiety is that respondents who behave proactively in an environmentally friendly manner perceive a sense of control and safety related to the consequences of climate change and therefore do not experience unpleasant emotions.

Therefore, in this study only the predictors general anxiety and relatedness to nature proved to be significant determinants, meaning that general anxiety predicts the maximum portion of variability of the criterion variable. Considering the findings of the study (Eklöf and Klöckne, 2026), in which respondents maximally expressed general anxiety and relatedness to nature, it is not surprising that these predictors explain the largest portion of variability in climate change anxiety.

The construct of general anxiety is a relevant determinant of the dependent variable of climate change anxiety, as respondents with more pronounced general anxiety also show more visible climate change anxiety (Tiitta, 2025). This finding is consistent with the results (Balme and Holm, 2023) which indicate that people who have general anxiety are at greater risk of perceiving climate change anxiety. The reason for this effect is that current anxiety symptoms may correlate with the consequences of climate change. The author (Barrett, 2026) noted that individuals who think more intensely about climate change should, through mindfulness techniques, consciously distance themselves from such thinking, that is, create a new interaction with the experience—acceptance rather than avoidance.

According to the results of the study (2022), relatedness to nature is a positive determinant of climate change anxiety. Individuals who are immersed in nature manifest more symptoms of anxiety because these remind them that nature is in danger. This is explained by the fact that people who are related to nature spend more time in it, and it is important for them to preserve the environment; therefore they pay more attention to the negative impacts that occur in the natural environment, which generates concern for natural conditions and potentially anxiety due to climate change. Despite this, pleasant emotions may also be experienced as a reaction to climate change. Researchers (Eklöf and Klöckner, 2026) believe that the emotional reaction to climate change is also conditioned by the social context, which can produce pleasant or unpleasant emotions. In this regard, the emotion of hope is a relevant motive for coping with climate change, e.i. when hope is based on denial, it is not a positive phenomenon that directs people toward proactive environmental behavior; rather, hope even as a pleasant emotion is perceived as an illusion and as the individual's inability to responsibly understand climate change. In contrast, when hope is based on confronting climate change, pleasant emotions provide energy for dealing with the problem and searching for solutions to climate change.

Regardless of the relevance of this study in applied ecological and climate psychology, there are several methodological shortcomings that limit the possibility of interpreting and generalizing the results to the general rural population. First, the research was conducted on an online sample, which reduces the possibility of drawing general conclusions regarding the prediction of the rural population. Second, due to differentiated measurement methods, the construct of climate change anxiety is complex to precisely operationalize and quantify, and therefore it may be biased because respondents often assess their own abilities, which reduces its reliability and validity of measurement. Third, during self-assessment respondents answer in a subjectively socially acceptable, that is “desirable,” manner instead of according to their real emotional capacity. Finally, the obtained minimal proportion of explained variance of climate change anxiety in rural, sparsely populated areas suggests that there are some additional factors that were not examined in this research, and that the conducted cross-sectional research design does not allow conclusions about causal-consequential relations, but only about predictive interactions between variables. Despite the mentioned methodological limitations, the obtained findings provide an empirical basis for improving strategies for the reduction of climate change anxiety among the rural population, as well as the need for additional empirical (longitudinal) studies with a more representative sample and the inclusion of other factors that influence climate change anxiety.

5. CONCLUSION

The results of this study indicate that anxiety has a relevant quantitative role in the perception of climate change among a sample of rural residents of both sexes in Serbia with an average age of 45 years. A statistically significant positive correlation was identified between the variables of general anxiety, relatedness to nature, proactive environmental behavior, and climate change anxiety. The findings of the hierarchical regression analysis, with a total of 19% explained variance, suggest that the predictors (general anxiety and relatedness to nature) are the only significant positive determinants of the criterion variable (climate change anxiety). The extracted minimal percentage of variance in the regression indicates potential determinants of the construct of climate change anxiety that were not tested in this cross-sectional online study. The obtained results are congruent with current empirical research emphasizing the role of general anxiety and relatedness to nature in the evaluation of climate change. The findings of this study in the field of applied psychology expand knowledge about the relevance of the influence of predictor variables on the prediction of the criterion variable in areas with low population density. Therefore, they may serve as a basis for developing interventions aimed at residents outside urban areas in order to reduce their perceived anxiety related to climate change.

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CLIMATE-RESILIENT AGRICULTURAL VALUE CHAINS AND AGROBUSINESS COMPETITIVENESS IN SOUTHEAST EUROPE

КЛИМАТСКИ ОТПОРНИ ЗЕМЈОДЕЛСКИ ВРЕДНОСНИ СИНЦИРИ И КОНКУРЕНТНОСТ НА АГРОБИЗНИСОТ ВО ЈУГОИСТОЧНА ЕВРОПА

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Abstract: *This study examines how digital agricultural technologies and climate adaptation practices influence agrobusiness competitiveness in Southeast Europe. The empirical analysis is based on survey data collected from 148 agricultural producers operating in North Macedonia, Serbia, and Bulgaria. The dataset was examined using statistical techniques together with spatial econometric analysis in order to explore the relationship between technological adoption, adaptive farm management strategies, and agrobusiness competitiveness. The findings suggest that farms using digital monitoring tools and adaptive management practices tend to achieve more stable production outcomes and stronger integration within agricultural value chains.*

Key words: *digital agriculture, climate resilience, agricultural value chains, rural development, agrobusiness competitiveness.*

Анстракт: *Ова истражување ја анализира врската меѓу примената на дигитални земјоделски технологии, стратегиите за климатска адаптација и конкурентноста на агробизнисот во Југоисточна Европа. Податоците од анкетата опфаќаат 148 земјоделски производители од Северна Македонија, Србија и Бугарија и беа анализирани со статистички и просторни економетриски методи. Резултатите покажуваат дека дигиталните системи за мониторинг и адаптивните практики во управувањето со фармите придонесуваат за поголема стабилност на производството и за посилен земјоделски вредносен синџир.*

Клучни зборови: *дигитално земјоделство, климатска отпорност, аграрни синџири, рурален развој, агробизнис.*

1. INTRODUCTION

Agriculture in Southeast Europe is increasingly influenced by climatic variability and technological change. Agriculture remains an important component of rural economies

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across North Macedonia, Serbia, and Bulgaria, where it continues to influence employment patterns, food supply, and household income structures. However, agricultural systems in the region increasingly face environmental pressures associated with climate change—irregular precipitation patterns, temperature fluctuations, and more frequent extreme weather events create growing uncertainty for production and complicate long-term planning decisions (Lobell et al., 2011; Ortiz-Bobea et al., 2020).

At the same time, agricultural production systems are undergoing technological transformation driven by digital innovation. Advances in satellite observation, remote sensing technologies, sensor platforms, and digital farm management systems enable more effective monitoring of environmental conditions and support improved decision-making at the farm level. In recent years, environmental data have become increasingly integrated into agricultural production management through these digital monitoring technologies (Wolfert et al., 2017; Trendov et al., 2019).

The convergence of these two trends, climatic pressure and technological opportunity, creates challenges and opportunities for agricultural producers in Southeast Europe. Yet the region's agricultural systems differ markedly from those in Western Europe. Unlike Western European agricultural systems, farms in our sample face unique challenges related to fragmented land ownership and post-socialist transition, which continue to shape investment capacity, technological adoption patterns, and access to agricultural advisory services. These structural legacies, combined with heterogeneous agro ecological conditions and varying levels of technological infrastructure, create diverse development trajectories that warrant specific empirical investigation.

Agricultural modernization and productivity growth are increasingly associated with technological innovation and institutional capacity that support the adoption of modern agricultural practices (World Bank, 2021). Understanding how digital technologies interact with climate adaptation strategies in this specific regional context represents an important analytical challenge. Previous research has demonstrated that digital monitoring systems can improve resource efficiency and reduce environmental pressures associated with excessive input use (Finger et al., 2019; Zhang et al., 2021). However, less is known about how these technologies function within the structural constraints characteristic of post-socialist agricultural systems.

This study contributes to the literature by combining survey evidence with spatial econometric analysis to examine how digital agricultural technologies and climate adaptation practices influence agro business competitiveness in Southeast Europe. The research considers how technological innovation and adaptive farm management strategies affect production stability and economic performance within agricultural enterprises operating under conditions of environmental uncertainty and structural constraint.

2. CONCEPTUAL AND EMPIRICAL FOUNDATIONS OF DIGITAL AGRICULTURE

Digital transformation increasingly influences agricultural production systems and the organization of global agricultural value chains. This study contributes to the literature by combining survey evidence with spatial econometric analysis to examine how digital technologies in agriculture and climate adaptation practices influence agro business

competitiveness. Digital agriculture refers to the application of digital technologies, environmental monitoring systems, and advanced data processing tools within agricultural production and farm management. These technologies include satellite observation systems, remote sensing platforms, sensor networks, and digital farm management software capable of processing environmental and production data (Wolfert et al., 2017).

The availability of satellite imagery, field sensor networks, and environmental data platforms enables agricultural producers to observe production conditions with greater precision and respond more effectively to environmental variability. Agricultural decision-making is increasingly supported by digital information systems that facilitate efficient allocation of agricultural inputs and improve production planning under conditions of climatic uncertainty (Trendov et al., 2019; Lowenberg-DeBoer et al., 2020).

Precision agriculture represents one of the most widely discussed applications within digital agriculture. Spatial monitoring technologies and sensor-based data collection allow producers to manage agricultural inputs according to local environmental conditions. Variable-rate technologies enable farmers to adjust the application of fertilizers, pesticides, and irrigation water according to soil characteristics and crop requirements, thereby improving resource efficiency and reducing environmental pressures associated with excessive input use (Finger et al., 2019; Zhang et al., 2021).

Digital agricultural technologies increasingly support climate adaptation strategies within agricultural production systems exposed to environmental variability. Monitoring platforms and environmental forecasting systems allow producers to observe climatic conditions and adjust agricultural practices accordingly. Access to environmental data supports irrigation planning, crop selection, and diversification strategies aimed at reducing production risks associated with climatic variability (Ortiz-Bobea et al., 2020; Herrero et al., 2021).

Recent technological developments integrate data analytics and artificial intelligence into agricultural monitoring systems. These systems combine information from satellite observations, meteorological stations, and soil sensors in order to improve production forecasting and farm management planning. Digital technologies increasingly function as components of broader agricultural innovation systems linking technological development, agricultural knowledge networks, and institutional support mechanisms (Klerkx et al., 2019; Rose & Chilvers, 2023).

The integration of digital technologies also affects agricultural value chains. These chains connect agricultural production with processing industries, distribution networks, and consumption markets. Digital technologies facilitate coordination between producers, processors, and market actors by improving monitoring of production volumes, quality standards, and supply chain logistics. Digital agricultural platforms increasingly support traceability systems and supply chain transparency, thereby strengthening agrobusiness networks and improving competitiveness within agricultural value chains (FAO, 2022).

Despite these technological opportunities, adoption of digital agricultural technologies remains uneven. Structural differences in farm size, financial capacity, technological knowledge, and institutional support influence the diffusion of digital innovations. Larger agricultural enterprises typically possess greater investment capacity and technological

expertise, while smaller farms often face financial and knowledge constraints that slow technological adoption (Klerkx et al., 2019).

Institutional environments therefore play an important role in shaping agricultural technological modernization. Agricultural advisory services, research institutions, and policy frameworks contribute to the dissemination of technological knowledge and support the adoption of innovative agricultural practices. International policy frameworks increasingly recognize digital transformation in agriculture as part of strategies aimed at strengthening agricultural productivity and climate resilience (OECD, 2019; European Commission, 2023).

Within Southeast Europe, agricultural systems are characterized by a high proportion of small and medium-sized farms, heterogeneous agroecological conditions, and varying levels of technological infrastructure. These structural characteristics create diverse patterns of technological adoption. Understanding how technological adoption interacts with climate adaptation strategies therefore represents an important analytical challenge for agricultural systems operating under environmental variability.

The conceptual framework developed in this study examines the relationship between digital agricultural technologies, climate adaptation practices, and agrobusiness competitiveness within agricultural value chains across Southeast Europe.

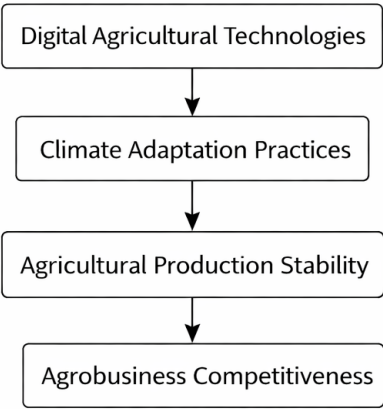


Figure 1. Conceptual model of digital agriculture, climate adaptation and agrobusiness competitiveness.

3. RESEARCH METHODOLOGY AND DATA FRAMEWORK

The empirical analysis examines how digital technologies in agriculture and climate adaptation practices influence the competitiveness of agricultural enterprises within value chains in Southeast Europe. The methodological framework combines survey-based empirical data with quantitative statistical analysis in order to evaluate how technological adoption influences production stability and economic performance within agricultural enterprises operating under conditions of climatic variability.

Differences in farm size, technological capacity, and market accessibility create heterogeneous development trajectories for agricultural enterprises across the region, which makes the examination of technological adoption particularly relevant. For this reason, the research design incorporates primary survey data obtained directly from agricultural producers and agrobusiness managers operating in rural regions of the analyzed countries. The empirical dataset was constructed through a structured questionnaire distributed among agricultural producers and agrobusiness managers operating in rural areas of North Macedonia, Serbia, and Bulgaria. These countries were selected because their agricultural sectors demonstrate comparable structural characteristics, including a significant presence of small and medium agricultural holdings, exposure to climatic variability, and gradual technological modernization within agricultural production systems. At the same time, agricultural enterprises within these countries participate in regional agricultural markets and share similar institutional environments related to rural development policies and agricultural support programs.

The questionnaire was designed to collect information on technological adoption, climate adaptation practices, and economic performance within agricultural enterprises. Several thematic groups of questions were included in order to capture the different dimensions of agricultural production and management practices. Respondents were asked to evaluate the extent to which digital agricultural technologies are incorporated into their farm management activities. These technologies include satellite-based crop monitoring systems, digital soil monitoring tools, automated irrigation platforms, and farm management software used for monitoring production processes and environmental conditions.

Climate adaptation practices were examined through questions related to crop diversification strategies, irrigation management, soil conservation practices, and other adaptive agricultural techniques implemented in response to climatic variability. Such practices represent commonly observed responses to environmental uncertainty within agricultural systems exposed to irregular precipitation patterns and temperature fluctuations. By collecting information regarding these adaptive management practices, the research aims to evaluate how agricultural producers respond to environmental pressures through modifications in farm management strategies.

Economic performance within agricultural enterprises was measured through indicators related to production stability, productivity development, and participation in agricultural value chains. Respondents evaluated their perception of economic performance using a five-point Likert scale ranging from very low performance to very high performance. Similar measurement scales were applied to the variables representing digital technology adoption and climate adaptation practices. The use of Likert-type measurement scales is common in empirical research examining management practices and technological adoption within agricultural enterprises, as it allows the quantification of qualitative perceptions related to economic and managerial performance.

The final empirical dataset contains responses from 148 agricultural producers and agrobusiness managers representing a wide spectrum of agricultural activities. The sample includes enterprises engaged in crop cultivation, fruit production, livestock farming, and agricultural processing activities. The diversity of agricultural production activities represented in the dataset provides a broader perspective on technological adoption and adaptive management strategies across different segments of agricultural production systems.

In order to summarize the principal characteristics of the dataset, descriptive statistical analysis was conducted for the main variables included in the empirical framework. Descriptive statistics provide information regarding the average level of technological adoption, climate adaptation practices, and agricultural competitiveness among surveyed agricultural producers. Such preliminary analysis allows the identification of general patterns within the dataset before more advanced statistical techniques are applied. Table 1 presents the descriptive statistics of the main variables included in the empirical analysis.

Table 1. Descriptive statistics of variables used in the empirical analysis

Variable	Mean	Standard Deviation	Minimum	Maximum
Digital technology adoption	3.21	0.87	1	5
Climate adaptation practices	3.08	0.91	1	5
Agrobusiness competitiveness	3.46	0.79	1	5
Farm size (hectares)	12.4	7.6	2	45

The descriptive statistics indicate moderate levels of digital technology adoption among surveyed agricultural producers. The average value of the digital technology adoption variable suggests that a considerable proportion of agricultural enterprises has begun incorporating digital monitoring technologies and farm management software into agricultural production processes. At the same time, the relatively high standard deviation indicates that technological adoption remains uneven across agricultural enterprises within the empirical sample.

Climate adaptation practices demonstrate comparable adoption levels. Agricultural producers increasingly apply crop diversification strategies, improved irrigation management, and soil conservation techniques in order to reduce production risks associated with climatic variability. The slightly higher average value observed for agricultural competitiveness indicates that economic performance within agricultural enterprises is influenced not only by technological adoption but also by broader structural factors such as farm size, market access, and participation within agricultural value chains.

Following the descriptive statistical analysis, correlation analysis was conducted in order to examine the relationships between digital technology adoption, climate adaptation practices, and agricultural competitiveness. Correlation analysis represents a widely applied statistical method in agricultural economics and rural development research for evaluating relationships between technological adoption and farm performance indicators (Zilberman et al., 2012). The Pearson correlation coefficient was calculated to evaluate the strength and direction of the relationships between the analyzed variables. The Pearson correlation coefficient can be expressed as follows:

$$r = \Sigma[(X_i - \bar{X})(Y_i - \bar{Y})] / \sqrt{(\Sigma(X_i - \bar{X})^2 \Sigma(Y_i - \bar{Y})^2)}$$

where r represents the correlation coefficient between variables X and Y , X_i and Y_i represent individual observations within the dataset, and $\bar{X}$ and $\bar{Y}$ represent the mean values of the respective variables. Values of the coefficient range from -1 to $+1$, where positive values

indicate a positive relationship between variables and negative values indicate an inverse relationship. Statistical significance was evaluated using a significance threshold of $p < 0.05$. Table 2 presents the correlation matrix of the principal variables included in the empirical analysis.

Table 2. Correlation matrix of key variables

Variable	Digital Technology Adoption	Climate Adaptation Practices	Agricultural Competitiveness
Digital technology adoption	1.00	0.58**	0.61**
Climate adaptation practices	0.58**	1.00	0.54*
Agrobusiness competitiveness	0.61**	0.54*	1.00

Note: * $p < 0.05$; ** $p < 0.01$.

The correlation matrix reveals positive relationships between all analyzed variables. The strongest relationship appears between digital technology adoption and agricultural competitiveness, indicating that agricultural enterprises implementing digital technologies tend to demonstrate stronger economic performance and greater participation within agricultural value chains.

In addition to correlation analysis, an econometric specification was developed in order to evaluate the influence of technological adoption and adaptive management practices on agricultural competitiveness. The econometric model can be expressed in the following form:

$$\text{AgComp}_i = \beta_0 + \beta_1 \text{DigTech}_i + \beta_2 \text{ClimateAdapt}_i + \beta_3 \text{FarmSize}_i + \varepsilon_i$$

where AgComp represents agricultural competitiveness, DigTech represents the level of digital technology adoption, ClimateAdapt represents climate adaptation practices, and FarmSize represents the size of agricultural holdings measured in hectares. The error term ε captures unobserved factors influencing economic performance within agricultural enterprises.

In order to capture potential spatial interactions between agricultural enterprises located in geographically proximate areas, the empirical framework incorporates spatial econometric analysis. Agricultural production systems often develop within regional clusters characterized by similar environmental conditions, technological diffusion processes, and institutional environments. Such spatial relationships may generate spillover effects in which technological adoption and adaptive agricultural practices implemented in one location influence agricultural performance in neighboring areas.

The spatial econometric specification extends the conventional regression model by incorporating a spatial lag component that captures geographic interdependence among observations. The spatial regression model is expressed as follows:

$$\text{AgComp}_i = \beta_0 + \beta_1 \text{DigTech}_i + \beta_2 \text{ClimateAdapt}_i + \beta_3 \text{FarmSize}_i + \rho \text{WAgComp}_i + \varepsilon_i$$

where W represents the spatial weight matrix describing the geographic relationships between observations included in the dataset, while ρ measures the degree of spatial dependence within the model. A statistically significant spatial coefficient indicates that agricultural competitiveness within one agricultural unit may be influenced by the performance of neighboring agricultural enterprises.

The spatial weight matrix was constructed based on geographic proximity between surveyed agricultural regions. Observations located within the same regional clusters were assigned higher spatial weights in order to reflect the assumption that agricultural producers operating within geographically proximate environments may share similar climatic conditions, technological knowledge networks, and market connections. Such spatial relationships are frequently observed in agricultural production systems where knowledge diffusion occurs through local advisory services, producer networks, and regional cooperation between agricultural enterprises.

By incorporating spatial econometric analysis, the methodological framework allows the empirical investigation to capture both direct relationships between technological adoption and agricultural competitiveness as well as spatial spillover effects generated by regional interactions among agricultural enterprises. The integration of spatial analytical techniques therefore contributes to a more comprehensive understanding of how technological innovation and adaptive agricultural management practices influence agricultural competitiveness within agricultural value chains across Southeast Europe. The statistical and spatial econometric analyses were conducted using R and GeoDa software environments.

4. EMPIRICAL RESULTS AND CORRELATION ANALYSIS

The empirical analysis relies on survey responses from 148 agricultural producers and agro business managers operating in North Macedonia, Serbia, and Bulgaria.

The descriptive analysis indicates that the diffusion of digital agricultural technologies remains uneven across agricultural enterprises. Approximately 39 percent of respondents report regular use of digital technologies within farm management activities, including satellite-based crop monitoring systems, digital soil monitoring platforms, automated irrigation systems, and farm management software. Another 26 percent report partial adoption, primarily through weather monitoring applications and irrigation management tools, while the remaining respondents rely predominantly on conventional agricultural management practices. The distribution of technological adoption across surveyed farms is presented in Figure 2.

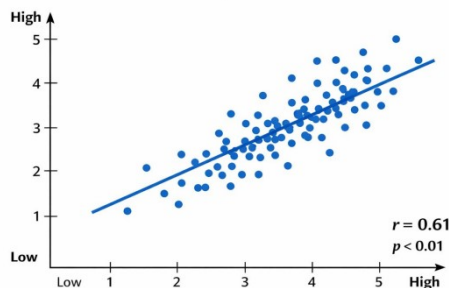


Figure 2. Distribution of digital technology adoption among surveyed farms

Differences in technological adoption are frequently associated with structural factors such as farm size, financial capacity, and access to technological knowledge. Agricultural enterprises with stronger financial resources and better connections with advisory services appear more likely to incorporate digital monitoring systems into their production processes.

The empirical analysis also examined climate adaptation strategies among surveyed agricultural producers. Climatic variability has become an increasingly important factor influencing agricultural production systems, particularly in regions exposed to irregular precipitation patterns and temperature fluctuations.

Approximately 45 percent of respondents report implementing crop diversification strategies, while 38 percent report soil conservation practices aimed at maintaining soil fertility and reducing erosion. Around 31 percent of respondents indicate investments in improved irrigation systems and water management technologies designed to stabilize production under irregular precipitation patterns. These strategies are illustrated in Figure 3.

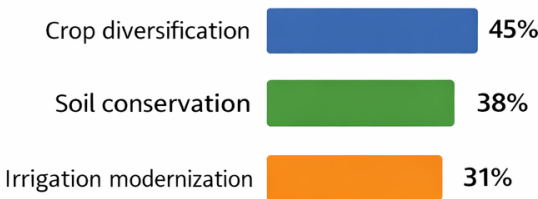


Figure 3. Climate adaptation strategies used by farms

Correlation analysis reveals statistically significant positive relationships between digital technology adoption, climate adaptation practices, and agricultural competitiveness. The correlation coefficient between digital technology adoption and climate adaptation practices equals $r = 0.58$ ($p < 0.01$), indicating that farms adopting digital monitoring technologies demonstrate greater capacity to implement adaptive agricultural strategies.

The relationship between digital technology adoption and agricultural competitiveness equals $r = 0.61$, indicating a moderately strong positive association between technological adoption and economic performance. Climate adaptation practices also demonstrate a positive relationship with agricultural competitiveness ($r = 0.54$; $p < 0.05$).

These findings correspond with previous research demonstrating that digital monitoring technologies support improved agricultural decision-making and more efficient resource allocation within agricultural production systems (Wolfert et al., 2017; Finger et al., 2019).

4.1. Spatial Econometric Results

In order to examine whether agricultural competitiveness demonstrates spatial dependence across the surveyed agricultural regions, spatial econometric diagnostics were conducted prior to estimating the spatial regression model. Agricultural production systems frequently develop within regional environments characterized by similar climatic conditions, technological diffusion processes, and institutional settings. Such spatial proximity often creates interactions among agricultural enterprises that may influence production practices,

technological adoption, and economic performance. For this reason, spatial econometric techniques were incorporated into the empirical framework in order to evaluate whether agricultural competitiveness exhibits spatial clustering across the analyzed regions.

The presence of spatial autocorrelation was evaluated using the Global Moran's I statistic, a widely applied indicator in spatial econometric analysis that measures the degree of spatial clustering in geographic data (LeSage & Pace, 2009). Moran's I values range between -1 and $+1$, where positive values indicate spatial clustering of similar observations, negative values indicate spatial dispersion, and values close to zero suggest a random spatial distribution. In the context of agricultural production systems, positive spatial autocorrelation may indicate that agricultural enterprises located in geographically proximate areas demonstrate similar levels of economic performance or technological adoption.

The results of the Moran's I diagnostic test indicate the presence of moderate spatial autocorrelation in agricultural competitiveness across the surveyed agricultural regions. The calculated Moran's I value equals 0.21 with a statistically significant Z-score of 2.34 and a p-value of 0.019. These results suggest that agricultural competitiveness is not randomly distributed across the observed agricultural regions. Instead, farms characterized by higher levels of competitiveness tend to be located in geographic proximity to other agricultural enterprises demonstrating similar levels of economic performance. Table 3 presents the results of the spatial autocorrelation diagnostic test.

Table 3. Moran's I spatial autocorrelation test

Variable	Moran's I	Expected value	Z score	p value
Agricultural competitiveness	0.21	-0.007	2.34	0.019

The positive value of Moran's I indicates the presence of spatial clustering within the observed agricultural production systems. Agricultural enterprises operating within the same regional environments appear to share similar levels of competitiveness. Such spatial patterns may reflect common agro ecological conditions, shared technological knowledge networks, and similar institutional environments affecting agricultural production systems within the analyzed countries.

Following the spatial diagnostic analysis, a spatial lag regression model was estimated in order to evaluate the influence of digital agricultural technologies and climate adaptation practices on agricultural competitiveness while simultaneously accounting for spatial spillover effects between neighboring agricultural units. Spatial lag models extend conventional regression frameworks by incorporating a spatially lagged dependent variable, which captures the influence of neighboring observations on the outcome variable.

The spatial regression model therefore allows the empirical analysis to evaluate whether agricultural competitiveness within one agricultural enterprise may be influenced by the performance of neighboring agricultural enterprises located within the same geographic environment. In agricultural systems, such spatial interactions frequently occur through the diffusion of technological knowledge, cooperation among producers, and shared exposure to environmental conditions. The spatial regression results are presented in Table 4.

Table 4. Spatial regression results

Variable	Coefficient	Standard Error	p value
Digital technology adoption	0.42	0.09	0.001
Climate adaptation practices	0.31	0.11	0.004
Farm size	0.18	0.07	0.036
Spatial lag coefficient (ρ)	0.27	0.08	0.012
Intercept	1.15	0.34	0.002

The estimated spatial regression model confirms that digital agricultural technologies and climate adaptation practices positively influence agro business competitiveness. The coefficient associated with digital technology adoption demonstrates the strongest positive relationship with agricultural competitiveness. Agricultural enterprises incorporating digital monitoring technologies, precision agriculture tools, and farm management software demonstrate higher levels of economic performance and improved participation within agricultural value chains.

Climate adaptation practices also demonstrate a statistically significant positive relationship with agricultural competitiveness. Agricultural producers implementing crop diversification strategies, soil conservation techniques, and improved irrigation systems tend to achieve more stable production outcomes and demonstrate greater resilience to climatic variability. The findings suggest that adaptive agricultural management practices contribute to strengthening the economic performance of agricultural enterprises operating within environmentally uncertain production environments.

Farm size appears as another statistically significant factor influencing agricultural competitiveness. Larger agricultural enterprises demonstrate slightly higher levels of competitiveness compared with smaller agricultural holdings. This relationship may be associated with differences in investment capacity, technological adoption potential, and access to agricultural advisory services. Larger farms often possess greater financial resources that facilitate investments in digital monitoring technologies and improved production infrastructure.

An important finding of the spatial regression analysis concerns the spatial lag coefficient. The spatial lag parameter is positive and statistically significant, indicating the presence of spatial spillover effects across neighboring agricultural regions. This result suggests that the competitiveness of agricultural enterprises is influenced not only by internal farm management practices but also by production conditions and technological adoption patterns observed within neighboring agricultural areas.

Spatial spillover effects may arise through several mechanisms. Agricultural producers frequently exchange information regarding production techniques, crop management strategies, and technological innovations through local knowledge networks and informal cooperation. Advisory services and regional agricultural institutions also contribute to the dissemination of technological knowledge within agricultural communities. Such interactions facilitate the diffusion of innovative agricultural practices and may contribute to

the formation of regional clusters characterized by higher levels of agricultural competitiveness.

The presence of spatial clustering within agricultural competitiveness therefore indicates that regional technological diffusion processes and knowledge networks may influence agricultural production systems. Agricultural enterprises located in regions where digital agricultural technologies are more widely adopted may benefit indirectly from technological knowledge spillovers and improved regional agricultural infrastructure.

By incorporating spatial econometric modelling into the empirical analysis, the research framework captures geographic interactions that influence agricultural production systems across Southeast Europe. The results suggest that technological innovation and adaptive agricultural management practices operate not only at the level of individual farms but also through regional networks connecting agricultural producers operating within shared geographic environments.

The spatial analytical findings therefore complement the correlation analysis presented earlier by demonstrating that agricultural competitiveness is shaped by both farm-level management practices and broader regional interactions. Such results provide additional insight into the mechanisms through which digital agricultural technologies and climate adaptation strategies influence the performance of agricultural value chains across rural regions of Southeast Europe.

5. DISCUSSION AND POLICY IMPLICATIONS

The results indicate that farms incorporating digital monitoring systems tend to achieve more stable production outcomes and greater capacity to adjust strategies under climatic variability. Access to digital information regarding soil conditions and weather patterns enables producers to improve planning and allocate inputs more efficiently, consistent with earlier research (Wolfert et al., 2017; Herrero et al., 2021).

However, these findings must be situated within the specific structural context of Southeast European agriculture. Unlike Western European systems, farms in our sample face unique challenges related to fragmented land ownership and post-socialist transition. The average farm size of 12.4 hectares masks considerable variation, from small subsistence holdings to larger commercial operations. This fragmentation—a legacy of land restitution processes following socialism—creates distinct barriers to technological adoption less prevalent in Western Europe where farm consolidation occurred earlier.

The analysis confirms that climate adaptation practices—crop diversification (45% of respondents), soil conservation (38%), and improved irrigation (31%)—contribute positively to competitiveness. In Southeast Europe, where irrigation infrastructure remains underdeveloped compared to Western standards—a legacy of transition-era underinvestment—these strategies become particularly critical for managing climatic uncertainty.

Structural differences in technology adoption persist. Larger farms demonstrate higher adoption levels than smaller holdings. This reflects the dual agricultural structure characteristic of post-socialist systems: a small number of large commercial farms coexisting with numerous small, semi-subsistence holdings. Smaller enterprises face barriers not only

in investment capacity but also in technical expertise to interpret digital data—gaps that extension services have only partially addressed.

The spatial lag coefficient ($\rho = 0.27$, $p < 0.05$) confirms significant spillover effects across neighboring regions. This empirically supports our field observations that farmers in areas like Pelagonia (North Macedonia), Vojvodina (Serbia), and Plovdiv (Bulgaria) exchange knowledge through informal networks and producer groups. When one farm adopts drip irrigation or digital monitoring, neighboring farms often follow within one to two seasons—suggesting observational learning remains powerful where formal extension systems have limited reach.

These spatial patterns likely reflect historical cooperation networks persisting despite land fragmentation. Former cooperative members, now farming individually, maintain information-sharing networks that partially offset the disadvantages of small farm size—social capital inherited from the socialist period enabling collective learning. This finding aligns with emerging international evidence suggesting that digital agriculture adoption may generate spatial spillovers across neighboring agricultural areas.

These findings carry important implications. First, agricultural policies in Southeast Europe have traditionally focused on individual farm support. Our results suggest interventions targeting regional clusters rather than isolated farms could leverage spatial spillover effects—investments in demonstration farms and regional innovation hubs may accelerate diffusion across entire landscapes.

Second, given small farm prevalence, policies promoting shared technology access—cooperatively owned monitoring equipment or fee-for-service digital advisory models—may prove more effective than subsidies for individual purchase. Extension services should build not only technical skills but also interpretive capacity to transform digital data into management decisions.

Finally, informal knowledge networks retain considerable influence where formal extension remains underfunded. Policies strengthening producer organizations and facilitating study groups could amplify the spillover effects we document while working within existing institutional structures.

This study has limitations. The sample size ($n = 148$) limits generalizability, though consistency across three countries suggests robustness. Reliance on self-reported competitiveness introduces potential bias—future research should incorporate objective financial data. The cross-sectional design captures adoption at one point; longitudinal research would provide insight into long-term impacts and whether spillover effects operate differently across technology types.

6. CONCLUSIONS

Using survey data from 148 agricultural producers in North Macedonia, Serbia, and Bulgaria, this study examines how digital technologies and climate adaptation practices influence agrobusiness competitiveness in Southeast Europe. The analysis reveals three main findings. First, digital monitoring technologies correlate positively with competitiveness ($r = 0.61$). Second, climate adaptation practices—crop diversification, soil conservation, improved

irrigation—contribute to production stability. Third, significant spatial spillover effects exist ($\rho = 0.27$, $p < 0.05$): technology adoption in one area influences neighboring farms.

These findings must be understood within the post-socialist context. Unlike Western Europe, our sample faces fragmented land ownership, underdeveloped irrigation infrastructure, and a dual structure of small subsistence farms alongside larger commercial operations. These constraints shape adoption patterns.

Encouragingly, spatial spillover effects suggest informal knowledge networks persist despite fragmentation. Farmers in regions like Pelagonia, Vojvodina, and Plovdiv exchange information through producer groups and observational learning—partially compensating for limited formal extension services.

Policy implications: Given small farm prevalence, shared technology access (cooperatively owned equipment, fee-for-service advisory) may work better than individual purchase subsidies. Supporting producer organizations and regional innovation hubs could amplify spillover effects.

Limitations include modest sample size and self-reported competitiveness data. Future research should use objective financial indicators and longitudinal designs.

Despite these limitations, the findings suggest digital technologies can strengthen climate resilience in Southeast Europe, provided policies account for the region's structural constraints and leverage its informal cooperation networks.

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DIGITALIZATION OF ESG MANAGEMENT IN THE CONTEXT OF ENVIRONMENTAL SUSTAINABILITY AND THE TWIN TRANSITION

ЦИФРОВІЗАЦІЯ ESG-МЕНЕДЖМЕНТУ В КОНТЕКСТІ ЕКОЛОГІЧНОЇ СТАЛОСТІ ТА ПОДВІЙНОГО ПЕРЕХОДУ

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Abstract: The paper examines the transformation of ESG management under the influence of digitalization in the context of environmental sustainability. It is argued that digital technologies play a key role in integrating environmental, social, and governance principles into corporate strategies, particularly in achieving climate neutrality and supporting the green transition. Special attention is paid to the concept of the «twin transition», which combines digital transformation and environmental sustainability. The study identifies key technological, economic, and social barriers to the implementation of digital ESG solutions, as well as highlights their potential in improving environmental monitoring, reducing carbon emissions, and increasing resource efficiency. The findings confirm that digitalization significantly enhances the effectiveness of ESG management and contributes to sustainable environmental development.

Key words: ESG management, digitalization, environmental sustainability, climate change, green transition, twin transition, decarbonization, sustainable development

Апстракт: У статті розглядається трансформація управління ESG під впливом цифровізації в контексті екологічної стійкості. Стверджується, що цифрові технології відіграють ключову роль в інтеграції екологічних, соціальних та управлінських принципів у корпоративні стратегії, зокрема у досягненні кліматичної нейтральності та підтримці зеленого переходу. Особлива увага приділяється концепції «подвійного переходу», яка поєднує цифрову трансформацію та екологічну стійкість. У дослідженні визначено ключові технологічні, економічні та соціальні бар'єри для впровадження цифрових ESG-рішень, а також висвітлено їхній потенціал у покращенні екологічного моніторингу, скороченні викидів вуглецю та підвищенні ефективності використання ресурсів. Результати дослідження підтверджують, що цифровізація значно підвищує ефективність управління ESG та сприяє сталому екологічному розвитку.

Ключові слова: ESG-менеджмент, цифровізація, екологічна стійкість, зміна клімату, зелений перехід, подвійний перехід, декарбонізація, сталий розвиток

1. INTRODUCTION

In the context of global environmental challenges, including climate change, resource depletion, and biodiversity loss, the issue of sustainable development has become a key

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priority for both governments and businesses. Modern enterprises are increasingly required to integrate environmental responsibility into their strategic management systems, which has led to the rapid development of ESG management as a comprehensive framework for sustainable governance.

At the same time, digitalization is emerging as a powerful driver of environmental transformation. Advanced technologies such as big data analytics, artificial intelligence, and the Internet of Things enable continuous monitoring of environmental indicators, improve resource efficiency, and ensure transparency in sustainability reporting. This creates the foundation for a new stage of ESG development, where digital tools become an integral part of environmental management.

The relevance of this study is due to the need to study the relationship between digitalization and ESG management in the context of environmental protection. In particular, the concept of the «twin transition» – combining digital and green transformations – requires further theoretical and practical substantiation.

Therefore, the purpose of this study is to analyze the role of digitalization in enhancing ESG management and its contribution to environmental sustainability within the framework of the twin transition.

2. RESEARCH RESULTS

The concept of ESG emerged as an evolution of responsible investing, transforming from the ethical avoidance of "sinful business" into a holistic management paradigm. (Wang, 2024; UNIDO, 2025) The process of forming the concept of environmental, social and corporate governance (ESG) is the result of a long evolution of views on the role of business in the global ecosystem. The origins of this concept date back to the 1950s, when the scientific foundations of corporate social responsibility (CSR) first began to take shape. In 1953, Howard Bowen published a work that laid the foundation for the understanding that corporations have duties to society that go beyond making a profit. (Bowen, 1953) At that time, business responsibility was seen mainly as a voluntary ethical practice of executives, focused on philanthropy and support for local communities. During the 1960s-1990s, the emphasis shifted to the growth of public awareness of social and environmental problems, and large-scale protests against environmental pollution raised the question of responsible resource management (UNIDO, 2025; Passas, 2024)

A qualitative transformation took place in the early 2000s, when the term ESG began to supplant the traditional concept of CSR. The main difference was that ESG integrates sustainability directly into the core of the business strategy, turning it into a tool for generating long-term strategic value for shareholders. The current stage of evolution is characterized by the emergence of the ESG 2.0 concept, which involves the transition from simple reporting to deep strategic integration, where sustainability becomes the basis of strategic management and planning.

Today, ESG management is defined as the systemic basis of three-dimensional, balanced management, covering environmental, social and managerial aspects of the activities of organizations, markets and territories (Patel, Gloor, 2022; Qing, Jin, 2022):

- Environmental (E): covers the management of resources, greenhouse gas emissions, biodiversity and the implementation of «green» technologies.
- Social (S): includes human rights protection, occupational safety, inclusion and community engagement.
- Governance (G): focused on transparency, ethics, independence of supervisory boards and the fight against corruption.

The ESG management paradigm is based on the belief that environmental and social factors have a direct financial impact. Non-compliance with ESG requirements jeopardizes the survival of businesses due to regulatory sanctions, investors' denial of capital, and loss of reputation (Passas, 2024). Thus, ESG becomes not only a form of responsibility, but also a mechanism for risk management and identification of new market opportunities in the context of the global transition to a green economy.

The modern investment world recognizes ESG factors as «key levers» for achieving climate neutrality by 2050 in the context of the formation of a green transformative economy in line with the European Green Deal (Morea et al. 2025), and the implementation of ESG principles directly contributes to the achievement of the UN Sustainable Development Goals, in particular by bridging development gaps with the help of digital technologies (Nikitenko et al. 2022). Currently, green transformation is becoming a conceptual platform for eco-modernization of production aimed at decarbonization and achieving strategic sustainable development goals (Podzizey, Tykhonov, 2025). This process acts as a fundamental context in which digitalization is turning into the main ESG management tool and acts as an impetus for accelerating the transition to a green economy, and modern enterprises are forced to integrate digital solutions into their strategies to ensure transparency in the transition to net zero and meet growing pressure from regulators and stakeholders. In this context, a systemic relationship between digitalization and green transformation of the economy is formed, which is manifested through changes in production models, resource management, and management decision-making. It is this relationship that determines the key directions for the implementation of the «twin transition» concept. The key aspects of such a relationship are (UNIDO, 2025; Podzizey, Tykhonov, 2025; Maksymova, 2024):

1. Circular economy: the transition from a linear take-do-throw model to a closed-loop model requires digital monitoring of the life cycle of products. Digitalization allows you to implement a 9R framework, optimizing the use of resources in real time.
2. Climate neutrality: Achieving net zero by 2050 requires massive emission reductions, which is impossible without big data analytics and automated carbon footprint accounting.
3. Eco-digital transformation: a new era of development, where technology becomes the foundation for sustainability, and ESG data is the most valuable resource for making management decisions. For example, digital ESG tools enable real-time monitoring of carbon emissions and environmental impact, contributing to more effective environmental protection policies.

It is advisable to consider this relationship between digitalization and green transformation of the economy not only in the analytical, but also in the structural and model plane. That is why in order to generalize the key determinants of the «twin transition» and reflect their systemic interaction, it is advisable to use a conceptual model of interpenetration of environmental and digital development factors, where the central element is the synergy between the «green paradigm» (decarbonization, recycling) and «digital transformation»

(intellectualization of management, the formation of information capital), the interaction of which ensures the formation of an innovative and resource-efficient economy.

The integration of digital solutions into decarbonization strategies is a key element of the «twin transition», but this process is accompanied by a number of complex barriers (UNIDO 2025; Maksymova, 2024). These challenges can be classified into technological, economic, social and regulatory.

1. Technology barriers and infrastructure constraints:

- Infrastructure gap: many industries, especially in low-income countries, lack stable internet connectivity and reliable power grids needed to power digital infrastructure.
- Complexity and novelty of technology: the use of tools such as artificial intelligence, blockchain, and IoT is a challenge for businesses that are accustomed to traditional processes.
- Compatibility and standardization issues: the lack of uniform global standards leads to compatibility problems between different digital systems, which hinders the creation of integrated carbon footprint monitoring frameworks.
- Cybersecurity risks: companies are often hesitant to adopt open platforms due to concerns for data privacy and threats of sensitive information leakage.

2. Economic and financial challenges:

- High capital expenditures: implementing advanced digital solutions requires a significant initial investment, which can be prohibitive for small and medium-sized businesses.
- ROI uncertainty: the effect of decarbonization digitalization is often long-term, making it difficult to justify investments when the payback is blurred over time.
- Maintenance costs: constant software updates and keeping sensors operational create an additional financial burden on companies budgets.

3. Human capital and social barriers:

- Digital skills deficit: there is a significant gap in the competencies of personnel who lack knowledge in the areas of big data analytics, operation of IoT systems, and interpretation of ESG metrics.
- Resistance to change: in industries with deep-rooted traditional working methods, there is cultural resistance to innovation, as digitalization is perceived as a threat to jobs.
- Low awareness: many stakeholders still do not fully understand the strategic benefits of combining green and digital technologies.

4. Data quality and regulatory complexity:

- The problem of «garbage at the entrance - garbage at the exit»: the effectiveness of decarbonization depends on the accuracy of the data; the use of unverified or fragmented indicators in digital models leads to erroneous management decisions.
- Scope 3 complexity: the biggest challenge is the collection of data on indirect emissions in supply chains, where partners' digital systems are often not integrated with each other.
- Regulatory turbulence: constantly changing legal requirements (e.g., CSRD in the EU or SEC regulations in the US) creates a state of uncertainty, forcing companies to postpone large-scale digital transformations.

In view of the above, it can be concluded that it is advisable to consider the integration of digital technologies in decarbonization strategies through the prism of the concept of a «twin transition», combining energy transformation and digitalization of the economy. On the one hand, there are infrastructure constraints, as well as energy barriers (the throughput and capacity of the system do not correspond to the loads of new technologies). On the other hand, the implementation of digital solutions is accompanied by economic and social challenges: the cost of maintaining the system may exceed the initial investment, and organizational or cultural factors (distrust of new technologies, staff resistance) slow down adaptation. Only overcoming these obstacles can achieve the key benefits of digital-energy integration, such as operational monitoring of energy consumption, increased resource efficiency and cost optimization.

Thus, the successful implementation of digital solutions in decarbonization strategies involves the comprehensive overcoming of technological, economic and social barriers, which is the essence of the «twin transition».

3. CONCLUSIONS

The conducted study of the digitalization of ESG management gives grounds to assert that modern approaches to enterprise management in the context of the green transformation of the economy are undergoing significant changes. ESG management is gradually moving from the formal and declarative implementation of socio-environmental initiatives to systematic management practices integrated into the overall «green» business development strategy. In this process, digital technologies play a key role, providing an analytical basis for making informed management decisions. They provide the necessary tools for achieving climate neutrality, reducing environmental risks, and increasing transparency in sustainability practices.

The concept of the «twin transition» emphasizes the close connection between digitalization and environmental sustainability. Their combined implementation enables businesses to better address environmental challenges and support long-term sustainable development. Therefore, digital ESG management can be considered an important tool for environmental protection, reducing carbon emissions, and facilitating the transition to a sustainable and climate-resilient economy.

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AGRO-ECOTOURISM DEVELOPMENT POTENTIAL AS A DRIVER OF RURAL ECONOMIC DIVERSIFICATION IN MACEDONIA

ПОТЕНЦИЈАЛ ЗА РАЗВОЈ НА АГРО-ЕКОТУРИЗМОТ КАКО ДВИГАТЕЛ НА РУРАЛНАТА ЕКОНОМСКА ДИВЕРЗИФИКАЦИЈА ВО МАКЕДОНИЈА

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Abstract: Rural areas in Macedonia are undergoing significant economic, social, and demographic transformations, with traditional agriculture increasingly unable to ensure sustainable livelihoods. In this context, rural economic diversification has emerged as a key strategy for improving resilience and promoting balanced regional development. The main objective of this paper is to analyze the potential and role of agro-ecotourism as an instrument for sustainable rural development in Macedonia. The study is based on a qualitative and quantitative research approach using secondary data analysis. Statistical data from the State Statistical Office (MakStat database), as well as relevant scientific literature and policy documents, are used to examine tourism trends, agricultural performance, and socio-economic conditions in rural areas. The results indicate strong tourism growth of approximately 71% over the observed period, primarily driven by a significant increase in foreign visitors of around 92%, alongside a high regional concentration of tourist activity. At the same time, rural areas are characterized by severe depopulation, fragmentation of agricultural holdings, and a decline in agricultural employment by 34.4% during the period 2012–2023, as well as a persistent trade deficit in agri-food products, reaching –€438.5 million in 2025. These trends highlight structural weaknesses and the limited sustainability of traditional agricultural models. The findings suggest that agro-ecotourism represents a significant opportunity for income diversification, strengthening local production, and promoting sustainable rural development. However, its development remains constrained by institutional weaknesses, administrative barriers, and limited support. Overall, agro-ecotourism can play a key role in enhancing rural resilience and supporting long-term economic diversification in Macedonia.

Key words: sustainable development, rural tourism, income diversification, local products, regional development

Анстракт: Руралните подрачја во Македонија се соочуваат со значајни економски, социјални и демографски трансформации, при што традиционалното земјоделство сè повеќе не е во состојба да обезбеди одржливи извори на егзистенција. Во таков контекст, диверзификацијата на руралната економија се наметнува како клучна стратегија за

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зголемување на отпорноста и поттикнување на рамномерен регионален развој. Основната цел на овој труд е да се анализира потенцијалот и улогата на агро-екотуризмот како инструмент за одржлив рурален развој во Македонија. Истражувањето се базира на квалитативен и квантитативен пристап преку анализа на секундарни податоци. За таа цел се користени статистички податоци од Државниот завод за статистика (МАКСтат база), како и релевантна научна литература, извештаи и стратешки документи, со цел да се анализираат трендовите во туризмот, перформансите на земјоделството и социо-економските услови во руралните средини. Резултатите укажуваат на значителен раст на туризмот од приближно 71% во анализираниот период, пред сè поттикнат од порастот на странските туристи од околу 92%, заедно со изразена регионална концентрација на туристичката активност. Истовремено, руралните подрачја се карактеризираат со сериозна депопулација, фрагментација на земјоделските стопанства и намалување на вработеноста во земјоделството за 34,4% во периодот 2012–2023 година, како и со постојан трговски дефицит кај земјоделско-прехранбените производи, кој достигнува –438,5 милиони евра во 2025 година. Овие трендови укажуваат на структурни слабости и ограничена одржливост на традиционалниот земјоделски модел. Наодите покажуваат дека агро-екотуризмот претставува значајна можност за диверзификација на приходите, зајакнување на локалното производство и поттикнување на одржлив рурален развој. Сепак, неговиот развој е сè уште ограничен поради институционални слабости, административни бариери и недоволна поддршка. Во целина, агро-екотуризмот може да одигра клучна улога во зајакнување на отпорноста на руралните средини и поддршка на долгорочната економска диверзификација во Македонија.

Клучни зборови: одржлив развој, земјоделски туризам, диверзификација на приходи, локални производи, регионален развој

1. INTRODUCTION

1.1 Rural economic diversification as a strategy for rural development in the EU and Macedonia

In recent decades, rural communities, both in the European Union and in Macedonia, have undergone profound transformations, primarily driven by the shift of economic activities and population toward urban areas, as well as the declining importance of agriculture as the dominant sector in terms of food production, rural economy, and employment. Traditionally, these areas were highly dependent on agriculture as the main, and often the only, source of income and employment. However, this model has become increasingly unsustainable due to a combination of global and local challenges, including climate change, market volatility, demographic decline, labor shortages, and rapid technological advancement (Ellis, 2000).

These processes have led to a crisis in the traditional structure and organization of rural areas, exposing them to significant economic, social, and environmental risks, affecting not only the agricultural sector but also the broader local economy and rural communities as a whole. Rural populations are increasingly seeking alternative ways to reduce their dependence on agricultural production as the sole source of income (Ellis, 2000), raising not only the issue of income diversification but also the broader multifunctional transformation of rural areas.

In the European Union, rural regions account for approximately 83% of the total territory and are home to around 30% of the population (European Commission, 2021). Despite their geographical significance, these areas contribute disproportionately less to overall economic output, highlighting structural imbalances between urban and rural regions. Similarly, in the

Republic of Macedonia, rural areas represent a substantial share of both the population and economic activity, with agriculture playing a significantly larger role in GDP compared to the EU average (World Bank, 2023). However, these areas face persistent challenges such as depopulation, aging populations, limited infrastructure, and restricted access to markets and financial resources (Gjosheva Kovachevikj et al., 2025a).

In response to these challenges, rural economic diversification has emerged as a key strategic approach in both academic literature and policy frameworks (OECD, 2020). Diversification refers to the expansion of rural economies beyond traditional agricultural activities into sectors such as tourism, services, small-scale production, and renewable energy (European Commission, 2021).

This process is closely linked to the concept of multifunctional agriculture, which recognizes that rural areas provide not only food production but also environmental, cultural, and social services (Lane & Kastenholz, 2015). Within the European Union, diversification is strongly supported through policy instruments such as the Common Agricultural Policy (CAP) and the European Agricultural Fund for Rural Development (EAFRD), which promote innovation, entrepreneurship, and sustainable development in rural areas.

1.2 Agro-ecotourism as a key form of diversification

One of the most promising forms of diversification is agro-ecotourism, which integrates agricultural activities with environmentally sustainable tourism. It represents an important component of sustainable rural development, combining agriculture with tourism services, supporting local communities, and promoting the preservation of natural and cultural heritage (Sima, 2019).

Agro-ecotourism enables farmers to diversify their income and develop multifunctional farm models that combine agriculture, hospitality, education, and recreation. It creates opportunities for value addition through activities such as product tastings, workshops, and participation in agricultural practices (Parasuraman et al., 2025). At the same time, it offers an alternative to mass tourism by providing authentic, sustainable, and experience-based services.

At the global level, agro-ecotourism is experiencing significant growth. According to Straits Research (2021), the global market reached USD 45.4 billion in 2021 and is expected to exceed USD 141 billion by 2030, confirming its increasing importance for rural economies.

1.3 Situation of agro-ecotourism in Macedonia

In contrast to the European Union, Macedonia is still at an early stage of rural economic diversification, particularly in the field of agro-ecotourism. Despite the availability of significant natural and cultural resources, the agro-ecotourism development remains constrained by limited farmer capacity, institutional weaknesses, insufficient investment, and the absence of strategic planning (Gjosheva Kovachevikj et al., 2025b).

Additionally, Macedonia lacks a clear definition of agro-ecotourism and operates within a fragmented regulatory framework. This creates significant administrative barriers for rural entrepreneurs, as reflected in the fact that only 14 households are officially registered as rural

households in accordance with the Law on hospitality activities, highlighting the gap between existing potential and actual development.

With regard to the legal framework, at the national level it consists of primary legislation with a direct regulatory role, such as the Law on Tourism Activities and the Law on Hospitality Activities, as well as complementary legislation that indirectly affects the sector, including laws related to construction, agriculture and rural development, environmental protection, food safety, and regional development (Gjosheva Kovachevikj et al., 2026). In addition, following the amendments to the Law on Tourism Activities in 2025, responsibilities were transferred to the Ministry of Culture and Tourism, while hospitality remains under the Ministry of Economy and Labour. This division has created institutional ambiguity, complicated inter-ministerial coordination, and resulted in more complex administrative procedures and increased legal uncertainty for stakeholders (Gjosheva Kovachevikj et al., 2026).

1.4 Research Objective

The main objective of this paper is to analyze the potential and role of rural economic diversification in enhancing rural economic resilience and sustainability, with a particular focus on agro-ecotourism in the Republic of Macedonia.

2. MATERIALS AND METHODS

This study is based on a qualitative and quantitative research approach using secondary data analysis. The research examines tourism development, as well as socio-economic indicators in rural areas and the agricultural sector, and their role in rural economic diversification in Macedonia. The analysis relies on data from the State Statistical Office (MakStat database), including indicators on tourism trends, regional distribution, GDP, agricultural value added, and employment in agriculture. In addition, relevant scientific literature, reports, and policy documents are used to support the analysis and interpretation of results. The study applies descriptive analysis, comparative analysis, trend analysis and literature-based analysis.

3. RESULTS AND DISCUSSIONS

3.1 General trend of tourism in Macedonia

The data presented in Table 1 on the number of domestic and foreign tourists for the period 2014–2024 indicate a strong and dynamic growth of the tourism sector in Macedonia, despite temporary disruptions caused by external shocks. The total number of tourists increased from 680 thousand in 2014 to 1,170 thousand in 2024, representing a growth of approximately 71%. This indicates a significant expansion of tourism activity over the observed period. A more detailed analysis reveals that domestic tourism experienced steady growth, increasing by 43% over the observed period. Nevertheless, this growth remains relatively modest compared to the significantly more dynamic expansion of international tourism by 92%. This highlights the increasing importance of international tourism as a key driver of overall sector expansion. However, the lack of official statistical data specifically related to agro-ecotourism limits the possibility of conducting a more detailed analysis of its development and contribution within the tourism sector.

However, a sharp decline is observed in 2020, when the total number of tourists dropped significantly due to the COVID-19 pandemic. The decline was particularly pronounced among foreign tourists, whose numbers fell drastically as a result of global travel restrictions. Nevertheless, the period after 2021 shows a strong recovery, with tourism indicators returning to pre-pandemic levels and continuing to grow.

However, attracting domestic tourists to rural areas, especially within agro-ecotourism, is equally important for the local economy. In countries such as Italy and Slovenia, domestic tourists represent a key target group for rural tourism development. In addition, domestic tourism contributes not only to the stability of the tourism sector but also to the promotion of local food production and the overall development of the agricultural sector (OECD, 2020; European Commission, 2021).

This is particularly important in times of external shocks, such as the COVID-19 pandemic or geopolitical crises, when international tourist flows decline significantly. In such situations, domestic tourism can play a stabilizing role, reduce the negative impact on the tourism sector, and support local supply chains (UNWTO, 2021). Recent global events further highlight the importance of strengthening domestic tourism as a more resilient and sustainable component of overall tourism and agricultural development (OECD, 2020).

Table 1: Number of domestic and foreign tourists (in millions), 2014–2024

Category	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	Change 2024 /2014
Total	0.68	0.76	0.79	0.93	1.09	1.13	0.45	0.68	0.93	1.1	1.17	71%
Domestic tourists	0.29	0.31	0.32	0.35	0.4	0.41	0.34	0.4	0.42	0.42	0.41	43%
Foreign tourists	0.39	0.45	0.46	0.58	0.69	0.72	0.11	0.28	0.51	0.68	0.75	92%
Share of foreign tourists	57%	59%	59%	63%	63%	63%	25%	41%	55%	62%	65%	+14%

Source: State Statistical Office (MakStat), tourism data, 2025

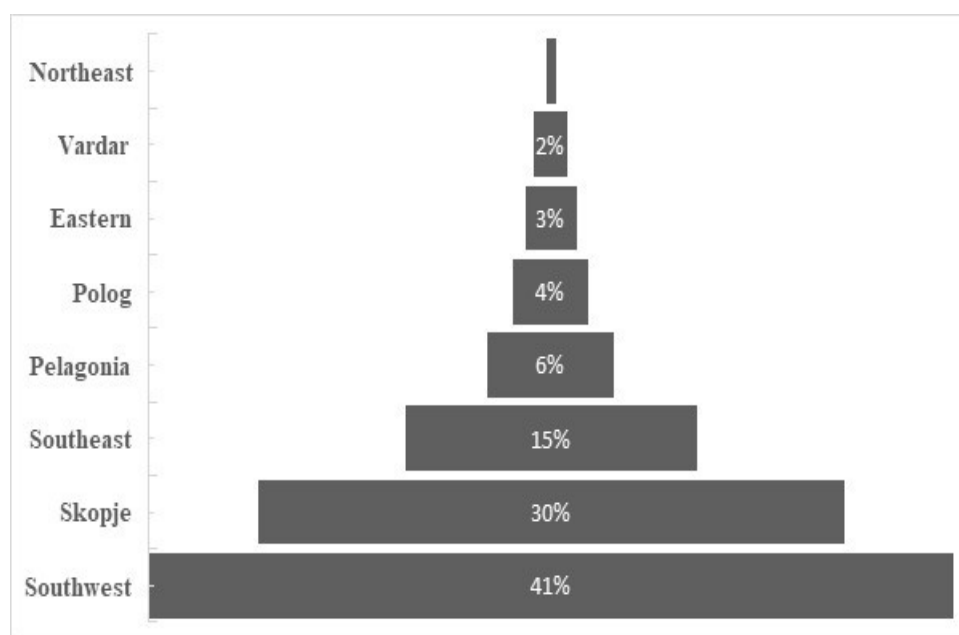
From the perspective of regional distribution presented in Graph 1, the Southwest region clearly dominates, accounting for the largest share of tourist visits (41%). This is primarily due to the presence of Ohrid, which represents the most important and internationally recognized tourist destination in Macedonia. Ohrid's natural, cultural, and historical attractions, including the UNESCO World Heritage status, significantly contribute to the concentration of tourism in this region.

The Skopje region ranks second, with a share of 30%, which can be explained by its role as the capital city. Skopje functions as the main administrative, economic, and transport hub of the country, attracting both business and transit tourism, as well as city tourism.

In contrast, all other regions have significantly lower participation in the overall tourism structure.

The Southeast region accounts for 15%, while the Pelagonia (6%), Polog (4%), Eastern (3%), Vardar (2%), and Northeast (1%) regions show relatively low shares, despite the fact that they include a significant number of rural settlements. This indicates an underutilization of their tourism potential.

This uneven distribution highlights a strong regional concentration of tourism activity, with the majority of tourist flows concentrated in only two regions. Such an imbalance suggests that large parts of the country remain underutilized in terms of tourism potential, while the existing tourism structure is predominantly oriented toward mass tourism rather than rural and sustainable forms such as agro-ecotourism.



Graph 1. Regional distribution of tourists by average share (%) for the period 2014–2024
Source: author's calculations based on State Statistical Office (MakStat).

3.2 Rural and agricultural socio-economic indicators and their role in agro-ecotourism development

According to census data, rural areas in Macedonia are facing severe demographic decline. In 1991, a total of 102 villages were completely depopulated, while recent data indicate a significant worsening of this trend. Out of 1,783 settlements, the latest census (State Statistical Office, 2021) shows that 205 settlements (11.5%) are completely abandoned. Additionally, 218 settlements (12.2%) have up to 10 inhabitants, while 682 settlements (38.3%) have fewer than 100 inhabitants. These figures indicate that over 60% of all settlements are experiencing severe depopulation or are already abandoned. This situation reflects deep structural imbalances in spatial development and increasing rural marginalization, with a high risk of further disappearance of rural settlements.

The data in Table 2 indicate significant structural changes in the agricultural sector of Macedonia over the period 2012–2023. While total GDP increased substantially by 95%, the gross value added (GVA) in agriculture remained almost unchanged (+0.3%), indicating stagnation of the sector in absolute terms. At the same time, the share of agriculture in GDP declined from 10.5% to 7.1%, representing a decrease of 32.1%, which reflects the gradual structural transformation of the economy toward other sectors, particularly services. A similar downward trend is observed in employment. The number of people employed in agriculture decreased by 31.2%, while its share in total employment declined from 24% to 16% (–34.4%). This indicates a significant reduction in the labor force engaged in agriculture, likely driven by migration, aging population, and limited economic opportunities in rural areas.

Table 2. Structural changes in Gross Value Added and employment in agriculture, 2012–2023

Year	GDP (million €)	Agricultural GVA (million €)	Share of Agriculture (%)	Employment in Agriculture	Share in Total Employment (%)
2012	6,564	690.9	10.5%	167,927	24%
2013	7,101	818.3	11.5%	183,031	25%
2014	7,449	873.2	11.7%	183,239	24%
2015	7,942	884.1	11.1%	182,843	24%
2016	8,384	887.1	10.6%	179,135	23%
2017	8,711	791.3	9.1%	178,249	22%
2018	9,332	910.2	9.8%	177,780	22%
2019	9,780	915.9	9.4%	177,607	21%
2020	9,562	932.5	9.8%	165,528	21%
2021	10,247	847.8	8.3%	166,439	21%
2022	11,501	966.0	8.4%	124,559	17%
2023	12,797	914.8	7.1%	115,457	16%
Change 2023/2012 (%)	+95.0%	+0.3%	–32.1%	–31.2%	–34.4%

Source: author’s calculations based on State Statistical Office (MakStat).

These trends clearly demonstrate that agriculture alone is no longer sufficient to sustain rural economies. The stagnation of agricultural output combined with declining employment highlights the need for economic diversification.

The data clearly show a highly fragmented structure of agricultural holdings in Macedonia. The vast majority of farms (99.8%) are individual holdings, while business entities account for only 0.2% of the total number of farms. Despite their dominance in number, individual farms operate on relatively small land areas, with an average size of only 1.5 hectares. In contrast, business entities, although very few in number, manage significantly larger areas, with an average size of 174.1 hectares.

This imbalance is further reflected in land distribution. Individual farms control 84.8% of total agricultural land, while business entities manage 15.2%, indicating a dual structure characterized by a large number of small-scale farms and a very limited number of large-scale operations. Such fragmentation limits productivity, efficiency, and competitiveness in

the agricultural sector. Small farm sizes make it difficult to achieve economies of scale, invest in modern technologies, or access larger markets.

Table 3. Structure of agricultural holdings by land size

Indicator	Total	Individual holdings	Business entities
Number of holdings	178,125	177,845	280
Total utilized agricultural land (ha)	320,738	271,989	48,749
Average size per holding (ha)	1.8	1.5	174.1
Share in total number of holdings (%)	100%	99.8%	0.2%
Share in land (%)	100%	84.8%	15.2%

Source: State Statistical Office, Farm Structure Survey, 2016

The fragmented structure of agricultural holdings, although limiting agricultural efficiency, creates favorable conditions for the development of agro-ecotourism based on small-scale, family-oriented rural experiences.

With regard to the trade in agri-food products, the period 2020–2025 is characterized by a continuous increase in both exports and imports. Exports increased from €590 million in 2020 to €973 million in 2025, with their share in total exports rising from 10% to 12%. At the same time, imports of agri-food products grew from €819 million to €1,412 million, maintaining a share of approximately 11–12% of total imports.

Throughout the analyzed period, a negative trade balance is observed, indicating that imports consistently exceed exports. The trade deficit increased from –€228.7 million in 2020 to –€438.5 million in 2025. The export/import ratio ranges between 63% and 72%, suggesting that exports cover only about two-thirds of the value of agri-food imports.

These trends indicate a structural weakness in the competitiveness of the domestic agri-food sector and highlight the need to strengthen production capacity, improve value addition, and enhance export potential.

Table 4. Trade in agri-food products (2020–2025)

Indicator	Unit	2020	2021	2022	2023	2024	2025
Total exports	million €	5,781	6,970	8,301	8,325	7,781	8,008
Agri-food exports	million €	590	625	711	770	855	973
Share in total exports	%	10%	9%	9%	9%	11%	12%
Total imports	million €	7,599	9,648	12,131	11,157	11,062	11,545
Agri-food imports	million €	819	940	1,136	1,200	1,319	1,412
Share in total imports	%	11%	10%	9%	11%	12%	12%
Trade balance (agri-food)	million €	-228.7	-314.7	-425.1	-430.6	-464.2	-438.5
Export/import ratio	%	72%	67%	63%	64%	65%	69%

Source: author's calculations based on State Statistical Office (MakStat).

In this context, agro-ecotourism can contribute indirectly to improving the agri-food sector by promoting local products and short supply chains, increasing demand for traditional and high-quality food products, supporting value-added production, and strengthening the link between agriculture and tourism. Thus, agro-ecotourism represents not only a diversification

strategy but also a mechanism for enhancing the competitiveness of domestic agri-food production.

4. CONCLUSION

The results of this study clearly indicate that rural areas in Macedonia are facing significant structural, economic, and demographic challenges. The analysis shows a continuous process of depopulation, fragmentation of agricultural holdings, declining employment in agriculture, and a persistent trade deficit in agri-food products. These trends confirm that traditional agriculture alone is no longer sufficient to sustain rural economies.

At the same time, the tourism sector demonstrates strong growth, particularly driven by foreign tourists, indicating increasing international attractiveness. However, tourism development remains highly concentrated in a few regions, primarily the Southwest region and the Skopje region, while large parts of the country remain underutilized. Moreover, the existing tourism model is largely oriented toward mass tourism, with limited development of rural and sustainable tourism forms.

In this context, rural economic diversification emerges as a necessary strategy for addressing structural imbalances and enhancing resilience in rural areas. Agro-ecotourism, in particular, represents a promising development model that integrates agriculture with tourism, promotes local products, and creates additional income opportunities for rural households.

The findings suggest that agro-ecotourism can contribute to reducing rural depopulation, improving farm sustainability, and strengthening the competitiveness of the agri-food sector. However, its development in Macedonia is still at an early stage, constrained by limited capacity of agricultural holdings, institutional weaknesses, administrative barriers and insufficient support mechanisms.

Therefore, future development should focus on increasing awareness among agricultural and rural households, as well as among domestic tourists, regarding agricultural and ecological tourism. It should also prioritize strengthening the legal and institutional framework, simplifying administrative procedures, increasing financial support, and promoting rural destinations and local products. Furthermore, a more balanced regional development approach is necessary to ensure that the benefits of tourism are more evenly distributed across rural areas.

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ORGANIC WASTE MANAGEMENT AS AN OPPORTUNITY FOR SUSTAINABLE RURAL TOURISM DEVELOPMENT

УПРАВЉАЊЕ ОРГАНСКИМ ОТПАДОМ КАО МОГУЋНОСТ ЗА ОДРЖИВИ РАЗВОЈ РУРАЛНОГ ТУРИЗМА

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Abstract: Organic waste in rural areas represents both a challenge and a potential resource for sustainable management. This review analyzes composting and anaerobic digestion, describing their phases, key success factors, and implementation challenges. Emphasis is placed on proper process management and community education to improve agriculture and environmental protection. In the context of rural tourism development, proper bio-waste management can contribute to environmental conservation and the improvement of the local economy by strengthening authentic tourism offerings of the local community. By integrating this practice into the local tourism offering through the concept of a circular economy, waste is transformed into resources, thereby reducing the negative impact on the environment and creating added value for the local community through the production of organic food, energy and educational content for visitors. Rural tourism based on the principles of sustainability is increasingly attracting modern tourist demand, which strives for an environmentally responsible experience.

Key words: organic waste, rural tourism

Анстракт: Органски отпад у руралним подручјима представља и изазов и потенцијални ресурс за одрживо управљање. Овај преглед анализира компостирање и анаеробну дигестију, описујући њихове фазе, кључне факторе успеха и изазове у имплементацији. Нагласак је стављен на правилно управљање процесом и едукацију заједнице ради унапређења пољопривреде и заштите животне средине. У контексту развоја руралног, односно сеоског туризма, правилно управљање биоотпадом може допринети очувању животне средине али и унапређењу локалне економије кроз јачање аутентичне туристичке понуде локалне заједнице. Интеграцијом ове праксе у локалну туристичку понуду кроз концепт циркуларне економије, на овај начин се отпад претвара у ресурс, чиме се смањује негативан утицај на животну средину и ствара додатна вредност за локалне заједнице кроз производњу органске хране, енергије и едукативних садржаја за посетиоце. Рурални туризам заснован на принципима одрживости све више привлачи савремену туристичку тражњу, која тежи еколошки одговорном искуству.

Кључне речи: органски отпад, рурални туризам

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1. INTRODUCTION

Rural tourism has emerged as an important avenue for the development of countryside communities, particularly in regions experiencing population decline and limited employment opportunities (Lane, 2009; UNWTO, 2020). This form of tourism helps preserve local traditions, cultural heritage, and natural landscapes, while also contributing to income diversification and strengthening the resilience of rural communities (Patwa et al., 2020).

As tourism activities increase, so does the generation of waste, with organic waste constituting a significant portion in rural destinations (Hoorweg and Bhada-Tata, 2012). Improper management of this waste can lead to soil and water pollution, methane emissions, and unpleasant odors, reducing both the attractiveness of the destination and the quality of life for local residents (Patwa et al., 2020).

Organic waste, however, can also be viewed as a valuable resource that can be reused through processes such as composting and anaerobic digestion (Font and McCabe, 2017; Sgroi et al., 2020). These practices convert waste into compost, bioenergy, or biofertilizers, supporting the principles of circular economy and sustainable resource use. In rural settings, where agriculture is often closely linked to tourism, such practices enable the creation of closed-loop systems that minimize environmental impact while providing additional economic benefits to local households (Waste Framework Directive, 2008/98/EC).

Because of all this, the management of bio-waste becomes crucial for the preservation of natural resources and the quality of the tourist offer. Namely, in this way a direct link is established between tourism and the concept of circular economy, where tourist activities do not burden the environment, but actively participate in its preservation (Geissdoerfer et al., 2017).

Linking rural tourism and organic waste management enables the creation of unique, authentic and ecologically responsible local tourist products, which can meet modern tourist demand. Tourists are increasingly looking for destinations that implement sustainable practices, which makes the proper management of biowaste not only an environmental obligation, but also an important factor in the competitiveness and long-term development of rural areas (UNEP, 2019).

2. ORGANIC WASTE MANAGEMENT IN RURAL AREAS

In rural areas, municipal solid waste differs significantly from urban waste, as organic waste constitutes more than half of the total waste generated, while the remainder is largely inorganic, and the fraction of hazardous waste is minimal (Patwa et al., 2020). This waste composition sets specific requirements for collection and treatment, as inadequate systems often lead to informal disposal at improvised dumpsites or open burning of waste. Such practices contribute to soil degradation, water pollution, and pose risks to the health of local populations (Novarlić, Stević, 2024).

Due to these challenges, organic waste management in rural areas increasingly relies on local and decentralized approaches, which are more flexible and better suited to village conditions than the centralized systems typical of urban regions (Novarlić, Stević, 2024). These approaches may include local collection initiatives, communal disposal points, and small-

scale treatment systems that divert organic matter from unmanaged dumpsites and prepare it for further processing or valorization (Vinti, Vaccari, 2022; Novarlić, Stević, 2024). The implementation of these local and decentralized models enables communities to reduce the amount of waste ending up in informal dumpsites, organize waste flows at the local level, and establish a framework for sustainable practices in line with circular economy principles. Such approaches support the reuse and valorization of organic waste, thereby reducing environmental impacts while contributing to more efficient resource use in rural areas (Vinti, Vaccari, 2022).

This approach highlights the importance of active community participation in waste management, as decentralized systems provide greater flexibility, easier adaptation to local needs, and the potential for long-term sustainability and ecological resilience in rural areas (Novarlić, Stević, 2024). Considering the high proportion of organic waste in rural areas, techniques such as composting and anaerobic digestion represent essential methods for its valorization and efficient management, thereby supporting sustainable waste treatment.

3. COMPOSTING OF ORGANIC WASTE: PROCESS AND SIGNIFICANCE

Composting is a biological process in which microorganisms decompose organic matter into a humus-like material known as compost (Meena et al., 2021). This process serves a dual purpose: it addresses the problem of organic waste and produces a value-added product-compost, a nutrient-rich fertilizer that improves soil health. In rural areas, composting provides a practical solution to manage locally generated organic waste, contributing to nutrient recycling and sustainable agriculture.

The composting process can be categorized into several microbiologically distinct phases, each characterized by specific temperature ranges and dominant microbial communities. Under optimal aerobic conditions, composting typically progresses through four main stages: mesophilic, thermophilic, cooling, and maturation (curing). During the mesophilic phase, mesophilic microorganisms dominate and initiate the decomposition of readily degradable organic compounds, producing heat that raises the temperature of the composting mass (Azim et al., 2018).

As the temperature increases to the thermophilic range (generally above 45 °C), thermophilic microbes take over, accelerating the breakdown of more complex organic matter and contributing to pathogen reduction (Zhang et al., 2023). When easily degradable substrates are depleted and heat generation decreases, the compost temperature gradually drops, marking the cooling phase, during which mesophilic organisms become active again. The final maturation (curing) phase occurs at lower temperatures, in which the compost stabilizes, humification continues, and the material becomes suitable for soil application (Azim et al., 2018; Zhang et al., 2023).

3.1 Historical overview and application

Since the late 1980s, composting has increasingly been applied in Europe, alongside the development of separate collection systems for bio-waste. Only through such approaches is it possible to obtain compost of satisfactory quality, free from harmful contaminants such as heavy metals, suitable for agriculture and soil quality improvement. The majority of bio-

waste is treated through aerobic conversion, while anaerobic conversion is still applied to a limited extent due to high investment costs and the need to treat waste together with wastewater. Estimates indicate that approximately 40 % of municipal solid waste in Serbia consists of biological (organic) materials, including garden waste and food residues, providing a significant potential for composting (Ministry of Environmental Protection, 2022). This historical perspective highlights how policy, infrastructure, and public awareness have influenced the development and adoption of composting practices in Europe and Serbia.

3.2 Public awareness and global initiatives

Raising public awareness about composting and its environmental benefits is a key component of sustainable organic waste management strategies worldwide. Educational campaigns and initiatives have been shown to increase participation in composting programs, improve environmental literacy, and promote sustainable behaviors among communities (De Boni et al., 2022; Craveiro et al., 2025). One of the most prominent initiatives is International Compost Awareness Week (ICAW), first launched in Canada in 1995 by the Compost Council of Canada, now celebrated annually during the first full week of May. The aim of this week is to educate the public about the benefits of composting, including improving soil structure, enhancing water retention, increasing plant resilience, and reducing the use of synthetic fertilizers and pesticides (Compost Foundation, 2025).

In addition to campaigns like ICAW, scientific studies on community composting and educational programs have shown that active community engagement and educational support significantly increase the success of composting initiatives, thereby contributing to sustainable organic waste management (De Boni et al., 2022). Furthermore, the application of compost to soil has been scientifically proven to improve soil quality, enhance nutrient availability, and support water conservation, confirming multiple environmental benefits of integrating composting into waste management strategies (Craveiro et al., 2025). In rural areas, these initiatives not only support sustainable agriculture but also strengthen community involvement and environmental education, creating long-term benefits for local populations.

3.3 Factors affecting the composting process

Composting is influenced by several external factors that determine the rate and efficiency of organic matter decomposition. Proper management of these factors can significantly accelerate decomposition and improve compost quality. The most important parameters include: oxygen availability (aeration), temperature, pH, moisture content, and the carbon-to-nitrogen (C:N) ratio of the material.

Aeration provides microorganisms with oxygen, preventing anaerobic conditions that can generate unpleasant odors. Temperature affects microbial activity and decomposition rate. Optimal pH and moisture support efficient microbial metabolism, while the C:N ratio ensures a proper balance of nutrients and energy during composting. Monitoring these factors is particularly important in small-scale or rural composting systems to ensure efficiency and quality of the final product (Sharma et al., 2021). Maintaining optimal parameters ensures a faster process, higher nutrient retention, and pathogen reduction, making the compost safe and effective for agricultural use.

3.4 Composting challenges and their connection to rural areas

Despite its benefits, composting faces operational challenges that can affect both the quality of the resulting compost and process efficiency. Common issues include:

Odors-Poor ventilation, excessive moisture, or inadequate aeration can generate unpleasant smells, affecting workers and nearby residents (Ayilara et al., 2020).

Pathogen control- Organic waste may contain harmful microorganisms. If the thermophilic phase is insufficient, pathogens may survive, posing a health risk (Ayilara et al., 2020).

Heavy metal contamination- Certain waste streams may contain metals like lead, cadmium, or arsenic. Accumulation in compost can limit its agricultural use (Awasthi et al., 2019).

Quality standardization- Maintaining the correct balance of nutrients, C:N ratio, moisture, and other parameters is critical for producing stable, safe, and effective compost (Ayilara et al., 2020).

In rural settings, composting allows communities to convert local organic materials, such as agricultural residues and household waste, into nutrient-rich fertilizer. Proper monitoring, process control, and community education are essential to overcome challenges and ensure safe, high-quality compost, supporting sustainable agriculture and soil conservation (Awasthi et al., 2019; Ayilara et al., 2020). Overall, integrating composting with education and community participation ensures both environmental benefits and long-term sustainability in rural areas.

4. ANAEROBIC DIGESTION OF ORGANIC WASTE: PROCESS AND SIGNIFICANCE

Anaerobic digestion of organic waste is a sequential, multi-step biological process in which different microbial communities break down organic matter in the absence of oxygen, producing biogas-mainly methane and carbon dioxide and nutrient-rich digestate (Cao et al., 2025; Song et al., 2026). It is widely applied for the treatment of municipal organic waste, agricultural residues, livestock manure, and industrial food by-products. Unlike aerobic composting, anaerobic digestion provides both renewable energy and stabilized organic material, contributing to resource recovery and climate mitigation.

The anaerobic digestion process can be divided into four main stages, each with distinct microbial activity and biochemical transformations, as widely described in scientific literature (Mata-Alvarez et al., 2014; Chen et al., 2021):

Hydrolysis-Complex polymers such as carbohydrates, proteins, and lipids are broken down into soluble monomers (sugars, amino acids, fatty acids) by hydrolytic bacteria (Chen et al., 2021).

Acidogenesis-Fermentative bacteria convert soluble monomers into volatile fatty acids, alcohols, hydrogen, and carbon dioxide (Mata-Alvarez et al., 2014).

Acetogenesis-Acidogenic products are transformed into acetic acid, hydrogen, and carbon dioxide, which serve as substrates for methanogenic archaea (Chen et al., 2021).

Methanogenesis-Methanogenic microorganisms produce methane and carbon dioxide, completing the energy conversion process and stabilizing the digestate (Mata-Alvarez et al., 2014).

Proper control of temperature, pH, nutrient balance, and retention time is essential to optimize biogas yield, stabilize digestate, and maintain efficient microbial activity. Mesophilic (30-40 °C) and thermophilic (50-60 °C) operating conditions can significantly affect microbial community structure, reaction kinetics, and biogas composition (Chen et al., 2021).

4.1 Benefits and application in rural areas

In rural communities, anaerobic digestion of organic waste offers an effective solution for managing organic residues while producing local renewable energy. Biogas can be used for cooking, heating, or electricity generation, reducing dependence on fossil fuels. Digestate serves as a high-quality biofertilizer, improving soil fertility and supporting sustainable agriculture (Cao et al., 2025).

Small- to medium-scale anaerobic digestion systems are particularly suitable for farms and rural households, where organic residues are abundant and energy needs are localized. Training and education are critical to ensure stable operation, optimize biogas production, and safely apply digestate as fertilizer. Integration of anaerobic digestion into rural waste management allows communities to achieve energy self-sufficiency, reduce environmental pollution, and reinforce circular economy principles (Mata-Alvarez et al., 2014; Song et al., 2026).

5. THE IMPORTANCE OF ORGANIC WASTE MANAGEMENT IN RURAL TOURISM

Rural tourism differs from mass tourism in that it focuses on the quality of experience and sustainability rather than the quantity of visitors. Rural tourism encompasses a wide range of activities, including rural accommodation, agro-tourism, participation in agricultural work and visits to local artisans and cultural events (Jovanović, 2018). The sustainable development of rural tourism has become an important topic in contemporary research in recent years, especially in the context of rational resource management and environmental conservation of local communities. Interest in the development of rural or village tourism has grown in the years following the corona virus pandemic.

A review of the literature on the importance of organic waste management in rural tourism indicates a growing connection between sustainable development, environmental protection and the tourist competitiveness of rural destinations. The concept of sustainable tourism is based on the principle that it "satisfies the needs of current generations without endangering future ones", while including ecological, economic and social dimensions (WCED, 1987). In this framework, rural tourism is seen as an important instrument for revitalizing villages, preserving natural resources and strengthening the local economy, but also as an activity that can cause negative consequences if it is not managed adequately. (Stanić, Jovanović, 2016). It is particularly emphasized that waste management is one of the key factors in the development of tourist destinations, because inadequate disposal of waste leads to environmental degradation and a decrease in the quality of the tourist experience (UNWTO, 2018).

Contemporary research further emphasizes the importance of the circular economy in rural areas, where organic waste can be transformed into a resource through composting and reuse

in agriculture, thus contributing to sustainability and closing production cycles (European Commission, 2020). Also, the development of organic agriculture and agritourism confirms that the preservation of soil, water and biodiversity is the basis of the long-term development of rural tourism, emphasizing the interdependence of ecosystem health and tourist offer (Stanić Jovanović, Ilić, & Miletović, 2025). Overall, the literature indicates that effective management of organic waste is not only an environmental issue, but also a strategic element of sustainable and competitive rural tourism.

6. CONCLUSION

Organic waste management in rural areas represents both a challenge and an opportunity for sustainable development of local communities. Through methods such as composting and anaerobic digestion, organic waste can be transformed into valuable resources – nutrient-rich fertilizer and renewable energy – reducing environmental impact and supporting soil and water conservation. Community education and active involvement are essential for successful implementation, while decentralized approaches enable more flexible and efficient waste management. Integrating these strategies enhances the sustainability of rural tourism and agriculture, providing economic and ecological benefits to local households.

Organic waste management represents a significant development opportunity for improving the sustainable development of rural tourism, as it connects the ecological, economic and social aspects of the development of rural areas. Through the application of practices such as composting, recycling and reuse of organic resources, it is possible to reduce the negative impact on the environment and at the same time improve local agricultural production.

In this way, a synergy is created between tourism and agriculture, which contributes to strengthening the local economy and preserving the authenticity of the local tourist destination. Sustainable waste management also affects the quality of the tourist offer and the satisfaction of visitors, who increasingly recognize and value environmentally responsible destinations. In this context, organic waste should not be seen as a problem, but as a resource and potential for the development of innovative and sustainable solutions in rural tourism. In the long term, the integration of the principles of sustainability and circular economy in waste management represents a key step towards a more competitive, resilient and environmentally friendly rural tourism.

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LOCAL RESOURCES AND GLOBAL CHALLENGES: AN INTEGRATED APPROACH TO SUSTAINABLE RURAL DEVELOPMENT IN THE ERA OF CLIMATE CHANGE

LOKALNI RESURSI I GLOBALNI IZAZOVI: INTEGRIRANI PRISTUP ODRŽIVOM RURALNOM RAZVOJU U ERI KLIMATSKIH PROMJENA

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Abstract: Climate change, global economic processes and demographic transformations increasingly influence the development of rural areas, highlighting the need for new approaches to managing local resources. Sustainable rural development is increasingly viewed through integrated models that connect economic activities, environmental protection and social cohesion within local communities. The aim of this paper is to analyse the role of local resources in shaping sustainable development models for rural areas in the context of climate change and to explore the potential of integrated approaches that connect agriculture, tourism, energy transition and natural resource management. The theoretical part of the paper is based on a review of relevant scientific and professional literature addressing climate change, sustainable development and rural tourism. The analysis includes studies available in international scientific databases as well as strategic documents of European and national institutions related to climate change adaptation, sustainable tourism and energy efficiency. The empirical part of the research is based on a case study analysis of Central Istria, a rural region rich in natural and cultural resources that has recently developed a development model based on the integration of agriculture, cultural heritage and selective forms of tourism. The analysis includes a review of development strategies, tourism trends and local events that contribute to shaping the tourism offer and strengthening local identity.

The results indicate that integrated development approaches that connect local resources with sustainable economic activities can strengthen the resilience of rural areas to climate change. Particular importance is given to the integration of tourism, agriculture and renewable energy sources, as well as to the active involvement of local communities in development processes. Central Istria represents an example of good practice in which the valorisation of natural and cultural resources contributes to sustainable development and the long-term competitiveness of rural destinations.

Key words: sustainable rural development, climate change, local resources, rural tourism, integrated development

Apstrakt: Klimatske promjene, globalni gospodarski procesi i demografske promjene sve snažnije utječu na razvoj ruralnih područja te potiču potrebu za novim pristupima upravljanju lokalnim

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resursima. Održivi ruralni razvoj sve se češće promatra kroz integrirane modele koji povezuju gospodarske aktivnosti, zaštitu okoliša i društvenu koheziju lokalnih zajednica. Cilj rada je analizirati ulogu lokalnih resursa u oblikovanju održivih razvojnih modela ruralnih područja u kontekstu klimatskih promjena te istražiti mogućnosti integriranog pristupa koji povezuje poljoprivredu, turizam, energetska tranziciju i upravljanje prirodnim resursima. Teorijski dio rada temelji se na analizi relevantne znanstvene i stručne literature o klimatskim promjenama, održivom razvoju i ruralnom turizmu. Analizirani su radovi dostupni u međunarodnim znanstvenim bazama podataka te strateški dokumenti europskih i nacionalnih institucija koji se odnose na prilagodbu klimatskim promjenama, održivi turizam i energetska učinkovitost. Empirijski dio istraživanja temelji se na analizi studije slučaja područja Središnje Istre, ruralne regije bogate prirodnim i kulturnim resursima koja posljednjih godina razvija model razvoja temeljen na integraciji poljoprivrede, kulturne baštine i selektivnih oblika turizma. Analiza uključuje pregled razvojnih strategija, turističkih kretanja i lokalnih manifestacija koje doprinose oblikovanju turističke ponude i jačanju lokalnog identiteta. Rezultati istraživanja ukazuju da integrirani pristupi razvoju, koji povezuju lokalne resurse s održivim gospodarskim aktivnostima, mogu doprinijeti jačanju otpornosti ruralnih područja na klimatske promjene. Pritom se posebno ističe važnost povezivanja turizma, poljoprivrede i obnovljivih izvora energije te aktivnog uključivanja lokalnih zajednica u razvojne procese. Središnja Istra predstavlja primjer dobre prakse u kojem valorizacija prirodnih i kulturnih resursa pridonosi održivom razvoju i dugoročnoj konkurentnosti ruralnih destinacija.

Ključne riječi: održivi ruralni razvoj, klimatske promjene, lokalni resursi, ruralni turizam, integrirani razvoj

1. INTRODUCTION

Rural areas today stand at the center of debates on sustainability, climate change, and the future of local communities. Changes in the climate are increasingly shaping economic activities, social relations, and the management of natural resources. Rising temperatures, changes in precipitation patterns, and the increasing frequency of extreme weather events affect agriculture, tourism, and the quality of life in many regions of the world (Jackson, 2021). Scientific and policy debates on climate change emphasize the need for new development models that integrate local resources, social innovation, and sustainable economic activities (Gore, 2007). Rural areas are gaining increasing importance because they possess natural and cultural resources capable of fostering the development of more resilient and environmentally sustainable economic systems.

Climate change represents one of the most complex challenges of contemporary society, and its impacts are felt at the global, national, and local levels. The international framework for addressing these challenges has been established through the United Nations Framework Convention on Climate Change (UNFCCC, 2009), which emphasizes the need to reduce greenhouse gas emissions and to adapt societies to changing climatic conditions. The European Union has developed a range of policies and strategies aimed at building climate-resilient societies and economies, with particular emphasis on the EU Strategy on Adaptation to Climate Change (European Commission, 2021). Through national documents and development plans, Croatia has directed attention toward strengthening the resilience of local communities and promoting the sustainable management of resources (Government of the Republic of Croatia, 2020). In this context, rural areas can play a significant role because they combine agricultural activities (Mihalić, 2016), renewable energy sources (Jelley, 2020), and selective forms of tourism (Geić, 2011), all of which contribute to the sustainable development of space.

The concept of sustainable rural development is based on the integration of economic, social, and environmental dimensions of development (Črnjar, Črnjar, 2009). Such an approach includes the responsible use of natural resources, the development of local entrepreneurship, and the encouragement of innovative forms of tourism and agriculture. Rural tourism, in this context, represents an important instrument for the diversification of local economies, as it enables the valorization of cultural heritage, landscapes, and traditional products. Research (Mihalič, 2016; Aquino et al., 2018; Lenzen et al., 2018) indicates that sustainable tourism models can contribute to the development of local communities and the preservation of the natural environment if they are based on the participation of local residents and responsible destination management. In recent years, particular attention has also been devoted to the role of renewable energy sources in rural areas (Boyle, 2017; Jelley, 2020), which can stimulate economic development while simultaneously reducing negative environmental impacts.

The paper is structured into several interrelated sections that enable an analysis of the relationship between local resources and the global challenges of climate change. Following the introductory section, the materials and methods section presents the methodological framework of the research. This section provides a review of scientific and professional literature addressing issues related to climate change, sustainable development, and rural tourism. The literature analysis was conducted on the basis of works available in relevant scientific databases such as Scopus, Web of Science, ScienceDirect, and Emerald, as well as in the national database Hrčak. In addition to scientific articles, books, professional online sources, and development documents and strategies of national and local institutions related to sustainable development, energy transition, and tourism development were also used (Šimleša & Vuković, 2021; National Plan for the Development of Sustainable Tourism until 2027; Strategy of Sustainable Development of the Republic of Croatia).

The empirical part of the paper is based on the analysis of a case study of the Central Istria area, which represents an example of a rural region rich in natural, cultural, and tourism resources. In recent years, Central Istria has been developing a model of tourism and economic development that seeks to integrate agriculture, cultural heritage, and selective forms of tourism (Ružić, 2011). The analysis includes a review of development strategies and statistical data on tourism trends, as well as the role of local events and cultural content in shaping the tourism offer (Smolčić Jurdana & Soldić Frleta, 2012). Particular attention is devoted to the possibilities of an integrated development approach that connects natural resource management, the development of renewable energy sources, and sustainable tourism, which can contribute to strengthening the resilience of rural areas to climate change and to the long-term development of local communities.

2. MATERIAL AND METHODS

In the preparation of the paper, a qualitative research approach was applied, based on the analysis of secondary data sources and interpretative content analysis, with the aim of understanding the relationship between local resources, climate change, and models of sustainable rural development. The first level refers to the review and analysis of existing scientific and professional literature addressing climate change, sustainable rural development, energy transition, and the development of selective forms of tourism. The second level includes an empirical analysis of a case study of the Central Istria area, as a

representative example of a Croatian rural region in which efforts are being made to link economic development with environmental protection and adaptation to climate change.

In the analytical part of the paper, the method of interpretative content analysis was applied to identify patterns of development and management of rural areas under conditions of climate change. The analysis focuses on the interpretation of concepts such as sustainable rural development, local resources, energy transition, climate resilience, and integrated tourism destination management. This approach enabled the connection of theoretical insights from the literature with the concrete example of the development of Central Istria, while taking into account the economic, social, and environmental dimensions of rural spatial development.

Within the research methodology, the following research questions were formulated:

RQ1. How do climate change processes affect the development of rural areas and the use of local resources?

RQ2. Which development strategies and governance models can contribute to the sustainable development of rural areas under conditions of climate change?

RQ3. In what way can the integration of agriculture, tourism, and local cultural heritage stimulate the sustainable development of rural regions?

RQ4. What role do renewable energy sources and the energy transition play in strengthening the resilience of rural areas to climate change?

RQ5. To what extent does the example of Central Istria demonstrate the possibilities of applying an integrated approach to sustainable rural development?

The objective of the research was to analyze the possibilities of an integrated approach to sustainable rural development under conditions of climate change, with particular emphasis on the role of local resources, selective forms of tourism, and the sustainable management of natural space.

The purpose of the research is to identify development models and practices that can contribute to the long-term sustainable development of rural areas and strengthen their resilience to climate change.

3. RESULTS AND DISCUSSION

3.1 Climate change in global and local context

In recent decades, climate change has become one of the most significant issues facing contemporary society. Its impacts encompass natural systems, economic activities, and social relations on a global scale. Changes in climate patterns are manifested through rising average temperatures, alterations in precipitation regimes, and an increased frequency of extreme weather events such as droughts, floods, and heatwaves (Gore, 2007). Scientific literature (Lenzen et al., 2018; Jackson, 2021) increasingly emphasizes that climate change no longer represents solely an environmental problem, but rather a complex socio-economic challenge.

The debate on climate change intensified at the beginning of the twenty-first century, particularly following the publication of numerous international reports and scientific studies warning of accelerated changes in the global climate system. In his analysis of the climate

crisis, Gore (2007) points to the growing imbalance between economic development based on fossil fuels and the capacity of natural systems to absorb greenhouse gas emissions. Such a development model has led to a significant increase in the concentration of carbon dioxide in the atmosphere, which directly contributes to global warming and changes in climatic patterns.

The international community has recognized the need for coordinated action through a series of international agreements and institutional frameworks. The United Nations Framework Convention on Climate Change established the foundations for global cooperation in reducing greenhouse gas emissions and adapting societies to climate change (UNFCCC, 2009). This document emphasizes the responsibility of states to develop policies and strategies that will enable the long-term reduction of the negative impacts of human activities on the climate system.

In addition to the global dimension, climate change is increasingly examined through the perspective of local and regional processes. Research indicates that the impacts of climate change often manifest differently across regions, depending on their geographical, economic, and social characteristics (Cox, 2022; Ančić et al., 2024). Consequently, there is growing interest in studies that analyze climate change within a local context, as local communities increasingly develop their own adaptation strategies, including spatial planning, water resource management, and the development of green infrastructure.

The process of urbanization further highlights the need to consider climate change within a broader societal context. According to data from the United Nations, the majority of the world's population now lives in urban areas, and this trend is expected to continue in the future (United Nations, 2018). The expansion of urban areas affects natural ecosystems and increases pressure on resources such as water, soil, and energy (Cox, 2022).

Climate change also significantly affects economic sectors that are closely linked to natural resources, with tourism being particularly sensitive to changes in climatic conditions. Climate change may influence the seasonality of tourism demand, the availability of natural resources, and the overall attractiveness of tourist destinations (Perić et al., 2017). Changes in temperature, the reduction of snow cover in mountainous regions, or the increased frequency of heatwaves may alter tourist flows and affect local economies that depend on tourism. Chomsky (2023) warns that the climate crisis requires profound changes in the organization of the global economy, including reducing dependence on fossil fuels and strengthening investments in renewable energy sources.

The European Union has developed a range of policies aimed at building a resilient and climate-neutral economy. The EU Strategy on Adaptation to Climate Change emphasizes the need to integrate climate considerations into all sectoral policies, including energy, transport, agriculture, and regional development (European Commission, 2021). This strategy encourages Member States to develop national and regional adaptation plans that take into account the specific characteristics of individual areas.

In Croatia, climate change has been recognized as an important development challenge in a number of strategic documents. The Strategy on Adaptation to Climate Change of the Republic of Croatia defines measures related to various sectors, including agriculture, tourism, forestry, and water resource management (Government of the Republic of Croatia,

2020). The document emphasizes the need to strengthen institutional capacities and to develop monitoring systems for climate change at both national and local levels.

The National Recovery and Resilience Plan further highlights the importance of the green transition and investments in sustainable development projects. The plan foresees significant investments in energy efficiency, renewable energy sources, and sustainable mobility, with the aim of reducing the negative environmental impact of the economy (Government of the Republic of Croatia, 2021).

Climate change can be viewed not only as a challenge but also as a stimulus for the development of new models of economic and social development. An increasing number of studies indicate that sustainable development, energy transition, and the strengthening of local communities can contribute to the creation of more resilient societies capable of responding to environmental changes. Climate change represents a complex phenomenon that transcends the boundaries of individual sectors and territories. Its impacts are felt across various spheres of social life, ranging from the economy and tourism to spatial planning and the management of natural resources.

3.2 The Importance of Local Resources in the Implementation of Sustainable Rural Development

Rural space is no longer viewed exclusively as an area of agricultural production, but rather as a complex socio-economic system in which natural resources, cultural heritage, traditional activities, and contemporary forms of entrepreneurship intersect. The concept of sustainable development is based on the idea of balance between economic activities, social well-being, and environmental protection, where the natural resources of rural areas acquire particular importance because they constitute the foundation of local development strategies (Črnjar & Črnjar, 2009). Responsible resource management is essential in order to ensure their preservation for future generations, and in rural areas this particularly refers to soil, water, forests, biodiversity, and landscape values that shape the identity of local space.

Local resources may take various forms and perform different functions. In some regions these include agricultural land, traditional products, and local gastronomy, while in others natural landscapes, cultural heritage, or specific forms of local knowledge and skills play a significant role. Selective forms of tourism, such as agritourism, cultural tourism, and gastronomic tourism, enable the valorization of local resources and the creation of additional sources of income for rural communities (Geić, 2011).

The development of rural tourism is closely associated with the growing interest of tourists in authentic experiences and direct contact with local culture. In this context, tourism is increasingly viewed as an instrument of sustainable development, provided that it is based on responsible destination management and the active participation of the local community. The concept of responsible tourism emphasizes the need to reduce the negative environmental and social impacts of tourism while increasing the benefits that local communities derive from tourism activities (Mihalič, 2016).

A significant potential for rural development lies in agriculture and food production. The agricultural sector in rural regions often represents the foundation of the local economy, but

it also faces numerous challenges, including global competition, changing market conditions, and demographic changes. Research indicates that many farmers are seeking to diversify their activities in order to increase competitiveness and ensure greater income stability (Cvrtnjak et al., 2013; Tonković, 2018).

Organic agriculture represents one of the important directions of rural development because it enables food production while preserving natural resources. The development of organic agriculture can contribute to the creation of new business opportunities in rural areas, particularly when it is connected with tourism offerings and local food markets (Deže et al., 2016).

Rural areas also possess significant potential for the development of energy projects based on solar energy, wind power, biomass, or geothermal sources. Renewable energy sources represent one of the most important elements of the energy transition because they enable the reduction of greenhouse gas emissions and the strengthening of energy security (Boyle, 2017). In rural areas, such projects may contribute to the diversification of the local economy and the creation of new employment opportunities. Vaughn (2015) emphasizes that the development of renewable energy projects can generate multiple benefits for local communities, including reduced energy costs, the development of new entrepreneurial initiatives, and increased energy independence. The European Court of Auditors (2018) points out that rural areas possess substantial resources for the development of such projects, although their potential in many countries has not yet been fully utilized.

In the Croatian context, Bratko (2024) notes that rural areas offer numerous opportunities for the installation of solar systems, the use of biomass from agricultural production, and the development of smaller energy facilities that can supply local communities. The role of public policies in promoting sustainable rural development is particularly emphasized in national and European development strategies. The Sustainable Development Strategy of the Republic of Croatia defines a framework for the integration of economic development, environmental protection, and social cohesion (Sustainable Development Strategy of the Republic of Croatia, 2009). This document highlights the importance of preserving natural resources, encouraging innovation, and developing sustainable economic activities in rural areas.

The National Plan for the Development of Sustainable Tourism until 2027 (Government of the Republic of Croatia, 2020) emphasizes the need to develop tourism products based on local resources and the authenticity of destinations.

Aquino et al. (2018) emphasize that social entrepreneurship in tourism can play a significant role in the development of rural communities because it enables the creation of business models that simultaneously achieve economic and social objectives. Vinšalek et al. (2021) highlight that technological change and globalization require the adaptation of business models and the development of new competencies in rural areas. Tonković (2018) draws attention to the problem of depopulation and population aging in many rural regions, which may limit the development capacities of local communities. These processes are often associated with the migration of young people to urban areas and the decline of economic activities in rural environments.

3.3 The Impact of Climate Change on the Sustainability of Rural Development in Local Regions

Changes in air temperature, the distribution of precipitation, and the increasing frequency of extreme weather events are exerting an ever-stronger influence on economic activities traditionally associated with rural areas. Agriculture, forestry, and tourism are among the sectors that are particularly sensitive to changing climatic conditions; therefore, the issue of climate change adaptation is becoming an integral part of discussions on the sustainable development of rural regions. Scientific literature emphasizes that climate change represents not only an environmental challenge but also a socio-economic process that affects the structure of local economies and the everyday life of rural communities (Jackson, 2021).

In many parts of the world, rural areas are already experiencing the consequences of changes in climatic patterns. Rising average temperatures, prolonged periods of drought, and more intense precipitation influence agricultural production, the availability of water resources, and the stability of ecosystems (Gore, 2007). In rural regions, this is particularly relevant to food production and the preservation of natural resources that enable the long-term sustainability of local communities.

Changes in climatic conditions may affect the productivity of agricultural crops, the availability of water for irrigation, and the emergence of new plant diseases and pests. Under such circumstances, sustainable models of agricultural production are gaining increasing importance. Organic agriculture and sustainable land management can contribute to the preservation of natural resources and the reduction of the negative impacts of climate change on food production (Deže et al., 2016).

In addition to agriculture, climate change also significantly affects the development of tourism in rural areas. Tourism activities often depend on the natural and landscape values of a region; therefore, changes in climatic conditions may influence the attractiveness of destinations and tourism flows. Research indicates that changes in temperature and seasonality may alter the structure of tourism demand and influence economic activities in destinations that rely on tourism (Perić & Šverko Grdić, 2017).

The issue of sustainable rural development is increasingly linked with the process of energy transition. Climate change has stimulated global discussions on reducing dependence on fossil fuels and developing energy systems based on renewable energy sources. Rural areas often possess significant potential for the development of such projects because they have access to natural resources such as solar energy, biomass, or wind power.

The development of sustainable economic models in rural areas requires cooperation among various social actors, including local communities, entrepreneurs, and public institutions. Corporate social responsibility is increasingly mentioned as one of the approaches that can contribute to the sustainable development of local economies (Alfirević et al., 2015). Such an approach emphasizes the responsibility of companies toward society and the environment and encourages the development of business models that take into account the long-term interests of local communities.

In this context, the role of social entrepreneurship in tourism and rural development is particularly emphasized. Aquino et al. (2018) highlight that social entrepreneurship can

contribute to the development of innovative projects that connect economic activities with social and environmental objectives. Such projects often involve local communities in decision-making processes and encourage the development of new forms of cooperation between the public and private sectors.

Despite numerous development opportunities, rural areas also face a range of structural challenges that may hinder adaptation to climate change. Depopulation, insufficient infrastructure, and limited access to financial resources often constrain the development capacities of rural communities (Tonković, 2018). Therefore, the sustainable development of rural areas requires well-designed public policies that will stimulate economic development and improve the quality of life of the local population.

3.4 Case Study: Central Istria as an Example of Good Practice in the Implementation of Local Resources for Sustainable Rural Development

Central Istria, a region encompassing the interior of the Istrian peninsula with towns and municipalities such as Pazin, Motovun, Svetvinčenat, Žminj, and the wider hinterland, has increasingly established itself over the past decade as a destination whose rural development is not built around a single “product,” but rather on a carefully structured combination of resources (Ružić, 2011). Within this mosaic, natural landscapes, cultural and historical heritage, agricultural production, local gastronomy, events, and contemporary destination management tools converge.

In their study on tourist satisfaction with Istria as a rural destination, Smolčić Jurdana and Soldić Frleta (2012) point to the importance of experiencing authenticity, the quality of the surrounding environment, and the overall organization of the tourism offer. In this sense, Central Istria can be viewed as an example where the “value of place” is constructed through the interpretation of resources (Istria Tourist Board, 2024): castles, medieval towns, gastronomy (truffles, wine, olive oil), outdoor activities, and local events collectively create a shared narrative of the destination.

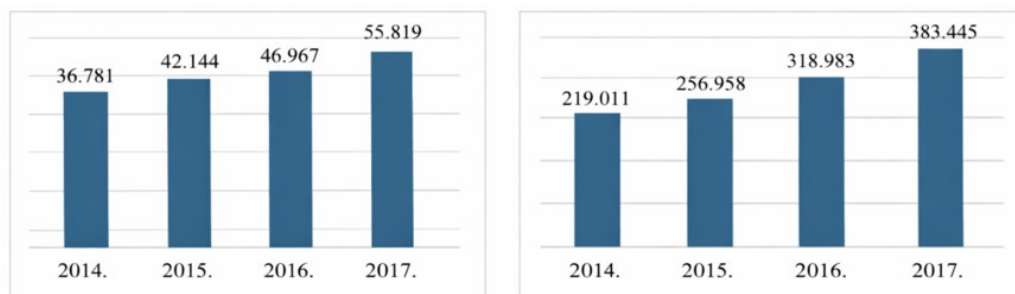
An empirical insight into the development of Central Istria can be supported by statistical indicators of tourist arrivals and overnight stays, as well as by an analysis of the structure of accommodation capacities. Available data on arrivals and overnight stays by destinations provide an overview of growth dynamics and the spatial distribution of tourism flows (Central Istria, 2026). In 2022, Central Istria recorded a total of 5,274 beds, representing an increase of 18.8% compared to the previous year. Private accommodation dominates the structure of accommodation capacities, with as many as 98.1% of the total 4,441 registered beds in 2023 located in private facilities (Central Istria Tourist Board, 2026).

In 2017, the Central Istria area recorded a total of 383,445 overnight stays, representing an impressive increase of more than 20% compared to the previous year. A similar growth trend was also observed in the number of tourist arrivals, which in the same year reached 55,819, marking an increase of 18.8% compared to 2016 (Central Istria, 2018). Nevertheless, despite these positive results, the area accounts for only 1.5% of the total number of overnight stays and 1.4% of tourist arrivals in the Istria County.

Over the past ten years, the number of tourist arrivals and overnight stays in this area has increased significantly. The average annual growth rate of tourist arrivals during this period

amounted to a high 16.2%, while at the level of the entire county it was 4.1%. At the same time, the average annual growth rate of overnight stays reached 24.6%, compared to 3.4% at the county level (Central Istria, 2018).

Table 1. Arrivals and overnight stays in destinations in Central Istria 2014 – 2017.



Source: Central Istria, 2018.

This significant growth in tourist traffic over the past decade can partly be attributed to the strengthening of the capacities of local tourist boards and the recognition of the potential for cooperation among municipalities within the area and the City of Pazin. This cooperation has been focused on improving the tourism offer, promoting and marketing local tourism products, which is consistent with the objectives of effective tourism governance at the local level.

Table 2. Accommodation Capacities of Central Istria

No.	Type of Accommodation	No. of Facilities 2016	No. of Facilities 2017	No. of Beds 2016	No. of Beds 2017
1	Hotels	2	2	105	105
2	Hostels	0	0	0	0
3	Campsites and Camping Areas	4	5	89	101
4	Rooms in Private Households	89	112	205	260
5	Apartments / Studio Apartments	359	381	1,087	1,158
6	Holiday Homes	521	619	3,230	3,864
7	Other	1	1	10	10
TOTAL		976	1,120	4,726	5,498

Source: Central Istria, 2018.

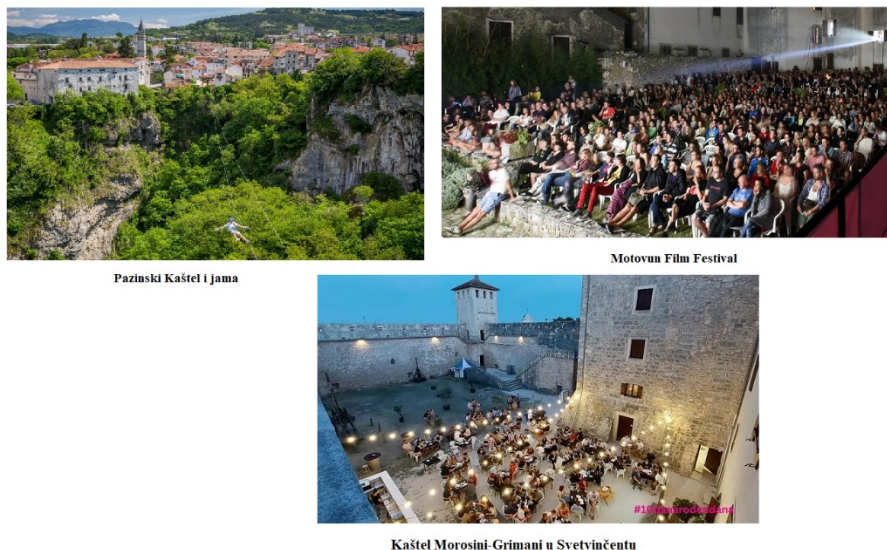
When observing the average annual growth rate of accommodation capacities over the past three years, it amounted to 26.9%. However, the entire increase refers exclusively to private accommodation, where capacities in this segment expanded by an impressive 62.9% during the same period. On the other hand, the share of overnight stays in hotels has shown stagnation at a level of 2.4% over the past two years (Central Istria, 2018).

A detailed analysis indicates that the largest share of accommodation capacities is within the category of holiday homes, which accounts for 70.3% of the total number of beds. This is followed by apartments with 21.1% and rooms in private households with 4.7%, while hotels and campsites have the smallest shares, accounting for 1.9% and 1.8% of beds respectively. Compared with 2022, the most significant increase in the number of beds in 2023 was recorded in rooms in private households, which grew by 26.8%, and in holiday homes, which recorded an increase of 19.6%.

One of the distinctive characteristics of Central Istria is the effort to ensure that the development of tourism and rural entrepreneurship does not occur in a spontaneous or uncoordinated manner, but rather through strategic documents. The *Tourism Development Strategy for the Areas of the Tourist Boards of Central Istria, Motovun and Žminj 2018–2025* represents an important framework, as it recognizes the growing demand for the inland areas of Istria while also emphasizing the need to manage this growth, particularly through product development, branding, and infrastructure improvement (Central Istria, 2018).

Documents developed in cooperation with consulting and professional stakeholders further elaborate the operational dimensions of this approach. The *Strategy for the Development and Management of Visitor Centers in the Area of the Central Istria Tourist Board*, as well as the marketing strategy and communication plan, provide a model for transforming individual attractions into a coherent tourism offer, for interpreting heritage, and for communicating the values of the destination to the market (HDC, 2022; HDC, 2023).

Figure 1. Historical and cultural heritage of Central Istria



Source: author's work based on the Istrian Tourist Board, 2026.

Central Istria is characterized by a dense layer of cultural and historical heritage (Istria Tourist Board, 2024): medieval town centers, fortifications, castles, sacred heritage sites, urban micro-centers, and narratives that can be transformed into experiential tourism products.

Svetvinčenat represents a good example of how a single strong cultural site can become a platform for broader local development. The Morosini–Grimani Castle, through its restoration and interpretation, functions as a venue for events and cultural programs, thereby increasing the attractiveness of the locality beyond the peak summer months. Informational materials about the castle emphasize both its historical value and its contemporary role in the cultural life of the destination (Grimani Castle, 2026).

Motovun, on the other hand, illustrates how cultural tourism can be connected with an international audience through festival-based programming, while simultaneously remaining linked to local resources through gastronomy and landscape. Information regarding cultural landmarks and events highlights the continuity and diversity of the program offer, which is particularly important for a destination aiming to maintain relevance beyond the strictly seasonal tourism framework (Motovun Tourist Board, 2024).

In Central Istria, gastronomy is not merely an addition to the tourism offer but rather one of the key mechanisms through which local agriculture is transformed into a driver of development. Ružić (2011) analyzes rural tourism in Istria from the perspective of development factors embodied in products such as wine, olive oil, cheese, prosciutto, and honey, as well as truffles, which represent a powerful symbol of Istrian gastronomy.

Figure 2. Gastronomic events of Central Istria



Source: author's work based on Buzet Tourist Board, 2026.

Gastronomy-focused events create a “rhythm” for the destination while simultaneously increasing the visibility of local producers. The Truffle Days in Buzet are recognized as an event that integrates a local resource (the truffle), the hospitality offer, and the tourist motivation for visiting, while also strengthening the region’s overall recognition (Buzet Tourist Board, 2026). Wines from Central Istria, including Malvazija and Teran, represent the pinnacle of the region’s wine offerings. Malvazija is a white wine distinguished by its refreshing taste and fruity notes, whereas Teran, a red wine, offers a richness of flavor characterized by pronounced tannins and intense aromas (Ružić, 2011). Wineries in the region frequently provide wine tours and tastings, enabling visitors to explore diverse grape varieties and experience traditional viticultural methods. Truffles constitute another key element of Central Istria’s gastronomy.

Central Istria encompasses several protected areas that offer opportunities to explore natural beauty. One such area is the Učka Nature Park, which, although largely located outside Central Istria, is easily accessible to visitors staying in the region. Učka Nature Park offers numerous hiking and cycling trails that traverse preserved forested areas and provide stunning panoramic views (Ružić, 2011). Additionally, biodynamic vineyards and farms in Central Istria practice ecological cultivation that respects natural cycles and biodiversity. These sites offer visitors the opportunity to participate in guided tours showcasing ecological farming methods and provide insights into sustainable agricultural practices. Ecotourism in Central Istria emphasizes the importance of conserving natural resources and educating visitors about sustainable practices. Numerous local organizations and ecotourism guides offer educational tours and workshops focusing on environmental conservation, biodiversity, and sustainable tourism (Geić, 2011). Such activities enable visitors to gain a deeper understanding of local ecosystems and contribute to the preservation of the region's natural heritage.

Agrotourism in Central Istria allows visitors to engage in authentic experiences connected to traditional agricultural practices and the rural way of life (Bošković & Saftić, 2010). This form of tourism emphasizes the importance of connecting with local communities and participating in everyday farm activities. Central Istria is renowned for its long-standing agricultural tradition, which includes the production of olive oil, wine, truffles, and other local products. Agrotourism farms and vineyards in the region provide visitors with opportunities to participate in grape, olive, and truffle harvesting, while learning about traditional production techniques. For instance, family-run farms (OPGs) offer guided tours that include visits to olive groves, wine cellars, and farms, where visitors can participate in production processes and taste local products (Smolčić Jurdana & Soldić Frleta, 2012). Furthermore, many agrotourism locations offer cultural workshops in which visitors can learn to prepare traditional dishes and enjoy authentic gastronomic experiences.

Agrotourism in Central Istria also promotes local gastronomic specialties. Restaurants and taverns in the region frequently use products sourced from their own farms, creating menus that reflect the local cuisine and seasonal ingredients (Ružić, 2011). Participation in the preparation and tasting of these dishes allows visitors to connect with local customs and traditions. Agrotourism contributes to the sustainable development of Central Istria by strengthening local communities and preserving the rural landscape.

3.5 Discussion

Central Istria can be described as an example of an integrated approach to rural development, in which local resources are not treated in isolation but are interconnected through a destination narrative and a management system. Ružić (2011) emphasizes the perspectives and development factors of rural tourism in Istria, highlighting that the synergy between agriculture, heritage, and tourism constitutes a fundamental prerequisite for sustainability. Smolčić Jurdana and Soldić Frleta (2012) complement this framework by considering tourists' perspectives and destination satisfaction, indicating that quality and authenticity are not merely abstract values but also market-driven factors. Bošković and Saftić (2010) provide an organizational framework through the concept of clustering and destination planning, which is evident in Central Istria's strategic documents that aim to standardize interpretation, branding, and product management (Central Istria, 2018; HDC, 2022; HDC, 2023). A particular value of Central Istria as a case study lies in demonstrating the potential for tourism

development that is not necessarily coastal but builds the identity of the interior on the foundations of cultural heritage and gastronomy. Cultural tourism, events, and interpretative content enhance the spatial experience (Istria Tourist Board, 2024), while gastronomy and agrotourism link tourism with local production (Ružić, 2011; Buzet Tourist Board, 2026). Events and digital destination platforms facilitate communication of the offer and create year-round dynamics, which is essential for resilience under variable climatic and market conditions (Central Istria, 2026).

If “good practice” is defined as the combination of development outcomes, preservation of identity, and risk management, Central Istria offers several elements that are relevant for other rural regions:

- Development relies on local resources that are difficult to replicate: landscapes, heritage, gastronomy, and local narratives.
- There is a visible effort at strategic guidance through documents linking interpretation, marketing, and visitor management (HDC, 2022; HDC, 2023; Central Istria, 2018).
- Events and cultural programs function as mechanisms for demand dispersion and community engagement, thereby giving tourism a social function in addition to an economic one (Central Istria, 2026; Svetvinčenat Tourist Board, 2026; Motovun Tourist Board, 2024).

In the context of climate change, the resilience of rural development stems not only from “green” projects but also from the destination’s ability to diversify its offer, extend the season, build a higher-value economy, and reduce dependence on a single market pattern. Central Istria, through a combination of cultural, gastronomic, and outdoor tourism, demonstrates a development trajectory capable of buffering seasonal fluctuations and enhancing the stability of the local economy. At the same time, issues of managing the growth of private accommodation and infrastructure pressures remain, requiring continuous monitoring and adaptation of development policies (Central Istria, 2018; Central Istria, 2026).

The tourism development of Central Istria during the 21st century can be seen as an example of the gradual transformation of rural space into a recognizable tourist destination that successfully integrates tradition, natural resources, and contemporary development approaches. This part of Istria has leveraged its natural landscapes, rich cultural heritage, and authentic gastronomic offerings to position itself as an attractive space for diverse forms of tourism. The development process has occurred within the context of a changing tourism market, as well as in response to evolving visitor demands for authentic experiences, high-quality local offerings, and sustainable engagement with the environment.

A key foundation for the tourism affirmation of Central Istria lies in the preservation and valorization of cultural and natural heritage. The region is rich in historical sites, old urban cores, medieval fortifications, and traditional settlements that retain the distinctive identity of Istria. Such heritage has become an integral part of the tourism offer, allowing visitors to experience an authentic historical and cultural atmosphere. Of particular importance in this context are numerous events that nurture local customs, traditional gastronomy, and historical heritage. Events dedicated to medieval history, local products, wine, or truffles not only contribute to the tourist recognition of the area but also actively engage the local population.

This strengthens the sense of community belonging while linking the preservation of cultural identity with economic development.

4. CONCLUSION

Sustainable rural development under the influence of climate change can no longer be viewed solely as a “sectoral” issue, but increasingly as the management of interdependencies: between natural resources and economic activities, between local communities and tourist demand, and between energy needs and ecosystem limitations. Climate change accelerates the need for adaptation while simultaneously revealing the vulnerabilities of rural areas that depend on weather stability, water availability, and landscape preservation. Within this framework, integrated approaches gain importance, as they enable the linking of agriculture, tourism, environmental protection, and energy into development models that reduce risks and strengthen local resilience. The literature particularly emphasizes that successful approaches are those that do not rely on one-off projects but on long-term planning, stakeholder coordination, and gradual community capacity building, with a clear awareness that development must adapt to changing climatic conditions (UNFCCC, 2009; European Commission, 2021; Government of the Republic of Croatia, 2020).

Local resources are not merely the “starting point” of development but its most crucial criterion for sustainability: when authentically incorporated into tourism products, local value chains, and the energy transition, they become a source of differentiation, more stable income, and a stronger territorial identity. Sustainable rural tourism, short supply chains, social entrepreneurship, and renewable energy are highlighted in theoretical analyses as complementary levers which, when combined, can mitigate demographic and economic pressures and promote more balanced development beyond urban centers.

In planning tourism development, the concept of sustainability is increasingly central. Tourism development in Central Istria is oriented toward models that seek to preserve the natural environment and use available resources rationally. The application of environmentally friendly solutions, including the use of renewable energy sources, responsible waste management, and landscape protection, has become an integral part of development strategies. This approach contributes to the preservation of natural assets, which form the foundation of the region’s tourism attractiveness. At the same time, it creates added value for visitors, who increasingly seek destinations where sustainability and responsible land management are evident in everyday practice.

A critical prerequisite for further tourism development is the continuous improvement of infrastructure. In recent decades, significant efforts have been made to enhance the transport connectivity and accessibility of this part of Istria. The development of the road network, improvement of local roads, and construction and marking of cycling and hiking trails have enabled better visitor mobility and connectivity with the coastal parts of Istria, as well as with the rest of Croatia and Europe. Alongside transport infrastructure, accommodation capacities across various categories—from small family-run agrotourism establishments to luxury villas and boutique hotels—have been expanded. The development of digital infrastructure, including internet availability and online booking systems, further facilitates access to information and trip planning within the destination.

The success of tourism development is also closely linked to how the destination is presented on the market. The systematic shaping of Central Istria's identity and brand has enabled clearer highlighting of its distinctive features, such as authentic gastronomy, unspoiled nature, wine routes, and cultural offerings. Digital communication channels, social media, and specialized tourism platforms play an increasingly important role in promotion, allowing direct engagement with potential visitors. Through such promotional channels, the destination reaches a diverse audience—from cultural tourists and nature enthusiasts to gastronomic aficionados and active travelers seeking experiences such as cycling, hiking, or exploring rural landscapes.

The diversity of the tourism offer further contributes to the region's attractiveness. Numerous thematic routes have been developed, linking cultural sites, wineries, agrotourism farms, and natural attractions. The organization of gastronomic festivals, cultural events, and sports activities extends the visitor experience and encourages arrivals throughout different periods of the year. A particularly notable aspect is the integration of tourism with local agriculture, through the provision of local products, wine, olive oil, and traditional dishes, thereby making tourism a driver of rural economic development.

Considering all these processes, tourism development in Central Istria can be described as a dynamic and multilayered process, intertwining heritage preservation, sustainable resource management, infrastructure investments, and modern forms of promotion. Although the destination faces challenges arising from global competition and changing tourist behaviors, its development thus far demonstrates an ability to adapt and adopt innovative approaches to tourism planning. The authenticity of preserved cultural heritage, genuine local offerings, sustainable land management, and high-quality promotion create a solid foundation for further strengthening the tourism identity of Central Istria and for developing tourism models that contribute to the long-term prosperity of the local community.

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CLIMATE CHANGE ADAPTATION IN CANADA: TRENDS, CHALLENGES, AND SECTORAL RESPONSES

АДАПТАЦИЈА НА КЛИМАТСКИТЕ ПРОМЕНИ ВО КАНАДА: ТРЕНДОВИ, ПРЕДИЗВИЦИ И СЕКТОРСКИ ОДГОВОРИ

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Abstract: Climate is changing globally, and Canada is particularly affected by extreme weather events, shifts in precipitation patterns, rising temperatures, and reductions in snow cover and ice masses. Climate models predict that these trends will intensify in the coming decades (IPCC, 2013). While reducing greenhouse gas emissions is a key step in mitigating climate change, some impacts are inevitable due to the inertia of the climate system. Therefore, adaptation, i.e., adjusting human activities and policies, becomes a necessary and complementary approach to reducing climate risks. Canada conducted its first national assessment of climate change impacts in 1998 (The Canada Country Study), and in 2007 published *From Impacts to Adaptation: Canada in a Changing Climate*, providing a detailed regional analysis of vulnerability and adaptation options. Updated reports, including *Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation* (2014) and *Advancing Our Knowledge for Action* (2023), indicate a growing number of adaptation measures across sectors, while highlighting an existing adaptation gap that still needs to be addressed. Indigenous communities and sensitive ecosystems are particularly vulnerable, while infrastructure, agriculture, and health sectors remain central to adaptation efforts. This paper synthesizes the latest data on climate change in Canada, sectoral impact assessments, and the development of adaptation policies, emphasizing the need for coordinated national and local approaches to reduce risks and enhance societal resilience to climate change.

Keywords: climate change, Canada, adaptation, mitigation, extreme weather events, national strategy

Анстракт: Климата се менува на глобално ниво, а Канада е особено погодена од екстремни временски настани, промени во моделите на врнежи, зголемување на температурите и намалување на снежната покривка и ледените маси. Климатските модели предвидуваат дека овие трендови ќе се интензивираат во наредните децении (IPCC, 2013). Иако намалувањето на емисиите на стакленички гасови е клучен чекор во ублажувањето на климатските промени, некои влијанија се неизбежни поради инерцијата на климатскиот систем. Затоа, адаптацијата, т.е. прилагодувањето на човековите активности и политики, станува неопходен и комплементарен пристап за намалување на климатските ризици.

Канада ја спроведе својата прва национална проценка на влијанијата од климатските промени во 1998 година (Студијата за земјата во Канада), а во 2007 година ја објави „Од влијанија до адаптација: Канада во клима што се менува“, обезбедувајќи детална регионална анализа на ранливоста и опциите за адаптација. Ажурираните извештаи, вклучувајќи ги „Канада во клима што се менува: Секторски перспективи за влијанијата и адаптацијата“ (2014) и „Унапредување на нашето знаење за акција“ (2023), укажуваат на растечки број мерки за

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адаптација низ секторите, истовремено истакнувајќи го постоечкиот јаз во адаптацијата што сè уште треба да се реши. Домородните заедници и чувствителните екосистеми се особено ранливи, додека инфраструктурата, земјоделството и здравствениот сектор остануваат централни за напорите за адаптација.

Овој труд ги синтетизира најновите податоци за климатските промени во Канада, проценките на влијанието по сектори и развојот на политики за адаптација, нагласувајќи ја потребата од координирани национални и локални пристапи за намалување на ризиците и подобрување на општествената отпорност на климатските промени.

Клучни зборови: климатски промени, Канада, адаптација, ублажување, екстремни временски настани, национална стратегија

1. INTRODUCTION

The climate is changing – both in Canada and worldwide. At the global level, international assessments increasingly indicate rising air and ocean temperatures, shifts in precipitation patterns, glacier retreat, decreases in snow cover and sea ice, sea-level rise, as well as changes in the frequency and intensity of extreme weather events (IPCC, 2013; Casati, Yagouti, 2010).

Although the rate of change varies depending on the indicator, overall trends clearly indicate climate warming, and climate models predict that many of the already observed trends will continue in the coming decades (IPCC, 2013).

In Canada, these global trends are further manifested through more intense and frequent extreme events, including wildfires, floods, heatwaves, and prolonged droughts. For instance, the extreme wildfire season of 2025 reached the second-worst levels in history, with a large number of active fires and mass evacuations, attributed to increasingly hot and dry conditions associated with climate change. (The Guardian)

Additionally, 2024 recorded a historic level of insured losses from weather-related disasters — approximately CAD 8.5 billion — further illustrating the growing economic burden of climate impacts. (Reuters)

Reducing greenhouse gas (GHG) emissions, i.e., mitigating climate change, represents a key step in limiting its intensity and speed. However, even with strong global emission reduction measures, certain climate impacts will be unavoidable due to the inertia of the climate system. Therefore, in addition to mitigation, adaptation — the adjustment of human activities and decisions to reduce risks, mitigate negative consequences, and seize new opportunities arising from changes — is necessary. Today, governments at all levels, the scientific community, the private sector, and non-governmental organizations view adaptation as an essential and complementary approach to reducing climate-related risks.

The Government of Canada published a national scientific assessment of climate change impacts and adaptation opportunities in 2007, titled *From Impacts to Adaptation: Canada in a Changing Climate* (Publications du gouvernement du Canada). This analysis applied a regional approach to examine existing and future climate impacts in Canada, identify vulnerabilities, and propose adaptation options. The study relied on the results of the first national assessment (The Canada Country Study, 1998) and incorporated all relevant available scientific sources.

The subsequent report, *Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation*, represents an updated version of the 2008 assessment. It emphasizes new knowledge and information, as well as progress in understanding climate impacts and adaptation opportunities from a sectoral perspective. The analysis is primarily based on scientific literature published up to the end of 2012. This synthesis consolidates the findings of individual report chapters, including an overview of climate changes in Canada (Chapter 2), thematic chapters dedicated to various sectors (Chapters 3–8), and a concluding chapter reviewing adaptation research and practice (Chapter 9). Key findings from Chapters 3–9 are presented in Box 1. The remainder of the synthesis is organized around high-level key conclusions, supported by examples and insights obtained from an integrative analysis of the topics addressed in the report.

Since these earlier assessments, Canada has continued with national assessments and adaptation activities through the new phase *Canada in a Changing Climate: Advancing Our Knowledge for Action*, culminating in the 2023 Synthesis Report. This document confirms that climate impacts are present and significant across many sectors and ecosystems, and that a growing number of adaptation measures are being implemented nationwide, although an “adaptation gap” remains. (Government of Canada Report)

Moreover, in June 2023, Canada adopted its first National Adaptation Strategy, providing a framework for coordinated action against climate risks and establishing long-term goals and guidelines for adaptation across all regions and sectors of society. (Canada’s National Adaptation Strategy)

2. KEY FINDINGS BY SECTOR IN THE CONTEXT OF CLIMATE CHANGE

2.1 Natural Resources (Forestry, Energy, and Mining)

Climate change poses a significant challenge to sectors managing natural resources. Changes in temperature, precipitation patterns, and the frequency of extreme weather events increase existing risks in the planning and exploitation of natural resources. Notable impacts include permafrost degradation, sea-level rise, and shifts in vegetation zones, which can alter resource availability and productivity.

At the same time, climate change can create development opportunities, particularly in northern regions, where longer growing seasons and changes in resource availability may stimulate new economic activities. However, these opportunities require careful management to minimize negative ecological and socio-economic effects.

Adaptation in the natural resource sector is often viewed through the lens of multiple concurrent factors. Climate change is sometimes not recognized as a priority compared to market or regulatory challenges. Nevertheless, integrating climate risks into existing planning processes—such as environmental impact assessments, sustainable forest management reporting, and investment risk assessments—can significantly contribute to the development of adaptation strategies.

The highest level of adaptive management has been observed in sectors where there is a direct link between climatic conditions and resource availability, such as forestry and hydropower. However, an increasing number of industries are beginning to implement flexible management models to reduce climate risks. (Intergovernmental Panel on Climate Change, 2023. Climate Change 2023: Synthesis Report. Geneva: IPCC)

2.2 Food Production

The impacts of climate change on food production differ between agriculture, fisheries, and traditional food sources in remote communities. Nevertheless, several common challenges are becoming increasingly evident, including the spread of invasive species, emergence of new diseases, and heightened vulnerability of transportation systems that enable food distribution.

In the medium term, longer growing seasons and rising temperatures are expected to allow for increased agricultural production in certain regions. These changes may enable the cultivation of new crops at higher latitudes and extend grazing periods for livestock. However, positive effects may be limited by increased pest pressure, more intense weather extremes, and greater year-to-year climate variability.

Northern and isolated communities are particularly vulnerable to climate change. Changes in the availability of natural resources and transportation logistics can simultaneously ease or further complicate access to food.

Regarding fisheries, climate change affects fish migration and the distribution of marine ecosystems. Consequently, regional changes in the availability of fish resources are expected, while invasive species and habitat degradation will further influence sector dynamics. Aquaculture shows a higher potential for adaptation compared to traditional fisheries, as production conditions can be technologically controlled and adjusted to changing climatic conditions. (IPCC)

2.3 Industry

The industrial sector is significantly exposed to changing weather conditions and extreme climate events. Impacts may include disruptions to production, logistics, supply chains, and financial performance.

So far, adaptive measures in industry have mostly been reactive, addressing specific extreme events such as floods or storms. Proactive planning based on long-term climate projections has not yet been fully integrated into the business strategies of most companies.

However, certain sectors, particularly tourism and insurance, are beginning to develop more advanced climate risk management strategies. These industries increasingly use climate projections to identify new business opportunities and reduce financial exposure to climate-related risks. Major barriers to adaptation include the lack of precise local climate data relevant to business, uncertainty regarding the costs and benefits of adaptation measures, and insufficient market incentives to invest in climate resilience. (IPCC)

2.4 Biodiversity and Protected Areas

Changes in the distribution of plant and animal species are already evident in many regions of the world. Different rates of species migration are leading to the creation of new ecosystems with altered compositions and functions.

For certain species, the pace of environmental change exceeds their capacity to adapt, increasing the risk of biodiversity loss. Therefore, climate change further emphasizes the importance of ecosystem management that enhances resilience and preserves biological diversity.

Protected areas, such as national parks and nature reserves, play a key role in conserving biodiversity. They can serve as refuges and migration corridors for species shifting their habitats in response to climate change.

Many countries today are expanding networks of protected areas and developing programs for research, monitoring, and public engagement to improve the management of natural resources under changing climate conditions. (IPCC)

2.5 Human Health

A growing body of scientific research confirms that climate change significantly affects human health. One example is the spread of vector-borne diseases, such as Lyme disease, whose vectors are expanding into more northern regions due to rising temperatures.

Furthermore, climate change can contribute to the deterioration of air quality in some regions, increasing concentrations of ground-level ozone and particulate matter.

Extreme events such as floods, heatwaves, and wildfires have both direct and indirect effects on human health, including injuries, psychological stress, displacement, and damage to health infrastructure.

Consequently, an increasing number of countries are developing adaptation strategies in public health, which include early-warning systems for heatwaves, monitoring programs for vector-borne diseases, and enhancement of urban green spaces to reduce the urban heat island effect. (IPCC)

2.6 Water and Transportation Infrastructure

Infrastructure resilience largely depends on its design, maintenance, and capacity to adapt to changing climatic conditions. Gradual changes in temperature and precipitation can be relatively easily incorporated into planning, but extreme weather events often exceed the design capacity of infrastructure.

Vulnerability assessments enable the identification of critical points in systems and the planning of appropriate adaptation measures. Standards and technical regulations play an important role in defining design and maintenance criteria for infrastructure systems.

Integrating climate projections into infrastructure asset management processes allows for more effective decision-making and reduces long-term costs associated with climate risks. (IPCC)

2.7 Adaptation – Linking Research and Practice

Climate change adaptation encompasses a wide range of activities aimed at increasing societal resilience. The most active sectors in this process are typically those directly exposed to climatic conditions, such as agriculture, forestry, and water management.

Although adaptation is often considered a local process, successful strategies require coordination among local, regional, and national institutions, as well as collaboration between the public sector, scientific institutions, and private sector.

Despite progress in understanding climate risks, the implementation of concrete adaptation measures is still at a relatively early stage in many countries. Most activities focus on planning, capacity building, and raising awareness, while concrete infrastructural and institutional changes remain limited.

Experience shows that the transition from awareness to concrete action can be accelerated through political leadership, clear public policy strategies, availability of scientific data, and experience with extreme weather events that highlight the reality of climate risks. (IPCC)

3. CLIMATE CHANGE IN CANADA

Canada's climate system is undergoing significant changes, reflected in variations in air temperature, precipitation amounts and distribution, snow and ice dynamics, and other physical climate indicators. Long-term measurements indicate that Canada's climate is gradually warming, and multiple indicators confirm that these changes are expected to continue in the coming decades.

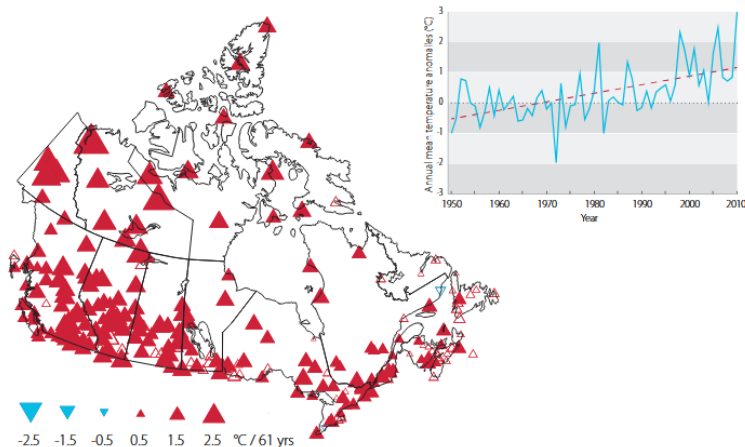


Figure 1: Patterns of change in mean annual temperature across Canada for the period 1950–2010. Upward-pointing (red) and downward-pointing (blue) triangles indicate positive and negative trends, respectively. Filled triangles represent trends significant at the 5% level (Source: Vincent et al., 2012). Inset: Average annual temperature change for Canada (°C), 1950–2010, relative to the 1961–1990 mean (represented as zero on the Y-axis).

Between 1950 and 2010, the average air temperature over Canadian land increased by approximately 1.5°C (Figure 1). This rise is roughly twice the global average warming over

the same period. The most pronounced warming has been recorded in northern regions of Canada, particularly during the winter and spring seasons. In addition to the increase in average temperatures, changes in extreme temperature values have also been observed – the number of very hot days has increased, while the frequency of extremely cold nights has decreased.

Changes in various elements of Canada’s climate system are summarized in Table 1, which provides an overview of the most important observed trends in temperature, precipitation, ice, snow cover, and sea level.

Table 1. Updated Climate System Trends in Canada (to 2025), (Canada.ca)

Climate System Component	Observed Trends (up to 2025)
Air Temperature	Canada’s national average temperature has risen significantly; in 2024 it was about 3.1°C above the 1961–1990 baseline, matching the warmest year on record, and seven of the ten warmest years have occurred in the last 20 years. Northern regions have warmed faster than southern regions. https://www.canada.ca/en/environment-climate-change
Extreme High Temperatures	Heat extremes continue to increase, contributing to more frequent and intense heatwaves across various regions of Canada overall. https://www.canada.ca/en/environment-climate-change
Extreme Low Temperatures	Extremely cold nights and winter lows have become less frequent in recent decades, reflecting warming at all seasons across the country. https://www.canada.ca/en/environment-climate-change
Precipitation	Observational data show changes in precipitation regimes and increasing variability, though long-term historical trend reporting is in transition due to updates in measurement technology; extreme and heavy rainfall events occur more often. https://www.canada.ca/en/environment-climate-change
Snow and Rain	Snow cover duration continues to decrease due to earlier snowmelt and later onset of winter snowpack, while rainfall is increasing in many regions, especially during transition seasons. https://arctic.noaa.gov/
River Flow	Patterns are shifting regionally: some southern systems show declines in minimum and maximum flows, while northern regions and Arctic river systems have altered flow regimes associated with earlier melt and precipitation changes. https://arctic.noaa.gov/
Snowfall	Snowfall is decreasing overall in many southern Canadian regions, whereas some northern areas see variations tied to seasonal precipitation shifts. https://arctic.noaa.gov/
Snow Cover Extent	Snow cover during June and late spring has dropped significantly, with summer snow extent in much of the Arctic being about 50% of what it was in the 1960s. https://arctic.noaa.gov/
Permafrost	Ongoing warming in northern Canada continues to raise permafrost temperatures, contributing to active layer increase and widespread

	thaw in many Arctic and sub-Arctic regions (reinforced by recent warming trends). https://www.oecd.org/en/publications/2025/05/oecd-economic-surveys-canada-2025
Sea Level	Sea levels continue to rise globally due to thermal expansion and ice melt; Canadian coastal areas are experiencing increased sea-level threats as part of these global trends. https://www.oecd.org/en/publications
Sea Ice	Arctic sea ice continues long-term decline. The winter maximum sea ice extent in 2025 was the lowest on record, and multi-year thicker ice has dramatically reduced, with most remaining multi-year ice near Greenland and the Canadian Arctic. https://arctic.noaa.gov/report-card/report-card-2025/
Glaciers	Glaciers in Canada and North America are experiencing unprecedented ice loss in recent years, with annual mass losses from 2021–2024 far exceeding previous decades. https://www.livescience.com/planet-earth/climate-change/glaciers-across-north-america
Ice on Lakes and Rivers	The period of ice cover on lakes and rivers continues to shorten, with earlier breakups and later freeze-ups documented in ongoing observational records. https://arctic.noaa.gov/report-card/report-card-2025/executive-summary-2025/
Oceans	Ocean temperatures, especially in Arctic adjacent waters, are among the warmest on record, contributing to changes in salinity, ecosystem structures, and increasing acidification concerns. https://www.rcinet.ca/eye-on-the-arctic/2025/12/16/arctic-report-card-2025

Source: Author

Notes on Recent Observations (2024–2025)

- Temperature anomalies for spring and summer 2025 show above-average departures relative to the long-term baseline (1961–1990), with spring 2025 about 1.3°C above average, and summer 2025 among the warmest on record in many regions.
- Winter 2024/2025 was also unusually warm, ranked among the top five warmest winters on record, with much of Canada recording winter temperatures 3.7°C above baseline.
- Arctic changes—sea ice, snowpack, tundra vegetation, and freshwater systems—continue rapid transformation, with implications for ecosystems and Indigenous communities.

3.1 Precipitation Changes

Between 1950 and 2010, Canada has generally become wetter. Average annual precipitation has increased in many regions, although the spatial patterns of change are not as uniform as those observed for temperature. In some areas, the increase in precipitation has been accompanied by more intense extreme rainfall events; however, at the national level, there is no fully consistent trend.

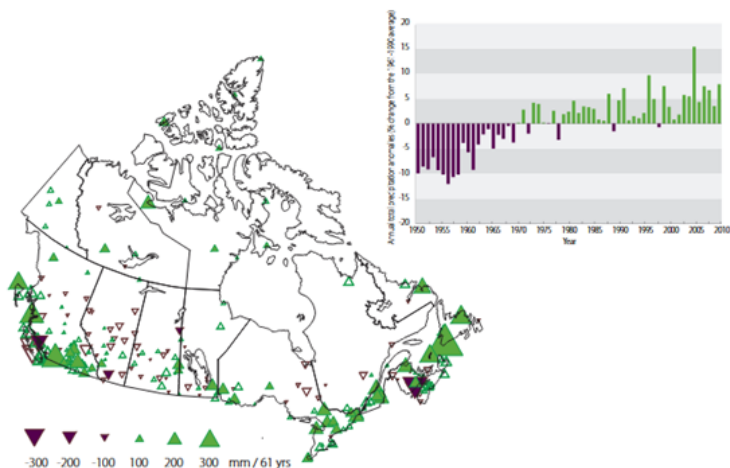


Figure 2. Patterns of change in total annual precipitation for the period 1950–2010. Upward-pointing (green) and downward-pointing (purple) triangles indicate positive and negative trends, respectively. Filled triangles represent trends significant at the 5% level (Source: Mekis, Vincent, 2011b).

Inset: Anomalies in total annual precipitation (expressed as percentage change from the 1961–1990 mean) for Canada, 1950–2010 (Source: Mekis, Vincent, 2011a).²⁷

3.2 Changes in the Cryosphere (Updated to 2025)

Climate change continues to have profound impacts on Canada’s cryosphere, with significant effects observed across multiple components of the frozen environment — including sea ice, glaciers, snow cover, lake and river ice, and permafrost.

Sea Ice: Arctic sea ice extent in Canada has declined rapidly over recent decades due to rising temperatures and associated climate feedbacks. Summer sea ice area in Northern Canadian waters reached particularly low values in 2024, with records showing the lowest levels of multi-year ice and substantial reductions in seasonal ice cover. Long-term observations indicate statistically significant decreasing trends in both total and multi-year sea ice areas across key navigational routes, such as the Northwest Passage, with declines of several percent per decade. Projections suggest that Arctic waters could become nearly ice-free in summer by the 2050s if current trends continue. The accelerating loss of sea ice is a hallmark of Arctic warming and has broad ecological, cultural, and socioeconomic implications for northern communities and ecosystems.

²⁷ In the past decade, average precipitation rates in Canada generally show a tendency toward higher values in many regions, though the spatial patterns of change remain heterogeneous, similar to historical trends; extreme precipitation events (heavy rainfall) have increased in frequency and likelihood due to human-induced climate change, with many individual extreme events since mid-2025 being attributed to warming conditions. Precipitation monitoring is being refined as measurement technology and data integration evolve, but regions such as southern Quebec and parts of the Pacific Coast experienced episodes of heavy rainfall and flooding in 2025, while other areas continued to show variability in precipitation totals.

(<https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/sea-ice>)

Glaciers: Glaciers and ice caps in Canada — particularly in western mountain ranges and the Arctic — are experiencing persistent mass loss and thinning driven by rising surface temperatures. Recent multi-decadal records show that Canadian Arctic glaciers have lost ice mass at a significant rate, contributing to global sea-level rise. Observations indicate that this trend is part of a larger Arctic-wide pattern of glacier shrinkage, with notable mass losses recorded between 2021 and 2024 that exceed previous decades' averages. Continued warming is expected to further reduce glacier volume, with substantial losses predicted by mid-century under medium emission scenarios. (<https://natural-resources.canada.ca/sites/www.nrcan.gc.ca/files/energy/Climate-chang>)

Snow Cover and Ice on Lakes and Rivers: Snow cover extent has declined across much of Canada, particularly where later onset of winter snow and earlier spring melt reduce the duration of snow-covered periods. Seasonal snow accumulation and snow water equivalent have decreased in many regions, altering hydrological regimes and reducing reflective albedo. Similarly, ice cover on lakes and rivers is shortening, with later freeze-ups and earlier breakup dates becoming more common, impacting freshwater ecosystems and ice-based transportation in northern areas. (https://changingclimate.ca/CCCR2019/chapter/5-0/?utm_source)

Permafrost: Permafrost temperatures have risen in many parts of Canada, especially in Arctic and sub-Arctic zones. Thawing permafrost threatens infrastructure stability, alters surface hydrology, and can release stored greenhouse gases, creating additional climate feedbacks. Long-term monitoring shows consistent warming trends in permafrost, which are expected to continue with ongoing atmospheric warming. (<https://changingclimate.ca/CCCR2019/chapter/5-0>)

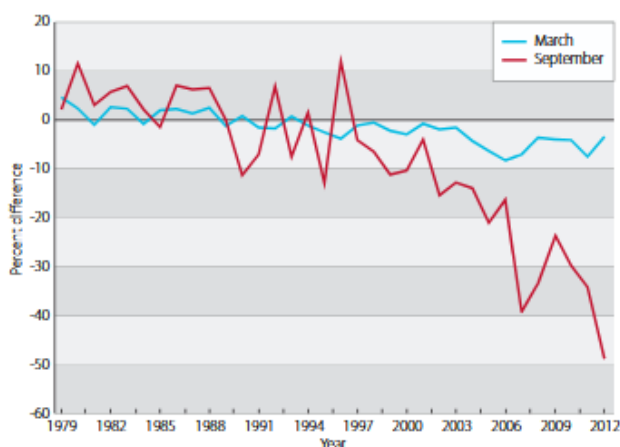


Figure 3. Trends in Arctic sea ice extent over the period 1979–2012 shown as time series of the percentage difference in ice extent in March and September relative to the mean values for the period 1979–2000. Both trends are statistically significant (Source: Perovich, et. al., 2012)

Taken together, these changes illustrate the rapid transformation of Canada's cryosphere in response to climate change. The observed decreases in sea ice, glaciers, and snow cover, together with permafrost warming, represent some of the clearest indicators of climate warming and have significant implications for ecosystems, water resources, northern communities, and climate feedback processes.

3.3 Projected Climate Changes in Canada

Climate models indicate that the warming trend will continue throughout the 21st century. On average, higher temperatures and increased precipitation are expected across much of the country, along with more frequent and intense extreme weather events.

The largest temperature increases are projected for winter and in northern regions of Canada. At the same time, the frequency of heat waves and extreme high temperatures is expected to rise, while extreme cold events will become increasingly rare.

Table 2. Projected Climate Changes in Canada

Climate Indicator	Projected Changes
Temperature	The largest temperature increases are expected in winter, particularly in northern Canada.
Extreme Temperatures	The frequency of hot days and nights will rise, while extreme cold events will become increasingly rare.
Heat Waves	The duration and intensity of heat waves are expected to increase.
Extremely Hot Days	A day that currently occurs once every 20 years could become a once-every-5-year event by mid-century.
Precipitation	Precipitation is projected to increase across most regions and seasons, except for potential decreases in parts of southern Canada during summer.
Heavy Precipitation	The frequency of intense rainfall events and the risk of flooding are expected to rise.
Snow Cover	The duration of snow cover is expected to decrease across much of the northern hemisphere.
Permafrost	Permafrost temperatures will continue to rise, leading to gradual thawing.
Sea Level	Global sea level could rise by several tens of centimeters to over one meter by 2100.
Arctic Sea Ice	By mid-century, the Arctic is likely to experience nearly ice-free summers.
Ice on Lakes	The duration of ice cover on lakes and rivers could shorten by about one month by mid-century.

Source: Author

Source: Examples of projected changes in the climate system for Canada, derived from ensembles of global climate models driven by the SRES scenarios (cccsn.ec.gc.ca). In general, the magnitude of the stated changes will increase under higher emission scenarios.

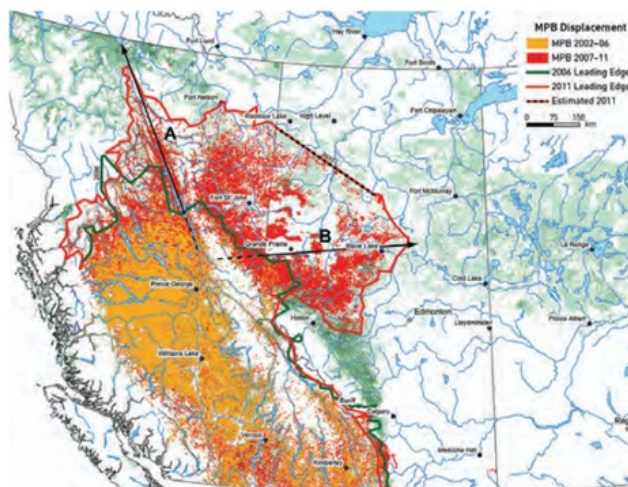
4. IMPACTS OF CLIMATE CHANGE ON THE NATURAL ENVIRONMENT, ECONOMY, AND HUMAN HEALTH IN CANADA

Climate change is increasingly affecting Canada's natural ecosystems, economic activities, and human health. Scientific research over the past decades indicates that many natural systems in the country are highly sensitive to changes in temperature, precipitation, and other climatic parameters. According to recent assessments by the Intergovernmental Panel on Climate Change (IPCC), northern latitudes, including Canada, are warming faster than the global average, leading to widespread environmental changes.

Significant shifts have been observed in the range and behavior of many species. Studies show that numerous birds, butterflies, and tree species have shifted their ranges northward in response to rising temperatures. In addition to spatial shifts, changes in the timing of biological processes have been recorded — for example, earlier bird migrations, earlier plant flowering, and alterations in reproductive cycles. A frequently cited example is the gradual northward expansion of maple forests, observed since the 1970s. Similar processes have been observed in marine ecosystems of the Bering Sea, where warmer waters facilitate the northward intrusion of species from southern regions.

At the same time, some wildlife populations have experienced significant declines. Research indicates that several common North American bird species have lost substantial portions of their populations in recent decades. Alongside climate factors, habitat loss and other anthropogenic pressures contribute to this trend. In western Canadian forests, increased frequency of droughts, wildfires, and insect outbreaks has led to higher tree mortality, particularly in British Columbia and the Canadian prairies.

Figure 4. Spatial Distribution of the Mountain Pine Beetle in Western Canada



Source: Natural Resources Canada 2012c

Climate change also affects aquatic ecosystems. Rising water temperatures in certain rivers, such as the Fraser River, have been linked to higher mortality rates among salmon populations, with consequences for both ecosystems and local economies.

Beyond environmental impacts, climate change has significant economic consequences. The most vulnerable sectors are those directly dependent on climatic conditions, including forestry, agriculture, fisheries, hydroelectricity, transportation, and tourism. A notable example is the mountain pine beetle outbreak in western Canada. Milder winters have allowed this insect to survive in larger numbers, leading to widespread forest damage. By the early 2010s, the pest had affected over 18 million hectares of forest, representing one of the largest recorded forest disturbances in North America.

Climate change is also affecting public health. The extension of the pollen season, particularly for ragweed (*Ambrosia*), has led to an increased incidence of allergic reactions and respiratory problems. In some Canadian cities, the ragweed season has lengthened by several weeks compared to the 1990s. Additionally, warmer climates have facilitated the expansion of ticks that transmit Lyme disease, resulting in a rise in reported cases in recent years.

Northern regions of Canada are particularly exposed to accelerated warming. In these areas, climate change affects the traditional lifestyles of local communities, including hunting, fishing, and travel across ice. Reductions in sea ice extent and decreased predictability of ice conditions increase risks for outdoor activities and threaten traditional food sources.

Permafrost thaw represents another serious challenge, as it can damage roads, buildings, and other infrastructure. The network of so-called winter roads in northern Canada, which relies on sufficiently thick ice cover, is particularly vulnerable. Shortened seasons for these roads reduce reliability and increase transportation costs. For example, the shortened season in 2006 forced the Diavik Diamond Mine to organize part of its supply by air, significantly raising operational costs.

Overall, these examples demonstrate that the impacts of climate change are already being felt across Canada. While climate is not the only factor shaping these processes, numerous cases indicate that such impacts are likely to intensify in the future as climatic conditions continue to change.

5. EXTREME WEATHER EVENTS AS A GROWING RISK IN CANADA

Extreme weather events represent one of the most significant challenges Canada faces under changing climate conditions. Contemporary scientific research increasingly confirms that certain types of extreme climate phenomena—such as heatwaves, heavy precipitation, floods, and severe storms—are expected to become more frequent and intense as the global climate continues to warm (Intergovernmental Panel on Climate Change, 2023; Environment and Climate Change Canada, 2023).

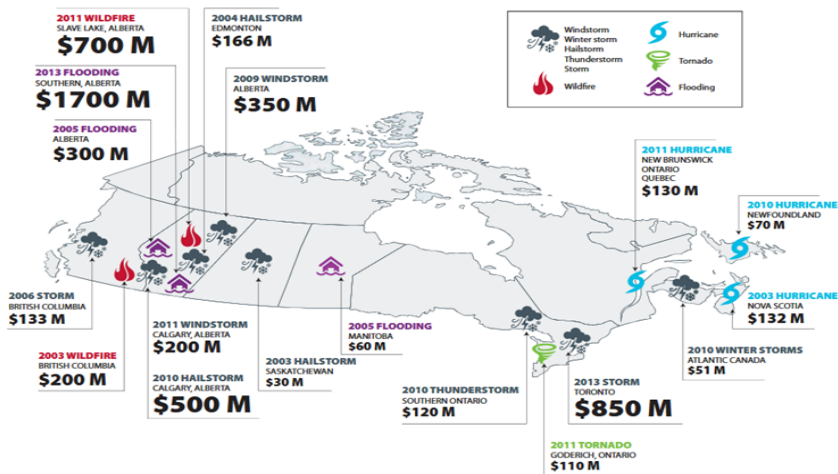
In recent decades, Canada has experienced a substantial increase in economic losses associated with extreme weather. Events such as severe storms (including wind, ice, and snow), floods, wildfires, and heatwaves have significant economic impacts, as well as serious consequences for public health and safety.

In the early 2010s, the Canadian insurance industry paid record amounts in claims for weather-related property damages. For instance, in 2011 alone, approximately CAD 1.7 billion was paid out for flood, wind, and wildfire damage. Just a few years later, this figure

was surpassed due to major floods in southern Alberta and extreme rainfall in Toronto. More recently, economic losses have continued to rise, with data from the Insurance Bureau of Canada indicating that damages from climate-related disasters in certain years have exceeded several billion dollars.

Although the increase in insured losses is also influenced by factors such as urbanization, rising property values, and aging infrastructure, climate change has significantly elevated the risk of extreme weather events. These trends highlight the growing vulnerability of Canadian society and the economy to climate hazards.

Figure 5. Examples of insured economic losses caused by extreme weather events in Canada



Sources: Examples of insured losses from extreme weather events in Canada (IBC, 2008, 2011b, 2013a, b; McBean, 2012).

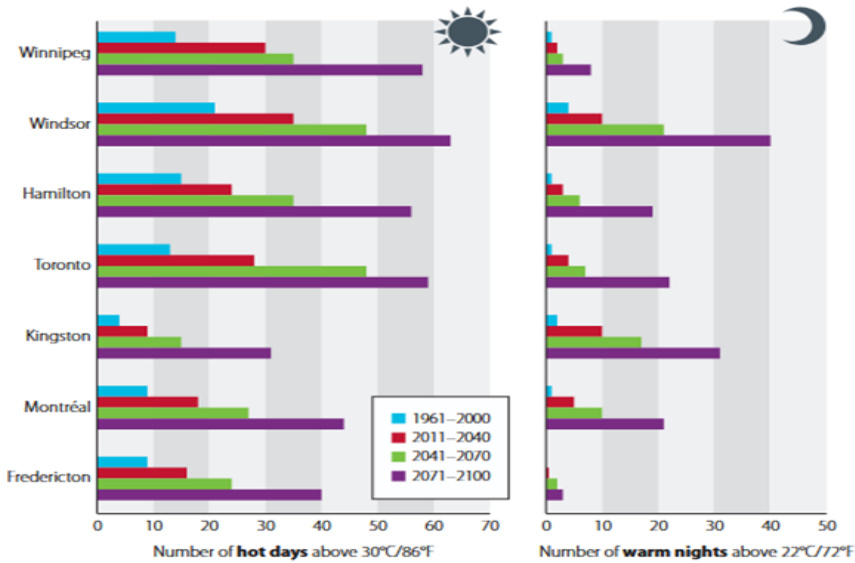
The scientific consensus is increasingly strong that certain types of extreme events will become more frequent and intense under global warming. Globally, it is virtually certain that the frequency and intensity of hot days and nights will increase, and it is very likely that heatwaves will occur more often, last longer, and be more intense (Intergovernmental Panel on Climate Change, 2023). In addition, an increase in the frequency of extreme precipitation and the risk of coastal flooding is expected.

Research conducted in Canada indicates that future conditions may lead to more frequent droughts, particularly in the southern parts of the Prairie provinces. At the same time, the number of intense precipitation events is expected to increase, raising the risk of flooding. Climate projections also point to a possible rise in the frequency of wildfires, severe storms, and periods of extremely high temperatures (Natural Resources Canada, 2022). Extreme weather events have consequences for a wide range of economic sectors. Systems that depend on water availability are particularly vulnerable. Both excess and shortage of water can cause serious challenges for infrastructure, agriculture, natural ecosystems, and human health. Floods, for example, can overwhelm sewage and drainage systems, damage transportation infrastructure, and disrupt supply chains.

Conversely, droughts can have significant economic and social impacts, particularly in agricultural regions. Agricultural production relies heavily on the relative predictability of seasonal weather conditions, which enables planning of planting schedules, crop selection, and infrastructure investments.

When weather conditions become unpredictable, the risk of economic losses increases significantly. An illustrative example is the unusually warm March 2012 in Ontario, when high temperatures led to early flowering of fruit trees. Subsequent April frosts, however, destroyed a large portion of the blossoms, with approximately 80% of apple blossoms damaged. Estimated total losses in sensitive fruit production that year amounted to roughly CAD 100 million (Environment Canada).

Figure 6. Historical and projected number of hot days and warm nights in selected Canadian cities



Sources: Historical and projected number of hot days and warm nights for selected cities in Canada (Casati and Yagouti, 2010)

All of the above examples indicate that extreme weather events pose an increasing risk to Canadian society, the economy, and natural systems. As climate change continues, the challenges associated with extreme weather conditions are expected to intensify, highlighting the importance of developing adaptation strategies and strengthening the resilience of infrastructure, economic sectors, and local communities.

6. ADAPTATION TO CLIMATE CHANGE IN CANADA

Adaptation is now widely recognized as an essential response to climate change, as it strengthens the social and economic resilience of society to its impacts. In Canada, the importance of adaptation measures that can reduce risks associated with extreme weather events, ecosystem changes, and economic losses is increasingly acknowledged (Intergovernmental Panel on Climate Change, 2023; Natural Resources Canada, 2022).

Over the past decade, awareness of the need for climate adaptation has grown across various sectors of Canadian society. Adaptation processes increasingly involve multiple levels of government, industrial sectors, scientific institutions, and local communities. This growing interest is reflected in the rising number of scientific publications, public policies, and media reports addressing climate adaptation.

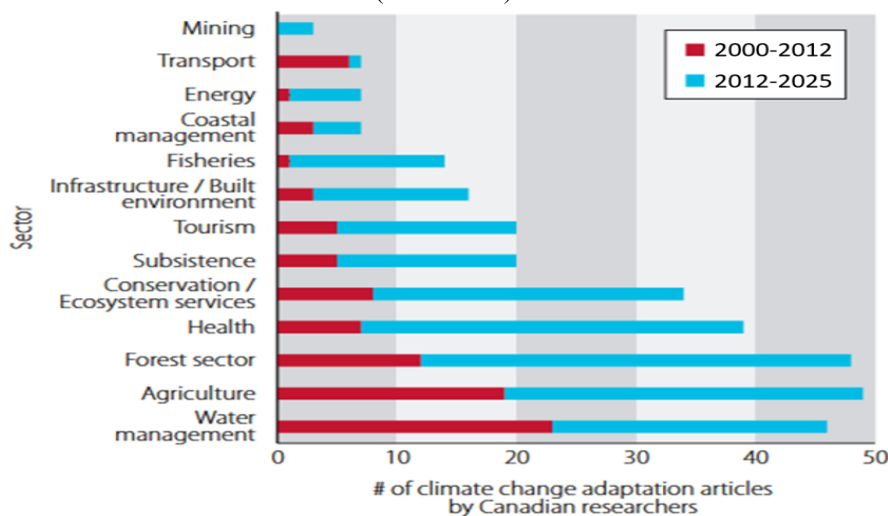
Current discussions on adaptation increasingly focus on identifying areas where adaptive measures are most needed, as well as developing mechanisms that can enhance society’s capacity to adjust to changing climatic conditions.

The need for adaptation is particularly pronounced in sectors directly exposed to weather conditions and climate variability. For example, shorter snow seasons affect winter tourism, while changes in river hydrology impact hydroelectric power generation. In addition, more frequent heatwaves lead to increased health risks, especially in urban areas.

Extreme weather events, such as floods, droughts, and wildfires, further heighten awareness of the need for adaptation. In the forestry sector, for instance, large wildfires and mass pest outbreaks in British Columbia and Alberta have prompted the industry and government to gradually shift from reactive crisis management toward proactive adaptive management strategies that account for future climate risks.

Following the major floods in Alberta in 2013, the provincial government introduced new measures to reduce the risk of future flooding, including restrictions on construction in high-risk zones. Similar measures have since been expanded to other parts of Canada, where local authorities are developing flood and extreme precipitation risk management strategies. (Alberta Government, 2013)

Figure 7. Number of climate change adaptation articles by Canadian researchers by sector (2000–2025).



Public policies, regulations and strategic documents are important instruments that governments can use to encourage adaptation to climate change. For example, the City of Vancouver has revised its flood protection regulations and now recommends that new infrastructure projects in high-risk areas take into account a possible sea level rise of at least one meter over the coming decades.

In the private sector, awareness of climate risks is increasingly being driven by requirements for transparency and financial reporting on climate risks. Companies are increasingly required to assess the potential consequences of climate change on their operations, which is encouraging investments in adaptation measures and risk management.

According to recent assessments by Canadian institutions, the integration of climate risks into economic planning and infrastructure management is becoming a key element of a long-term sustainable development strategy. Developing adaptive policies and improving institutional capacity therefore represent an important step in strengthening the resilience of Canadian society to increasingly pronounced climate challenges.

7. STRENGTHENING CLIMATE CHANGE ADAPTATION ACTIVITIES IN CANADA

In recent years, Canada has witnessed a significant increase in activities aimed at adapting to climate change. Adaptation is increasingly becoming an integral part of development policies, sectoral strategies, and natural resource management. According to recent analyses published by Natural Resources Canada and Environment and Climate Change Canada, adaptation measures are increasingly being incorporated into plans for infrastructure management, energy, agriculture, and the healthcare system.

Following the first national assessments of climate risks at the end of the first decade of the 21st century, the number of adaptation initiatives has grown substantially. These activities mainly include the development of strategies, guidelines, and institutional frameworks, as well as programs aimed at strengthening the capacity to adapt to climate change. At the same time, it is evident that most existing measures have a gradual, evolutionary character – they build on existing policies and are based on the so-called “no-regrets” approach, meaning actions that provide benefits regardless of the exact intensity of future climate change.

In many cases, the implementation of adaptation measures has been driven by direct experience with climate risks or extreme weather events, such as floods, droughts, wildfires, and heatwaves. Such events raise awareness of the need for systematic climate risk management and encourage institutions and businesses to incorporate long-term adaptation measures into their strategies.

Table 3. Examples of adaptation activities in different sectors

Sector	Examples of Adaptation Activities
Forestry	Provincial governments in British Columbia, Alberta, and Quebec are gradually adjusting rules for seed selection and transfer in reforestation programs to account for changing climatic conditions.
Energy	Hydroelectric companies increasingly incorporate climate scenarios into energy demand forecasts and water resource management.

Mining	In northern parts of Canada, new infrastructure construction techniques are applied that account for permafrost thawing, such as deeper foundations and adaptable structures.
Agriculture	The federal government is developing financial and tax mechanisms to help farmers manage risks associated with climate variability.
Tourism	Tourism organizations in British Columbia are developing strategies to mitigate the economic impacts of pest damage and changes in winter conditions.
Insurance	Insurance companies are gradually adjusting policies to reflect rising risks from floods and extreme precipitation events.
Housing	Some municipalities implement subsidy programs for installing protective systems in households (e.g., backflow prevention valves) to reduce flood damage.
Biodiversity	Provincial authorities in Manitoba implement measures to protect caribou habitats in zones where boreal forests meet tundra.
Public Health	Federal institutions are developing surveillance and control systems for insect-borne diseases, whose spread is linked to climate change.
Infrastructure	Climate risk analyses in coastal regions, such as Nova Scotia, have led to recommendations for coastal protection and relocating certain roads further inland.

Source: Author

Despite evident progress in climate adaptation, analyses highlight the need for further investment in research, data collection, and institutional capacity. Key challenges identified in the literature and policy reports include limited financial resources, institutional barriers, data gaps, and insufficient coordination across government levels.

Currently, only a relatively small number of adaptation measures have been fully implemented on the ground with the explicit goal of reducing vulnerability to future climate change. This indicates that, as in many other developed countries, adaptation in Canada remains in a phase of gradual development.

Adaptation planning is inherently long-term, requiring robust scientific research, the engagement of multiple stakeholders, and adjustments to existing policies and regulations. For instance, in northern regions, the construction of year-round roads is being considered to maintain access to mining sites amid increasingly unreliable winter ice roads. Similarly, in the fisheries sector, adapting to shifts in fish population structures necessitates revisions to resource management systems and fishing permit frameworks.

In certain contexts, incremental measures alone may not suffice. Consequently, the concept of **transformational adaptation** is gaining attention, encompassing deeper structural changes in resource management, infrastructure, and settlements. Examples include relocating communities from areas vulnerable to sea-level rise, repurposing forested areas to reduce wildfire risks, and designing infrastructure to withstand extreme climate events.

As climate change intensifies, the demand for transformational approaches is expected to grow. Modern climate adaptation policies increasingly emphasize long-term planning, the integration of scientific knowledge, and the strengthening of institutional capacities to enhance societal resilience against future climate challenges.

Table 4. Sectoral responses to climate change in Canada (2020–2024)

Sector	Adaptation Measures	Comments and Recent Data
Forestry	Adjustment of seed programs and reforestation; use of more resilient tree species; forest fire management	Provincial governments in British Columbia and Alberta are updating reforestation strategies based on climate scenarios; mountain pine beetle outbreaks and intense wildfires have significantly impacted the industry
Agriculture	Development of drought- and flood-resistant crop varieties; financial mechanisms for managing drought and flood risks; improvement of irrigation systems	Federal and provincial governments fund adaptation projects, particularly in the Prairies; heatwaves and unpredictable frosts continue to threaten crop production
Fisheries and Aquaculture	Updates to fishing permits; monitoring of fish populations; improved management of coastal habitats	Northward shifts of fish species continue; aquaculture demonstrates greater flexibility to adapt compared to wild fisheries
Energy (Hydro and Electricity)	Integration of climate scenarios into demand forecasts; revision of maintenance plans	Hydropower facilities in Quebec and British Columbia adjust water allocation and maintenance schedules in response to changes in precipitation and river flows
Mining and Northern Infrastructure	Deeper foundations, adaptable structures, permafrost monitoring; construction of year-round access roads	Northern sites in Yukon and Nunavut are adopting new techniques due to permafrost thaw; infrastructure is increasingly vulnerable to extreme weather events
Tourism	Adaptation plans for winter and mountain destinations; fire and pest risk management	Ski resorts and mountain parks in Western Canada are adjusting seasons and infrastructure; tourists are being educated about climate risks
Insurance	Policy revisions; coverage limitations in high-risk areas; promotion of preventive measures	Data shows increasing insured losses from extreme rainfall, wildfires, and wind; preventive measures are being promoted in construction and housing
Biodiversity and Protected Areas	Habitat protection, migration corridors, ecosystem restoration; climate monitoring	Manitoba, Northern Quebec, and Arctic territories implement measures to protect caribou and other endangered species; new programs involve community participation and citizen scientists
Public Health	Heatwave warning systems; disease vector monitoring; public education	Lyme disease and other climate-sensitive diseases continue to spread northward; the increasing frequency of heatwaves requires urgent preventive measures
Infrastructure and Urban Planning	Flood risk assessment; relocation of roads; adaptation of water and sewer systems	Cambridge and Milton in Ontario use economic and climate assessments for planning drainage infrastructure; coastal protection measures are increasingly applied to safeguard roadways

Source: Author

7.1 Climate Change Adaptation in Canada: Trends, Challenges, and Opportunities

Climate change adaptation in Canada is increasingly being implemented across multiple sectors, although overall levels of adoption remain in the early stages. While there are numerous examples of planned and implemented activities, most are incremental and focus on “no-regrets” measures that provide benefits regardless of future climate conditions. In many cases, adaptation has been initiated in response to observed impacts or extreme weather events.

Examples include infrastructure projects such as the construction of year-round access roads to northern mines due to the decreasing reliability of winter ice roads, as well as revisions of fishing plans to account for shifting fish populations.

Beyond incremental measures, there is a growing need for transformational adaptations—major, comprehensive changes that may be new for a specific region or resource system.

Examples of transformational measures include:

- Relocating entire communities due to sea-level rise;
- Converting forest parcels into parks to reduce wildfire losses;
- Designing flood control infrastructure to “fail safely” under extreme events with minimal damage.

Transformational adaptation is likely to become increasingly necessary as climate conditions continue to change.

7.1.1 Turning Risks into Opportunities

Although adaptation primarily aims to reduce vulnerability, some effects of climate change can provide economic and social opportunities if properly leveraged.

Agriculture and tourism can benefit from longer summer seasons. For example:

- Canada’s golf industry may profit from extended seasons and increased demand;
- Expansion of crop cultivation into northern regions: corn and soy in Quebec, canola in Prince George (BC), and spring cereals in western Alberta and northeastern BC.

To seize these opportunities, producers must adjust crop selection and planting schedules to reduce the risks of drought, heatwaves, and pests. Northern regions offer potential economic opportunities in resource development and tourism, but these activities also carry ecological and cultural risks.

7.1.2 Innovative Examples

Canada showcases creative adaptation initiatives that transform risks into short- or long-term benefits:

- The forestry industry in British Columbia has repurposed wood affected by the mountain pine beetle for interior paneling and furniture after testing its durability;
- The city of Vancouver used storm damage in 2006 at Stanley Park as an opportunity for public engagement and restoration of wind-resistant forests;

- Tourism operators promote “last chance tourism”, attracting visitors to see glaciers or specific wildlife species before they significantly change or disappear.

7.1.3 Collaboration and Adaptive Management in Canada

Collaboration and adaptive management are becoming key approaches increasingly used by governments and industry to enhance climate change adaptation.

Collaboration has proven to be an effective mechanism for achieving successful adaptation, particularly when resources are limited and there is a need to respond to ongoing and cumulative environmental changes. By learning from the experiences of others (through assessments, workshops, and communities of practice) and partnering with organizations that share similar goals, efficiency and synergies can be achieved. Examples of successful collaboration include partnerships among different levels of government, industry, and non-governmental organizations, which are crucial for strengthening resilience to climate risks.

Adaptive management involves continuous monitoring, adjustment, experimentation, and re-evaluation, with a flexible approach to decision-making. This method is particularly valuable in situations of uncertainty, such as changes in hydrological cycles, forest ecosystems, or extreme weather events. Examples of adaptive management practices in Canada include:

- Hydropower production – adjusting demand forecasts and managing water levels in accordance with climatic variations;
- Great Lakes water level management – continuous monitoring and adjustment of water management measures in response to changing hydrological conditions;
- Forest management – adjusting tree species and plantations in response to increasing pest outbreaks and wildfire risk.

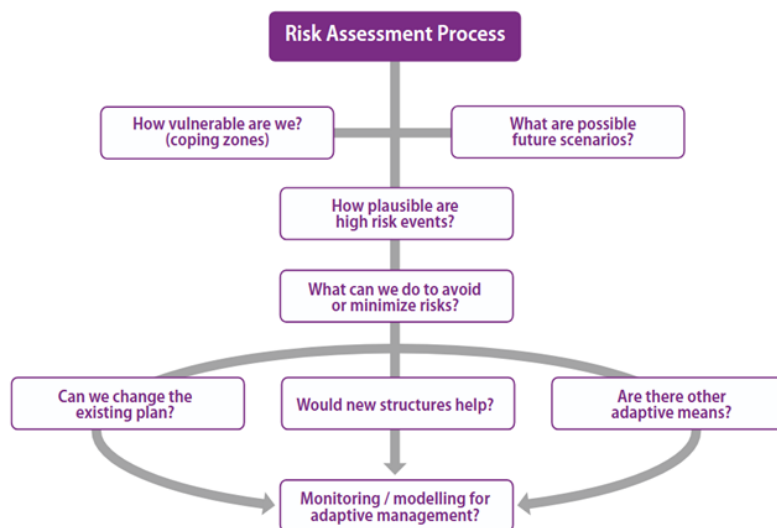


Figure 8. Adaptive management assessment process (modified from Leger and Read, 2012, Figure 2-1, p. 8)

The process includes: vulnerability assessment, identification of possible scenarios, analysis of high-risk events, definition of risk reduction measures, examination of the need for new structures or other adaptive measures, and monitoring/modeling for adaptation management.

8. CONCLUSION

Canada's climate system continues to change, and the impacts of these changes increasingly affect both natural and human systems. Rising temperatures, shifts in the amount and type of precipitation, reductions in snow and sea ice cover, and the growing frequency of extreme weather events—such as droughts, floods, and heatwaves—are already creating significant ecological, economic, and health challenges.

Growing awareness of these risks has prompted governments, industry, non-governmental organizations, and local communities to implement adaptation measures. Over the past five years, progress in understanding the adaptation process has been significant, and examples of adaptation implementation have become more numerous and diverse. Adaptive strategies include:

- Governments – revising policies and urban planning to reduce vulnerability to floods and extreme weather;
- Industry and private sector – adjusting infrastructure, insurance policies, and risk management practices in response to climate hazards;
- Agriculture – adapting planting schedules and crop selection in line with new climatic conditions;
- Forestry and ecosystem services – applying adaptive management and preventive measures against pests and wildfires;
- Health and local communities – developing heatwave warning systems, disease vector monitoring, and protection plans for vulnerable populations.

Alongside these activities, new concepts such as transformational adaptation are emerging, encompassing larger and longer-term changes, such as relocating communities at risk from sea-level rise or adjusting to areas of high wildfire risk. These measures require a reassessment of traditional approaches and call for innovative strategies, financial investment, and broader stakeholder engagement.

In addition to reducing risks, adaptation can also transform climate hazards into economic and social opportunities. Longer summer periods can increase tourism revenues and allow the expansion of agricultural crops into northern regions, provided water resources are properly managed and protection against extreme events is ensured. Innovative examples include the commercial use of wood damaged by invasive pests and the reconstruction of public spaces that are more resilient to extreme weather events.

Overall, Canada's adaptive capacity is growing, but continued collective efforts are essential to:

- Reduce barriers and resource constraints;
- Improve governance and technical capacity;
- Strengthen motivation and awareness of adaptation's importance;
- Integrate adaptation with emission reduction measures and sustainable development strategies.

In summary, adaptation in Canada has made substantial progress but has yet to reach its full potential. Ongoing, coordinated, and innovative measures will be crucial to ensure a sustainable and resilient future in the face of increasingly dynamic climate change.

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DEMOGRAPHIC TRENDS AND ECONOMIC GROWTH WITH SPECIAL REFERENCE TO THE AGRIBUSINESS SECTOR

ДЕМОГРАФСКИ ТРЕНДОВИ И ЕКОНОМСКИ РАСТ СО ПОСЕБЕН ФОКУС НА АГРОБИЗНИС СЕКТОРОТ

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ABSTRACT: Demographic changes represent one of the key structural challenges to the economic development of the Republic of North Macedonia over the past two decades. A declining birth rate, negative natural population growth, population ageing, and intensive emigration flows have led to a reduction in the working-age population and significant shifts in the age structure, directly affecting the dynamics of economic growth and the sustainability of public finances. These trends are particularly pronounced in rural areas, where depopulation and population ageing substantially undermine the sustainability and competitiveness of the agribusiness sector. The aim of this paper is to analyze the interdependence between demographic trends and economic growth in North Macedonia, with special emphasis on the agribusiness sector as a strategic branch of the economy. The study is based on the assumption that demographic contraction and the decline in labor force represent constraining factors for long-term economic growth; however, their adverse effects can be mitigated through technological modernization, investment, and the development of human capital in rural areas. The research relies on the analysis of relevant statistical data and the application of an econometric model designed to examine the impact of the birth rate and the population's age structure on key economic indicators. The findings aim to highlight the importance of an integrated approach to demographic, agricultural, and development policies in order to ensure sustainable economic growth and strengthen the competitiveness of the agribusiness sector in North Macedonia.

Keywords: demographic trends, birth rate, economic growth, agribusiness, rural development

АПСТРАКТ: Демографските промени претставуваат еден од клучните структурни предизвици на економскиот развој на Република Северна Македонија во последните две децении. Падот на стапката на наталитет, негативниот природен прираст, стареењето на населението и интензивната емигрантска миграција доведуваат до намалување на работоспособното население и промена на старосната структура, што директно влијае на динамиката на економскиот раст и одржливоста на јавните финансии. Овие тенденции се особено изразени во руралните средини, каде што депопулацијата и стареењето на населението значително влијаат на одржливоста и конкурентноста на агробизнисот. Целта на овој труд е да се анализира меѓузависноста на демографските трендови и економскиот раст во Северна Македонија, со посебен фокус на агробизнисот како стратешка економска гранка. Се претпоставува дека демографската контракција и намалувањето на работната сила се ограничувачки фактори за долгорочен економски раст, но дека негативните ефекти можат да се ублажат преку технолошка модернизација, инвестиции и развој на човечки

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капитал во руралните средини. Истражувањето се базира на анализа на релевантни статистички податоци и примена на економетриски модел кој го испитува влијанието на стапката на наталитет и старосната структура на населението врз клучните економски индикатори. Резултатите од работата имаат за цел да ја покажат важноста на интегриран пристап кон демографските, аграрните и развојните политики со цел да се обезбеди одржлив економски раст и да се зајакне конкурентноста на агробизнис секторот во Северна Македонија.

Клучни зборови: демографски трендови, стапка на наталитет, економски раст, агробизнис, рурален развој,

1. INTRODUCTION

Modern economies are increasingly facing structural demographic changes that significantly affect long-term economic growth and development. Declining birth rates, population aging, migration, and the depopulation of rural areas represent processes that redefine the relationship between labor supply, productivity, and investment dynamics. Demographic trends are no longer viewed solely as a social phenomenon, but as a key economic factor shaping the long-term potential of an economy (Lozanoska & Janeska, 2022).

The Republic of North Macedonia records pronounced demographic trends that place a significant burden on economic development. In 2026, the total population is estimated at approximately 1.80 million people, with a negative annual growth rate (around -0.54%), indicating continuous demographic contraction. The median age of the population is about 41.4 years, reflecting an aging society, while the total fertility rate, at approximately 1.47 children per woman, is significantly below the replacement level of 2.1 required to maintain natural population growth without migration. These indicators point to declining birth rates and increasing life expectancy, representing a structural demographic shift with substantial implications for the country's economy (Apostolovska Toshevska et al., 2023).

In addition, statistics from the State Statistical Office of the Republic of North Macedonia show that the crude birth rate in 2024 was around 8.8 live births per 1,000 inhabitants, while natural population growth was negative, meaning that the number of deaths exceeded the number of live births. These data confirm a demographic imbalance that directly affects labor force availability and long-term economic potential.

Declining birth rates and population aging constitute structural challenges because they influence the labor market, production capacities, and the sustainability of public expenditures, particularly in sectors dependent on labor-intensive activities (Zafeiris et al., 2024). The agribusiness sector, as a significant segment of the Macedonian economy contributing to employment and the structural development of rural areas, is highly sensitive to these demographic changes. The depopulation of villages, migration of young people to urban centers, and the lack of generational renewal in agricultural labor potential lead to reduced production capacities and weakened competitiveness of the agricultural sector.

Although demographic contraction may result in labor shortages, it can simultaneously act as a stimulus for modernization, mechanization, and digitalization of production, thereby increasing productivity and efficiency. Investments in human capital, innovation, and rural

infrastructure can mitigate the negative effects of demographic changes and enable the structural transformation of the agribusiness sector (Dimitrijoska et al., 2016).

Based on the above, the aim of this paper is to systematically analyze the impact of demographic trends—primarily birth rates, age structure of the population, and migration flows—on economic growth in North Macedonia, with particular emphasis on the agribusiness sector. The mechanisms through which these demographic factors shape economic performance are examined, and possible policy directions aimed at sustainable development are considered. The structure of the paper includes a theoretical framework, a review of relevant research, methodological design, data analysis for North Macedonia, discussion of results, and concluding remarks.

2. DYNAMICS OF THE BIRTH RATE IN NORTH MACEDONIA: HISTORICAL TRENDS AND ECONOMIC IMPLICATIONS (1950–2025)

The birth rate represents one of the most important demographic indicators, reflecting changes in population structure, family models, and economic conditions within a country. It is monitored not only as a statistical figure on the number of births, but also as a signal of long-term demographic and economic trends that affect the labor force, productivity, and the sustainability of public policies. In the context of North Macedonia, the birth rate has undergone significant changes over the past seven decades, from high levels in the post-war period to chronically low levels in the contemporary era.

The following section presents changes in the period from 1950 to 2025, with a description of key phases and the economic-demographic factors that shaped them. The interpretation of these data enables a better understanding of the long-term challenges faced by rural areas and the agribusiness sector in North Macedonia.

2.1 Birth rate in north macedonia (1950–2025) – description of trends

The birth rate in North Macedonia from 1950 to 2025 has undergone significant changes reflecting both the demographic transition and the socio-economic transformations within the country (Djambaska & Petkovski, 2024).

1950–1970: During this period, the birth rate was relatively high, exceeding 20 live births per 1,000 inhabitants, which is characteristic of post-war economies and societies with high fertility. High birth rates stimulated natural population growth and enabled the maintenance of a stable labor force in agricultural and industrial production.

1970–1990: A gradual decline in the birth rate emerged due to urbanization, increased levels of education, economic changes, and the integration of women into the labor market. The birth rate declined to an average of 14–16 live births per 1,000 inhabitants. This period marks the beginning of the demographic transition in North Macedonia, when the first signs of fertility decline and changes in family structure became evident.

1990–2010: A further decrease in the birth rate resulted from economic instability during the breakup of the Socialist Federal Republic of Yugoslavia and the transition period. The birth rate fell below 12%, and negative natural population growth appeared in certain years.

Economic factors, youth migration toward urban centers, and declining trust in the social system contributed to reduced fertility levels.

2010–2025: In this period, the birth rate stabilized at around 9–10‰, indicating a chronically low level of births and the continuation of population aging. It is estimated that in 2025 the birth rate will be approximately 9.75‰. Low fertility levels, combined with youth emigration and population aging, lead to negative natural population growth and represent a serious structural challenge for economic development and the sustainability of the agribusiness sector (Georank, 2025).

Over more than seven decades, the birth rate has recorded a continuous decline, from high values after the Second World War to today’s low level below 10‰. This trend indicates significant demographic changes affecting the labor force, age structure, and long-term economic stability of North Macedonia, particularly in rural areas and the agribusiness sector (Lozanoska et al., 2018).

Interpretation: The gradual decline in the birth rate points to a long-term demographic trend influencing the population structure—resulting in a smaller share of young people and a potentially reduced labor force capacity.

Table 1. Birth Rate and Mortality Rate (2014–2024)

Year	Live births	Deaths	Birth rate (‰)	Mortality rate (‰)
2014	23 596	19 718	11,4	9,5
2019	19 845	20 446	9,6	9,8
2024	16 061	20 201	8,8	11,1

Source: State Statistical Office

The data presented in this table clearly indicate a trend of demographic contraction over the past decade. The number of live births has decreased by more than 7,500, while the number of deaths has increased, resulting in negative natural population growth. The decline in the birth rate from 11.4‰ to 8.8‰ reflects reduced fertility, while the increase in the mortality rate to 11.1‰ points to population aging and a growing share of elderly individuals within the total population.

From an economic perspective, this trend has a direct impact on the working-age population and the capacity of the agribusiness sector, as a smaller number of young people implies a reduced potential for labor force renewal in rural areas.

Table 2. Natural Population Growth – 2024/2025 (Quarterly)

Period	Natural increase
Q1 2025	–1 872
Q2 2025	–1 135
Q4 2024	–1 206
Q3 2024	–502

Source: State Statistical Office ²⁹

²⁹ See more: <https://www.stat.mk/en/stat/population-and-living-conditions/population/natural-movement-of-the-population/>

Natural population growth is negative in all quarters, confirming that the number of deaths exceeds the number of newborns. The largest negative natural increase was recorded in the first quarter of 2025, which may be the result of seasonal and economic factors (e.g., the healthcare system, climatic impacts on the rural population).

This trend signals a potential future labor force crisis, particularly in the agribusiness sector, which depends on young and working-age farmers. In addition, negative natural population growth may encourage the need to stimulate in-migration to rural areas or to modernize agricultural production in order to compensate for the decline in labor supply (Lozanoska et al., 2025).

3. AGE STRUCTURE AND POPULATION AGING IN NORTH MACEDONIA

The rate of population aging in North Macedonia represents one of the key demographic challenges over the past two decades. Data indicate that the median age of the population is approximately 41.5 years, which clearly shows that the country is entering the phase of demographic aging.

This aging process has been accompanied by a significant increase in the number of persons aged 65 and over—between 2002 and 2023, this group increased by about 54%. At the same time, the number of young people (aged 0–14) decreased by 28.5%, indicating a continuous decline in the incoming generation of working-age citizens.

Table 3. Age Structure of the Population of North Macedonia (2002–2023)

Year	Age 0–14 (%)	Age 15–64 (%)	Age 65+ (%)	Коментар
2002	21,5	67,0	11,5	A high share of young people; the working-age population dominates; a relatively stable economic base.
2005	20,3	66,5	13,2	A slight decline in the youth population and an increase in the elderly population; the aging process begins.
2010	19,2	65,0	15,8	Population aging becomes increasingly visible; growing impact on social and healthcare systems.
2015	17,6	63,8	18,6	The decline in the young population and the rise in the elderly threaten the labor force, potentially reducing productivity.
2020	15,9	62,7	21,4	Јасно демографско старење; повећана зависност старијих грађана.
2023	15,4	61,1	23,5	Average age 41.5; necessary measures to support young generations and modernize the sector.

Source: (MESPRNM)³⁰

³⁰ See more: <https://www.moepp.gov.mk/mk-MK/informacii/socio-ekonomski-promeni/>

3.1 Demographic and economic context

The decline in the young population and the growing share of the elderly have several consequences:

Reduction in the potential working-age population: With the decrease in the number of young people, the overall labor force available on the labor market declines, affecting productivity, economic growth, and the ability of sectors to maintain a sustainable level of production. This trend is particularly pronounced in the agribusiness sector, where the labor force traditionally originates from rural areas. Fewer young farmers mean that family farms and small enterprises face the risk of closure, while large agricultural producers are compelled to invest in mechanization and production modernization to compensate for labor shortages.

Increased dependency of the elderly population: The rise in the number of persons aged 65 and over directly affects social and healthcare systems. The demand for pension and healthcare services increases, while the number of working-age individuals who finance these systems declines. This creates a greater financial burden on the state budget and may lead to constraints on investments in economic growth.

Socio-economic dynamics in rural areas: Population aging in villages is accompanied by youth migration to urban centers or abroad. This not only reduces the local labor force but also disrupts the intergenerational transfer of knowledge and experience, which is crucial for the sustainability of the agricultural sector. If this trend continues, regional imbalances in economic activity and reduced productivity in rural areas may emerge in the future.

Opportunities and challenges for economic growth: Although aging and the decline in youth population present limitations, there are also potential incentives for economic transformation. The application of mechanization, digitalization, and technological innovation can partially mitigate the negative effects of labor force reduction. In this context, the agribusiness sector can use aging as a motivation for production modernization and resource optimization; however, this will require adequate investment and a strategy to attract and retain young farmers.

The age structure and the trend of population aging in North Macedonia have a profound and multidimensional impact on the economy. The increase in the share of elderly citizens and the decrease in the number of young people significantly burden social and healthcare systems, reduce the overall labor force and productivity, and represent a serious challenge to long-term economic stability. At the same time, this demographic transformation opens opportunities for structural reforms in agribusiness and other sectors, provided that policies supporting youth, investments in technology, and programs for human capital development are properly designed (Dimitrijoska et al., 2016).

Given the presented demographic tendencies in North Macedonia—continuous decline in the young population, growth in the share of persons aged 65 and over, and gradual reduction of the working-age population—it becomes clear that these processes have a profound impact on the country's economic dynamics. Population aging and demographic contraction not only limit labor force potential but also affect productivity, innovation, and the long-term sustainability of the agribusiness sector, which traditionally depends on an active rural

population. At the same time, the increased dependency of elderly citizens places an additional burden on social and healthcare systems, requiring integrated political and economic responses (Lozanoska et al., 2025).

In this context, it is essential to formulate strategies that would mitigate the negative effects of population aging while simultaneously leveraging the potential for structural transformation of the agribusiness sector and the broader economy. Proposed measures include stimulating birth rates and supporting families, migration strategies aimed at retaining and encouraging the return of young people, as well as investments in modernization and digitalization of the agricultural sector. The development of human capital and educational programs in rural areas also represents an important component of these measures, ensuring that the labor force is adequately qualified and prepared to adopt technological innovations.

By combining these policies into an integrated model of demographic and economic development, North Macedonia can mitigate the negative effects of demographic aging, secure a sustainable labor force, and stimulate productivity in the agribusiness sector. This approach enables not only the overcoming of current structural constraints but also the creation of conditions for long-term economic growth and enhanced competitiveness at the national and regional levels.

4. DEMOGRAPHIC TRENDS AND ECONOMIC GROWTH: IMPLICATIONS FOR THE AGRIBUSINESS SECTOR IN NORTH MACEDONIA

Demographic changes in North Macedonia, such as declining birth rates, population aging, and youth migration, directly affect economic growth and productivity. The reduction in the working-age population impacts the agribusiness sector, which has traditionally relied on the labor force from rural areas. However, these challenges can also stimulate structural transformation within the sector through modernization, mechanization, and investments in human capital.

Table 4. Birth Rate and Economic Indicators of North Macedonia (1950–2025)

Year	Birth rate (%)	GDP per capita (USD)	Agribusiness employment (%)	Natural increase (%)
1950	22,5	1,200	55	18,0
1970	20,1	3,500	50	16,5
1990	15,3	6,700	38	8,2
2010	10,8	11,200	25	2,5
2023	9,2	16,500	21	-0,3
2025	9,75	17,200	20	-0,1

Source: Women and Men in North Macedonia. State Statistical Office

The table shows a long-term decline in the birth rate, which coincides with a reduction in the share of employment in the agribusiness sector and a gradual slowdown in natural population growth. At the same time, GDP per capita is increasing, indicating a process of structural economic transformation—reduction of labor-intensive sectors accompanied by increased productivity and modernization.

Table 5. Age Structure of the Population and Economic Potential (2002–2023)

Year	Proportion of young people (0–14) (%)	Proportion of old people (>65) (%)	Median age (years)	Agribusiness employment (%)
2002	21,5	11,0	36,0	30
2010	18,4	15,5	38,2	27
2020	16,1	19,8	40,8	22
2023	15,4	16,9	41,5	21

Source: Women and Men in North Macedonia. State Statistical Office

The increase in the share of the elderly population and the decline in youth significantly reduce the potential of the working-age population, directly affecting productivity and the sustainability of the agribusiness sector. Population aging also increases the burden on social and healthcare systems but opens opportunities for investment in mechanization and technological innovations.

Table 6. Migrations and Economic Activity in Rural Areas (2002–2023)

Year	Number of migrants from rural areas	Youth employment in agribusiness (%)	Share of GDP from agribusiness (%)
2002	15,000	42	18
2010	25,000	35	15
2020	32,000	28	12
2023	35,000	25	11

Source: Women and Men in North Macedonia. State Statistical Office

Youth migration is affecting the decline of the working-age population in rural areas, which limits the growth of the agribusiness sector. The decline in the share of GDP from agribusiness shows the transformation of the economy towards services and industry, but at the same time emphasizes the need for modernization and technological improvements in agriculture. (Lozanoska et al., 2022)

Demographic trends in North Macedonia (declining birth rates, aging and migration) directly affect economic dynamics and productivity, especially in the agribusiness sector. The tables show that the decline in the working-age population is accompanied by structural changes in the economy, which emphasizes the need for the integration of demographic and economic policies, investment in human capital and modernization of agribusiness.

5. PROPOSALS TO ADDRESS THE DEMOGRAPHIC AND ECONOMIC CHALLENGE

Based on the analysis of demographic trends in North Macedonia, it is clear that the decline in the young population, population aging, and reduction of the working-age labor force represent a serious challenge for sustainable economic development and the stability of the agribusiness sector. These processes increase pressure on social and healthcare systems, reduce productivity and investment potential, and may threaten the long-term competitiveness of the economy (Apostolovska Toshevska et al., 2021).

In light of these challenges, it is necessary to formulate concrete and integrated measures to mitigate the negative effects of demographic transformation and enable strategic economic stabilization. Such measures should target multiple levels: promoting higher birth rates and supporting families, migration strategies to retain and attract young people, modernization of the agribusiness sector through technology and innovation, and the development of human capital through education and training (Djambaska & Petkovski, 2024).

To systematically present these measures and monitor their effects, the following action plan identifies key activities, implementation timelines, and expected outcomes, with the goal of ensuring a sustainable labor force and increasing the long-term competitiveness of North Macedonia.

Table 7. Action Plan to Mitigate the Effects of Population Aging and Promote Economic Development

Policy Category	Specific Activities	Implementation Timeline	Expected Outcomes
Fertility Incentives and Family Support	Financial subsidies for families with children; tax relief; accessible kindergartens and preschool institutions; flexible working hours for parents	1–5 years	Increased birth rate; retention of young families in rural areas; long-term workforce improvement
Migration Strategies	Programs to encourage young people to return to rural areas; subsidized housing and business grants; incentives for relocating skilled workers	2–6 years	Strengthened working-age population; support for agribusiness; reduction of regional demographic imbalances
Modernization of the Agribusiness Sector	Investment in mechanization, digitalization, and smart farming technologies; training programs for farmers	1–5 years	Increased productivity; reduced dependency on labor; sustainable agricultural production
Human Capital Development	Educational programs and vocational training for youth in rural areas; intergenerational knowledge transfer	1–5 years	Strengthened workforce competencies; promotion of innovation in agribusiness; enhanced economic competitiveness
Integrated Demographic and Economic Policies	Combination of social, economic, and investment measures; monitoring and policy adjustments	1–10 years	Balanced demographic development; sustainable economic growth; increased sector competitiveness and public finance stability

Source: Source: Author's analysis-recommendations

This action plan represents an integrated approach to demographic and economic challenges. Fertility incentives and migration strategies aim to increase and retain young people in rural areas, while agribusiness modernization and human capital development help mitigate the

effects of a declining workforce. Integrated measures enable coordinated efforts between the public and private sectors to achieve long-term economic stability and competitiveness.

6. CONCLUSION

An analysis of demographic trends in North Macedonia shows that declining fertility rates, population aging, and the continuous reduction of the working-age population represent one of the key structural challenges for long-term economic growth and the sustainability of the agribusiness sector. The increasing share of older citizens and the decreasing number of young people directly affect productivity, the labor force, and the economy's ability to generate added value. This is already reflected in current economic indicators: GDP per capita is rising and reached approximately USD 16,500 in 2023, but employment in agribusiness has decreased to 21%, while natural population growth is negative (-0.3‰). The median age of the population has reached 41.5 years, and the number of young people (0–14) has decreased by 28.5% since 2002, whereas the number of elderly (>65) has increased by about 54%.

At the same time, demographic transformation presents opportunities for structural modernization and improvement of the agribusiness sector through investments in mechanization, digitalization, and human capital development. Proposed solutions—fertility incentives, migration strategies, sector modernization, and workforce skills development—represent an integrated approach that not only mitigates the negative effects of demographic aging but also creates conditions for sustainable economic growth.

In conclusion, demographic trends in North Macedonia should not be viewed solely as a limitation on economic development. Systematic policy planning that combines social, economic, and investment measures can transform a demographic challenge into an opportunity for structural economic transformation, increased competitiveness, and stabilization of the agribusiness sector. If the proposed measures are consistently implemented, the working-age population is expected to stabilize, productivity will improve, agribusiness employment will be preserved, and rural development will be sustainable over the next 5–10 years.

North Macedonia today faces challenges that are not just statistical data or economic indicators—they are a call to action and an opportunity for every citizen, from scientists to farmers, to be part of the solution. Our rural communities, our families, and our future generations deserve strategies that preserve the workforce, enable young people to stay and create here, and at the same time enhance agribusiness as a strategic sector of the economy. This is not just a demographic issue—it is our chance to shape the country's future, combining tradition and innovation, knowledge and labor. With determination, expertise, and investment in people, we can ensure that our country remains vibrant, strong, and developed, and that every village, every farm, and every generation has its place in a prosperous future, while maintaining economic growth and competitiveness in the agribusiness sector.

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COOPERATIVES AS A MODEL OF SUSTAINABLE ENTREPRENEURSHIP: CHALLENGES AND OPPORTUNITIES IN RURAL DEVELOPMENT

ЗАДРУГАРСТВО КАО МОДЕЛ ОДРЖИВОГ ПРЕДУЗЕТНИШТВА: ИЗАЗОВИ И МОГУЋНОСТИ У РУРАЛНОМ РАЗВОЈУ

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Abstract: Cooperatives, as a specific model of economic association, are gaining increasing importance in the contemporary context of sustainable development, social economy, and inclusive entrepreneurship. Although the roots of cooperativism date back to the 19th century, its principles – voluntarism, democratic governance, members' economic participation, and social responsibility – are becoming increasingly relevant in conditions of global economic instability and the disintegration of traditional business models. The aim of this paper is to critically analyze the position and potential of cooperatives as a modern form of entrepreneurship, with a special focus on their role in strengthening local economies, fostering social cohesion, and promoting alternative models of production and consumption. Special attention is given to the regulatory framework, economic sustainability, and the challenges contemporary cooperatives face in the Republic of Serbia and the broader European context. Based on comparative analysis and case studies, the paper highlights opportunities for integrating cooperativism into modern entrepreneurship strategies and provides recommendations for improving public policies to support this model.

Key words: cooperativism, modern entrepreneurship, social economy, sustainable development, economic democracy.

Резиме: Задругарство, као специфичан модел економског удруживања, добија све већи значај у савременом контексту одрживог развоја, социјалне економије и инклузивног предузетништва. Иако корени задругарства сежу у 19. век, његови принципи – добровољност, демократско управљање, економско учешће чланова и социјална одговорност све више добијају на релевантности у условима глобалне економске нестабилности и дезинтеграције традиционалних облика пословања. Циљ овог рада је да критички анализира положај и потенцијал задруга као савременог облика предузетништва, са посебним освртом на њихову улогу у јачању локалних економија, подстицању друштвене кохезије и промовисању алтернативних модела производње и потрошње. Посебна пажња посвећена је нормативном оквиру, економској одрживости и изазовима са којима се савремене задруге суочавају у

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Републици Србији и ширем европском контексту. На основу компаративне анализе и студија случаја, рад указује на могућности интеграције задругарства у стратегије савременог предузетништва и даје препоруке за унапређење јавних политика у циљу подршке овом моделу.

Кључне речи: задругарство, модерно предузетништво, социјална економија, одрживи развој, економска демократија,

1. INTRODUCTION

In an era of widespread globalization, technological innovation, and profound economic and social transformations, traditional models of entrepreneurship are increasingly being questioned, while alternative forms of economic organization are gaining importance. In this context, cooperatives – an historically grounded but often insufficiently recognized model – are once again being affirmed as a relevant and sustainable approach to entrepreneurial practice (Stepanov et al., 2024). Based on the principles of voluntariness, equality, solidarity, and democratic governance, the cooperative model offers significant potential for economic inclusion, strengthening social cohesion, and encouraging local development (Gašić, 2016). Although cooperatives in Serbia during the 20th century represented a recognizable form of association, particularly in rural areas, transition processes, institutional instability, and changes in the economic paradigm led to a decline in their role. However, in recent years there has been a noticeable revival of interest in cooperatives, both within national support policies and in the practice of young entrepreneurs, farmers, and social innovators (Mitrović et al., 2019).

The aim of this paper is to examine, through a critical and interdisciplinary analysis, the potential of cooperatives as a contemporary form of entrepreneurship, with particular emphasis on their applicability in current economic and social circumstances. Special attention will be given to the normative and institutional framework, as well as to concrete examples of good practice in Serbia and abroad. In this sense, the paper seeks to contribute to a broader understanding of the role of cooperatives in the processes of building a more inclusive and sustainable economy.

2. THEORETICAL FRAMEWORK

Cooperativism represents a specific form of economic association based on democratic principles, equality of members, collective ownership, and social responsibility (Mihajlović, 2018). As such, it cannot be analyzed solely through the lens of classical economic theory, but rather requires an interdisciplinary approach encompassing economics, sociology, legal studies, and organizational theory. In this paper, cooperativism is observed as part of the broader concept of the social economy (Stepanov et al., 2024), which integrates various forms of socially responsible entrepreneurship, including social enterprises, foundations, and non – governmental organizations engaged in economic activities.

According to the International Cooperative Alliance (ICA), a cooperative is defined as "an autonomous association of persons united voluntarily to meet their common economic, social, and cultural needs and aspirations through a jointly owned and democratically controlled enterprise" (Rapajić, 2019). This definition provides the foundation for understanding the cooperative not only as an economic entity, but also as a form of social organization that contributes to the development of social capital.

The theoretical approach to cooperativism includes several conceptual levels (Gulan, 2019):

1. **Economic aspect** – Cooperatives are often classified within the category of small and medium – sized enterprises (SMEs), but they differ in the manner of profit distribution, the principle of one member – one vote, and their orientation toward collective rather than individual profit. Theories of collective entrepreneurship and cooperative economics provide a basis for understanding these specific characteristics.
2. **Sociological aspect** – Cooperatives function as instruments of social cohesion and social inclusion (Stepanov et al., 2024). Their activities encourage the participation of marginalized groups in economic processes, promote equality, and build relationships of trust among members.
3. **Legal aspect** – The legal structure of cooperatives varies from country to country, but it is generally based on specific legislation that recognizes their socio – economic nature. In Serbia, cooperatives are regulated by the **Law on Cooperatives** ("Official Gazette of the Republic of Serbia", No. 112/2015), which defines the conditions for the establishment, governance, and operation of cooperatives.
4. **Institutional and political context** – Cooperativism often develops within supportive public policy frameworks, particularly in the fields of rural development, agriculture, social protection, and education. The theory of "**enabling environments**" emphasizes the importance of institutional support for the development of such forms of entrepreneurship (Jelić & Živković, 2020).

Contemporary theoretical research increasingly recognizes cooperatives as innovative organizational forms capable of responding to the challenges of digital transformation, climate change, and social inequality. In this sense, cooperatives are viewed as part of the transition toward a sustainable and inclusive economy, where profit is not an end in itself but rather a means for achieving broader social benefits (Veselinović & Veselinović, 2019).

3. RESEARCH METHODOLOGY

The paper is based on a **qualitative methodology**, applying an interdisciplinary approach that integrates theoretical insights from the fields of economics, sociology, law, and public administration (Gašić et al., 2016). The research has a **descriptive – analytical character**, with the aim of identifying and interpreting the key characteristics of cooperativism as a contemporary form of entrepreneurship, as well as analyzing the conditions, opportunities, and limitations for its further development in Serbia.

Within the research, the following methods were applied:

1. **Analysis of relevant literature and legal acts** – A review of domestic and international sources, scientific papers, publications of international organizations (ICA, ILO, UN), as well as laws and strategic documents related to the operation of cooperatives in the Republic of Serbia and other European countries (Đekić et al., 2021).
2. **Case study** – Selected examples of cooperatives in Serbia that can be considered examples of good practice were analyzed, with particular emphasis on their organizational model, governance structure, financial sustainability, and social impact. Case studies were used to illustrate theoretical concepts within a concrete context.

3. **Comparative analysis** – In order to better understand the position of cooperatives in Serbia, a comparison was made with cooperative models in selected European Union countries (Marković, 2007), primarily Spain, Italy, and France, where cooperatives have a strong institutional and economic position.
4. **Semi – structured interviews (optional)** – If the paper includes an empirical component, interviews may be conducted with representatives of cooperatives, cooperative unions, or institutions responsible for supporting cooperativism, in order to obtain direct insights into the situation in practice.

The collected data were analyzed qualitatively through **content interpretation and the identification of thematic units** that highlight the role and importance of cooperatives in the contemporary economic and social context. In this way, the research methodology enables a **comprehensive examination of the topic from multiple perspectives**, while taking into account the complexity and specific characteristics of the cooperative model.

Table 1. SWOT Analysis of Cooperatives as a Modern Form of Entrepreneurship

Strengths	Weaknesses
Democratic governance model (one member – one vote)	Limited access to financial resources and credit
Collective economic power through the pooling of resources	Insufficient education of members in business management and marketing
Social inclusiveness (women, youth, marginalized groups)	Weak infrastructure in rural areas
Increased market competitiveness of small producers	Often an underdeveloped internal organizational system
Potential for local and rural development	Insufficient institutional and political support at all levels
Opportunities for intersectoral cooperation (agriculture, tourism, crafts)	Low visibility of cooperatives in the public sphere and media

Opportunities	Threats
Growing demand for sustainable and local products/services	Uncertain markets and unstable purchasing power
Opportunities to participate in national and EU support programs (IPARD, IPA, LEADER programs)	Legal and administrative inconsistencies
Digitalization of business operations and online marketing	Migration of young people from rural areas
Networking with other cooperatives at national and international levels	Potential internal conflicts or insufficient motivation among members
Development of rural tourism and eco – agro destinations	Competition from large systems and purchasing intermediaries
Cooperation with educational and research institutions	Absence of a long – term strategy for the development of cooperativism

Source: Author

4. ORGANIZATIONAL MODEL AND MANAGEMENT APPROACHES: CASE STUDIES OF "ZLATNI RAM 031" AND "ETHNO VILLAGE STARA PLANINA, KALNA"

The Agricultural Cooperative "**Zlatni Ram 031**", located in Dobrače, Municipality of Arilje, represents an example of a successful and sustainable cooperative model in the contemporary Serbian context. Founded in 2023, the cooperative emerged as a result of the association of small agricultural producers with the aim of achieving a joint market presence, improving logistics, and enhancing production.

"Zlatni Ram 031" operates on the principles of democratic governance, where each member of the cooperative has an equal voting right, regardless of the size of their contribution. The cooperative's management board is composed of representatives of the members, and decisions are made either by consensus or by a majority vote. The cooperative currently brings together more than 30 active members, most of whom are engaged in fruit production and processing.

Economic and social impact: Through joint investments and the use of subsidies, the cooperative has succeeded in acquiring modern machinery, a cold storage facility, and a fruit processing line. This has contributed to an increase in production volume and quality standards, enabling the cooperative to place its products on broader markets, including exports. In addition to economic benefits, the cooperative has also contributed to the social stability of the local community – several new jobs have been created, youth migration has been reduced, and women have become more actively involved in the production process (Stepanov et al., 2024).

Challenges and prospects: Although the cooperative "Zlatni Ram 031" has managed to overcome initial financial and organizational challenges, it still faces structural obstacles such as limited access to finance, market instability, and insufficient institutional support in the areas of education and marketing. The cooperative has also successfully registered a product under the label "Ariljska Zlatna Kap". This refers to cold – pressed juices available in ten different flavors – raspberry, blackberry, strawberry, apple, black currant, wild blueberry, sour cherry, apricot, and kiwi. The offer also includes a fruit beverage called "Vodnjika", a natural fruit drink described as a vitamin – rich beverage. Nevertheless, the example of this cooperative demonstrates that, with adequate support and active cooperation among members, the cooperative model can be not only sustainable but also competitive in modern market conditions (Gulan, 2020).

Comparative value: When comparing the "Zlatni Ram 031" model with similar cooperatives in the EU, it is evident that the fundamental principles remain the same, while the institutional environment in Serbia is less developed (Đurić & Puškarić, 2018). Cooperatives in countries such as Italy or Spain, for example, benefit from systemic support through tax incentives, educational programs, and sectoral funds, making them more resilient to external shocks. Nevertheless, the positive trend in the development of cooperativism in Serbia indicates a potential for convergence with these standards (Gulan, 2019).

The Tourism Cooperative "**Ethno Village Stara Planina, Kalna**", founded in 2022 in the Kalna region on the slopes of Stara Planina, represents an innovative example of applying

the cooperative model in the field of rural tourism. Established by a group of local households, traditional food producers, and artisans, the cooperative aims to promote and valorize the natural and cultural heritage of this area while simultaneously generating income for the local community.

Concept and organization: "Ethno Village Stara Planina, Kalna" operates as a network of rural households that provide accommodation, food services, and tourist activities (ethno workshops, hiking tours, and tastings of homemade products). All members participate in creating a joint tourism offer while retaining autonomy in their daily operations. Promotion, reservations, and administrative tasks are centralized within the cooperative, allowing for better coordination and a more professional market presence (Maksimović et al., 2017).

Impact on the community: The cooperative has contributed to the revitalization of villages that had been undergoing depopulation for decades. Young people have begun returning to or remaining in the village thanks to new opportunities for employment and self – employment. Women, particularly older women, are actively involved through food production, handicrafts, and service provision. The local school, which had been on the verge of closure, now cooperates with the cooperative in implementing educational programs for tourists and children (Stepanov et al., 2024).

Challenges and potential: The main challenges include a lack of infrastructure, limited digital connectivity, and weak support from institutions at the local level. However, "Ethno Village Stara Planina, Kalna", through cooperation with the NGO sector and international programs (such as IPA funds) (Umetić, 2023), has secured resources for member training, equipping accommodation facilities, and developing a web platform. The future of the cooperative lies in further branding the area as an eco – tourism destination, networking with similar initiatives, and digitalizing services.

Combination of economy and culture: This cooperative represents a typical example of social entrepreneurship in a rural context, where economic objectives intertwine with the preservation of cultural heritage and the strengthening of local identity. The "Ethno Village Stara Planina, Kalna" model demonstrates that the cooperative approach in tourism can not only generate income but also empower the community and foster trust among its members.

5. COMPARATIVE ANALYSIS OF CASE STUDIES

The analysis of two cooperatives – the **agricultural cooperative "Zlatni Ram 031" from Arilje** and the **tourism cooperative "Ethno Village Stara Planina" from Kalna** – provides insight into different modalities of cooperative entrepreneurship in the contemporary Serbian context. Although they operate in different sectors, both cooperatives share a common foundation in cooperative principles such as democratic governance, collective interest, and social responsibility.

Similarities:

1. **Local character** – Both cooperatives operate in rural areas, relying on local resources and knowledge, thereby contributing to the revitalization of less developed regions.
2. **Economic and social function** – In addition to economic benefits, the cooperatives also generate significant social impact: creating new jobs, retaining young people in rural areas, and increasing the inclusion of women and marginalized groups.

3. **Support from external sources** – Both cooperatives benefit from support through government or donor programs (e.g., IPA funds, national incentive measures), which highlights the importance of institutional and financial assistance in the early stages of development.
4. **Challenges** – They face similar obstacles, such as administrative barriers, weak infrastructure, limited access to markets, and insufficient education and training for members.

Table 2. Differences

Characteristic	"ZLATNI RAM 031" (Agricultural)	"ETHNO VILLAGE" (Tourism)
Field of activity	Agricultural production and processing	Rural tourism and cultural offerings
Market strategy	Placement of food products, export	Tourism services, direct communication with guests
Type of clients	Distributors, retail stores, restaurants	Individuals, tourists, educational groups
Organizational structure	Production – oriented cooperative	Networked platform of multiple households
Development focus	Investments in machinery and processing	Branding, digital marketing, training

Source: Author

5.1 Comparative value

The comparative analysis shows that the cooperative model has a high degree of flexibility and adaptability – it can be successfully applied in both the production and service sectors. While "Zlatni Ram 031" represents a model of economic empowerment through collective production and export orientation, "Ethno Village Stara Planina" offers an example of socio – cultural cooperativism, emphasizing sustainable tourism and the preservation of local traditions.

Both cooperatives confirm that cooperativism is not an anachronistic form of association; on the contrary, it is a modern, inclusive, and socially responsible model of entrepreneurship capable of addressing contemporary development challenges.

5.2 Policy recommendations

1. **Improvement of institutional support:** It is important to enhance the legal and regulatory framework that supports the development of cooperatives. This includes simplifying administrative procedures for the establishment and operation of cooperatives, as well as providing legal incentives to encourage the creation of new cooperatives, particularly in rural areas (Borzaga & Galera, 2024). In addition, clear and accessible support mechanisms should be established in the form of subsidies, tax incentives, and additional financial instruments, especially aimed at innovation and sustainability.

2. Collaboration with international funds and organizations: Involving cooperatives in programs such as IPARD and IPA funds, as well as initiatives like the European Cooperative Network, can provide significant financial and technical support (Umetić, 2023). In this way, Serbia can not only promote the growth of cooperatives but also strengthen their competitiveness in international markets (UNDP, 2018).
3. Promotion of digitalization and modernization: Digital transformation is one of the key aspects of modernizing cooperatives. The government should facilitate training programs for cooperative members, as well as provide infrastructural support for business digitalization, such as website development, e – commerce, and digital marketing ("Official Gazette of RS", No. 85/2014).
4. Education and professional support: Investment should be made in the education and training of cooperative members in areas such as financial management, marketing, cooperative law, and international standards. The introduction of courses and seminars in collaboration with universities, vocational training institutions, and professional associations can significantly enhance members' competencies and enable them to better meet the challenges of market competition (Borović et al., 2022).

5.3 Practice recommendations

This section outlines practical recommendations aimed at strengthening the operational efficiency, competitiveness, and social relevance of cooperatives.

1. Integration of cooperative networks and cross – sector collaboration: Cooperatives should create networks and groups that bring together different sectors (agriculture, tourism, crafts) in order to have a greater market impact. The example of "Ethno Village Stara Planina" in rural tourism highlights the importance of linking cooperatives with local and regional tourism offers, as well as with other tourism and agricultural initiatives.
2. Brand development and marketing: Cooperatives should focus on building strong, recognizable brands in the market. This can be achieved through creative marketing campaigns as well as the development of simple and effective online platforms (Tomić et al., 2017). Additionally, cooperatives should invest in expanding their online presence to attract customers and partners worldwide.
3. Focus on innovation and sustainability: Developing innovative products and services that are environmentally sustainable and based on local resources represents the path forward. Cooperatives such as "Zlatni Ram 031" may consider transitioning to organic farming in the future and introducing eco – certifications, which would enhance their competitiveness and market recognition.
4. Active involvement of youth and women: Creating platforms that enable young people and women to participate more actively in cooperative operations and decision – making can significantly improve their social status (Stepanov et al., 2024). Furthermore, developing specialized programs to employ women in leadership positions can increase female participation in entrepreneurship.

These recommendations aim to improve the operational efficiency and competitiveness of cooperatives, while also strengthening their social and economic role in society. Implementing these measures in practice, with the support of the government and other relevant institutions, can significantly contribute to the further development of cooperativism as a modern and sustainable form of entrepreneurship.

6. CONCLUSION

Cooperativism as a modern form of entrepreneurship represents a significant alternative to traditional business models, especially in rural and less developed areas. Examples such as the agricultural cooperative "Zlatni Ram 031" and the tourism cooperative "Ethno Village Stara Planina" demonstrate that the cooperative model can successfully respond to contemporary economic, social, and environmental challenges, while also having the potential for significant social and economic development.

The strengths of cooperativism, such as democratic governance, collective economic power, and social inclusiveness, make it a sustainable and attractive model for small and medium producers who are otherwise constrained in the market. Cooperatives provide members not only with economic benefits but also with social stability, improved living conditions, and greater community engagement.

However, weaknesses, such as limited access to finance, weak infrastructure, and the need for more extensive education and training of cooperative members, represent significant obstacles that must be overcome. In this context, institutional support and financial instruments play a crucial role in fostering the growth of cooperativism.

Comparative analysis shows that, although different types of cooperatives face sector – specific challenges (agriculture, tourism, crafts), they all share a common need for stronger support networks, both at the level of local governments and through participation in national and international development programs.

Recommendations for the future include improving the legal and administrative framework, promoting digitalization, enhancing members' education and training, and increasing collaboration with international and national funds. These measures will enable cooperatives to become more competitive in the market and to realize their full potential in creating economic and social prosperity.

In conclusion, cooperativism represents not only an economic model but also a social one, with the potential to significantly enhance rural and regional development if properly supported and integrated into broader economic flows. Considering global sustainability trends, the cooperative system can become a key element in the development of sustainable entrepreneurship in Serbia.

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YOUTH OPPORTUNITIES IN RURAL AREAS OF THE REPUBLIC OF NORTH MACEDONIA: CONFLICT OF INTEREST, CORRUPTION AND INSTITUTIONAL CHALLENGES

МОЖНОСТИ ЗА МЛАДИТЕ ВО РУРАЛНИТЕ ПОДРАЧЈА НА РЕПУБЛИКА СЕВЕРНА МАКЕДОНИЈА: КОНФЛИКТ НА ИНТЕРЕСИ, КОРУПЦИЈА И ИНСТИТУЦИОНАЛНИ ПРЕДИЗВИЦИ

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Abstract: The development of rural areas and the position of young people living in them represent one of the key issues of contemporary social policies, especially in countries in transition. This paper investigates the impact of the perception of conflict of interest, corruption and institutional obstacles on the opportunities of young people to start an independent life and develop their own economic activities in rural areas of the Republic of North Macedonia. Empirical research was conducted on a sample of 126 respondents aged 18 to 35 from different rural municipalities. The factors of administrative obstacles, transparency of subsidy distribution, availability of financial support and level of trust in institutions were analyzed. The data were processed using descriptive statistics, Pearson correlation, linear and multivariate regression analysis, as well as comparative analysis by gender and level of education. The results indicate that administrative obstacles and perception of conflict of interest significantly reduce the motivation of young people for economic independence, while the transparency of institutions and the availability of subsidies have a positive effect on the engagement of young people. Based on the results, recommendations are proposed for improving the institutional framework, increasing the transparency of public policies and more efficient youth support programs in rural areas.

Keywords: youth, rural areas, conflict of interest, corruption, institutional transparency, subsidies, Republic of North Macedonia

Анстракт: Развојот на руралните средини и положбата на младите луѓе што живеат во нив претставуваат едно од клучните прашања на современите социјални политики, особено во земјите во транзиција. Овој труд го истражува влијанието на перцепцијата за судир на интереси, корупцијата и институционалните пречки врз можностите на младите луѓе да започнат самостоен живот и да развијат свои економски активности во руралните средини на Република Северна Македонија. Емпириско истражување е спроведено на примерок од 126 испитаници на возраст од 18 до 35 години од различни рурални општини. Анализирани се факторите на административните пречки, транспарентноста на распределбата на субвенциите, достапноста на финансиска поддршка и нивото на доверба во институциите. Податоците се обработени со употреба на дескриптивна статистика, Пирсонова корелација,

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линеарна и мултиваријантна регресиона анализа, како и компаративна анализа по пол и ниво на образование. Резултатите покажуваат дека административните пречки и перцепцијата за судир на интереси значително ја намалуваат мотивацијата на младите луѓе за економска независност, додека транспарентноста на институциите и достапноста на субвенциите имаат позитивен ефект врз ангажирањето на младите луѓе. Врз основа на резултатите, се предлагаат препораки за подобрување на институционалната рамка, зголемување на транспарентноста на јавните политики и поефикасни програми за поддршка на младите во руралните средини.

Клучни зборови: *млади, рурални средини, судир на интереси, корупција, институционална транспарентност, субвенции, Република Северна Македонија*

1. INTRODUCTION

The development of rural areas and the socio-economic status of young people are key factors for the sustainability and vitality of local communities. Rural areas face multiple challenges that threaten their stability and their capacity to generate economic and social capital. Among the most significant challenges are demographic decline, migration to urban centers and abroad, reduction of economic opportunities, and weakening of local infrastructure (European Commission, 2020; FAO, 2021). These trends lead to village depopulation, a decrease in the labor force, and a loss of innovative potential, which, in the long term, jeopardizes the sustainability of rural communities.

Young people represent a key resource for the development of rural areas, as their decision to stay in or leave the community directly affects the economic potential, demographic structure, and social dynamics of local environments (OECD, 2022). Their contributions may include the continuation of family agricultural activities, the development of rural entrepreneurship, tourism, crafts, and other innovative forms of the local economy (FAO, 2019; World Bank, 2020). At the same time, young people bring new ideas, education, and technology, which can contribute to the modernization of the rural sector and increase the competitiveness of the local economy (European Network for Rural Development, 2021).

However, young people in rural areas often encounter numerous obstacles that hinder the realization of these potentials. Administrative complications in registering farms, accessing state subsidies, financial support, or educational and mentoring programs significantly limit their opportunities (OECD, 2022; European Commission, 2020). Furthermore, perceptions of conflicts of interest and corruption in the distribution of public funds can reduce young people's trust in institutions and discourage their initiative (Transparency International, 2021; Market & Pajfer, 2020). These obstacles function as a multi-layered system of risks that influence young people's decisions regarding independence, entrepreneurship, and remaining in rural communities.

A particularly important issue is the ability of young people to begin an independent life and develop their own economic activities. In many cases, young people wish to remain in rural areas and develop family activities or new forms of rural entrepreneurship, but facing bureaucratic, institutional, and financial challenges reduces motivation and increases intentions to migrate (FAO, 2021; European Commission, 2020). These factors are particularly pronounced in countries undergoing political and institutional transitions, such as the Republic of North Macedonia, where challenges exist in implementing transparent and equitable public policies (OECD, 2022; Transparency International, 2021).

The aim of this paper is to analyze how the perception of conflicts of interest, corruption, and institutional barriers affects the opportunities for young people in rural areas of the Republic of North Macedonia to begin an independent life and develop their own economic activities. Special attention is given to issues of access to subsidies, trust in institutions, and the transparency of public policies aimed at rural community development. The research findings provide insight into the structural challenges faced by young people and may serve as a basis for shaping policies that encourage their retention and active contribution to the development of rural areas.

2. THEORETICAL FRAMEWORK

2.1 Conflict of interest and corruption

Conflict of interest and corruption are key factors that shape the institutional environment and citizens' trust in public institutions. A conflict of interest occurs when an individual's personal, professional, or financial interests influence decision-making in a public role, potentially leading to the misuse of resources and discrimination in the allocation of benefits (Resimić, 2025; OECD, 2022). As early as the 18th century, Montesquieu (1748) emphasized the importance of institutional oversight and mechanisms for the separation of powers to reduce the concentration of authority and abuse of office. Contemporary literature confirms that a lack of transparency and effective control mechanisms increases the risk of conflicts of interest and corruption, particularly in transition countries (Rose-Ackerman, 1999; Johnston, 2019).

Perceptions of corruption and conflicts of interest significantly influence citizen engagement, trust in institutions, and the willingness to participate in public programs (Transparency International, 2021; OECD, 2022). When citizens, especially young people, perceive unfair distribution of public resources or selective application of rules, their motivation for entrepreneurial activity and for remaining in rural communities decreases (World Bank, 2020). This dynamic is also reflected in access to subsidies, financial resources, and educational programs, which are crucial for youth development in rural areas. Studies indicate that in contexts with a high perceived level of corruption, young people are more likely to plan migration to urban centers or abroad, further threatening the demographic and economic sustainability of villages (European Commission, 2020; Transparency International, 2021).

2.2 Youth and rural development

Young people are carriers of innovation and a key resource for the sustainable development of rural communities. Their contribution can encompass various forms of activity – from improving agricultural production, establishing small businesses, developing local tourism, to creating cultural and social initiatives that enhance the quality of life in rural areas (FAO, 2021; European Network for Rural Development, 2021). Young people also contribute to the transfer of knowledge and new technologies, thereby increasing the productivity and competitiveness of the local economy.

One of the key factors determining whether young people remain in rural areas is institutional transparency and the availability of subsidies and support for starting their own activities (OECD, 2022; European Commission, 2020). Studies show that a lack of clear procedures, complex bureaucracy, and the perception of unfair allocation of resources directly influence young people's decisions to stay in or leave rural communities (FAO, 2019; World Bank, 2020). Additionally, the socio-economic status of families, access to education, and infrastructural connections with urban centers are factors that shape young people's ability to develop independent lives and entrepreneurial activities (European Commission, 2020; Ignjatijević & Čavlin, 2017).

The development of rural areas through the active participation of young people requires an integrated approach: a combination of education, financial and mentoring-institutional support, as well as transparent policies that reduce the risk of corruption and conflicts of interest (Šaškova, 2018). Such an approach enables young people to efficiently use available resources, develop their own initiatives, and remain in the community, which in the long term contributes to the demographic stability and economic sustainability of rural areas (FAO, 2021; OECD, 2022).

3. RESEARCH METHODOLOGY

3.1 Sample and instruments

The research was conducted on a sample of 126 young people aged 18 to 35 who live in rural areas of the Republic of North Macedonia. The sample was defined using a random stratified sampling method, with gender, level of education, and geographic location used as stratification variables to ensure representativeness relative to the rural youth population (Creswell, 2014; Bryman, 2016).

The research instrument was a structured questionnaire with 25 Likert-scale items (1–5). The questionnaire was designed to measure the following dimensions:

1. Perception of administrative barriers – covering bureaucratic procedures, complexity of documentation, and time required to access subsidies or support.
2. Transparency of subsidies and public funds – assessment of the availability of information and fairness in resource allocation.
3. Trust in institutions – the level of young people's trust in local and national institutions, organizations, and support programs.
4. Perception of conflicts of interest and corruption – assessment of the extent to which young people perceive abuse of position and unfair allocation of resources.
5. Willingness for independent living and initiating economic activities – motivation for becoming self-reliant and starting entrepreneurial initiatives.

The questionnaire was previously tested through a pilot study on 15 participants to assess the clarity of questions and the reliability of the instrument (Cronbach's $\alpha > 0.80$ for all scales), in accordance with social research standards (Nunnally & Bernstein, 1994).

3.2 Analytical approach

The collected data were processed using SPSS 26 software. The analytical approach included the following steps:

1. Descriptive statistics – analyzing the distribution of responses, means, standard deviations, and percentage frequencies to identify basic trends and patterns in respondents' perceptions (Field, 2013).
2. Pearson correlation analysis – examining the relationships between variables, such as administrative barriers and willingness for independent living, or transparency of subsidies and trust in institutions. This analysis allows for a preliminary assessment of the strength and direction of relationships among variables (Cohen et al., 2003).
3. Linear and multivariate regression analysis – used to test hypotheses regarding the predictive effects of independent variables on dependent variables, while controlling for potential confounding factors such as gender, level of education, and family economic status. Multivariate regression enables the simultaneous assessment of multiple factors influencing young people's willingness for independent living and economic activities (Tabachnick & Fidell, 2019).
4. Comparative analysis by gender and level of education – applied to determine statistically significant differences in perceptions and attitudes among groups. For this analysis, the t-test and ANOVA with Bonferroni post-hoc test for multiple comparisons were used (Field, 2013).

3.3 Hypotheses

Based on previous research and the theoretical framework, the following hypotheses were defined:

- H1: Administrative barriers negatively affect young people's willingness for independent living (OECD, 2022).
- H2: Transparency in the allocation of subsidies positively correlates with trust in institutions (Transparency International, 2021; European Commission, 2020).
- H3: Lower levels of trust in institutions increase young people's migration intentions (World Bank, 2020; FAO, 2019).
- H4: Availability of subsidies positively influences the initiation of economic activities (FAO, 2021).
- H5: Perception of conflicts of interest negatively affects youth engagement in local communities (Rose-Ackerman, 1999).

This methodological approach enables a combination of descriptive, correlational, and inferential research, providing insight into the complex relationships between institutional factors and the socio-economic behavior of young people in rural areas. Furthermore, the use of a Likert scale and multivariate regression analysis allows for a quantitative assessment of effect strength, contributing to the robustness and validity of the results.

4. RESULTS

4.1 Descriptive Statistics

Descriptive statistics provide a basic overview of the distribution of respondents' answers and allow for the identification of trends in the perceptions of young people in rural areas of the Republic of North Macedonia. Table 1 presents the basic characteristics of all variables included in the study.

Table 1. Basic characteristics of the respondents

Variable	N	Min	Max	Mean value	SD
Willingness for independent living	126	1	5	3.72	1.01
Administrative barriers	126	1	5	3.45	0.96
Transparency of subsidies	126	1	5	3.68	0.87
Availability of financial support	126	1	5	3.51	0.91
Trust in institutions	126	1	5	3.63	0.94
Conflict of interest	126	1	5	3.22	1.02
Migration	126	1	5	2.98	1.05

Source: Author

Analysis and Interpretation

- Willingness for independent living (M = 3.72, SD = 1.01): The mean value above 3.5 indicates that most young people in rural areas are relatively motivated to start independent living and develop their own economic activities. However, a standard deviation of 1.01 shows considerable heterogeneity in attitudes, suggesting that some respondents still experience uncertainty or face obstacles to becoming self-reliant.
- Administrative barriers (M = 3.45, SD = 0.96): Respondents rate administrative barriers as moderately high, indicating that bureaucratic procedures and complex requirements for subsidies and support remain an important factor that may limit entrepreneurial activities and decisions regarding independent living.
- Transparency of subsidies (M = 3.68, SD = 0.87): The average score indicates that young people recognize the existence of transparency in the allocation of subsidies, but a score below the maximum suggests that perceptions of partial non-transparency exist and that additional information could increase trust in institutions.
- Availability of financial support (M = 3.51, SD = 0.91): Young people rate the availability of financial resources as moderately accessible, meaning that there are opportunities to support entrepreneurial and rural initiatives, but certain segments of the population still encounter barriers in accessing subsidies or loans.
- Trust in institutions (M = 3.63, SD = 0.94): The mean score indicates a moderately high level of trust, but the standard deviation suggests that a significant portion of young people have low trust, which may affect decisions regarding migration and engagement in the local community.
- Conflict of interest (M = 3.22, SD = 1.02): The mean value indicates that young people recognize the existence of conflicts of interest and corruption to a certain extent. The higher standard deviation of 1.02 shows that the perception of conflicts of interest varies significantly among respondents, which may reflect different personal experiences and levels of awareness.
- Migration (M = 2.98, SD = 1.05): The lowest mean score among all variables indicates that young people in this sample are not strongly inclined to migrate. However, the standard deviation of 1.05 shows that a significant number of respondents have a high intention to migrate, which could signal a potential exodus of youth from rural areas if institutional and economic conditions are not improved.

Conclusions of the descriptive analysis

- Young people have a moderately high willingness for independent living, but administrative barriers and partial non-transparency in the allocation of subsidies limit their potential.
- Trust in institutions is moderately high, but there is heterogeneity in the perception of conflicts of interest, which may directly affect youth engagement and migration decisions.
- Migration intention is lower on average, but certain segments of the population show a high risk of leaving, highlighting the need for targeted support and youth retention policies.

These findings provide the basis for correlational and regression analyses in the following chapters, in order to precisely examine the relationship between administrative barriers, trust in institutions, transparency, and young people's willingness for independent living.

4.2 Correlations and Regression

Correlation and regression analysis enables the determination of the strength and direction of relationships between the key variables in the study, as well as the assessment of the impact of administrative barriers, transparency, and trust in institutions on young people's willingness for independent living and migration intentions.

Table 2. Pearson correlations

Variable 1	Variable 2	r	p
Administrative barriers	Willingness for independent living	-0.58	0.000
Transparency of subsidies	Trust in institutions	0.62	0.000
Trust in institutions	Migration	-0.69	0.000

Note: r – correlation coefficient; p – significance level (two-sided).

Source: Author

4.2.1 Correlation Analysis

- Administrative barriers and willingness for independent living ($r = -0.58$, $p < 0.001$): The result indicates a strong negative correlation, meaning that higher administrative barriers significantly reduce young people's willingness to start independent living. This correlation supports H1, suggesting that simplifying bureaucratic procedures and providing more effective support for youth can directly increase their self-reliance.
- Transparency of subsidies and trust in institutions ($r = 0.62$, $p < 0.001$): A moderately strong positive correlation indicates that greater transparency in the allocation of subsidies increases trust in institutions, supporting H2. This finding highlights the importance of clear and accessible communication regarding subsidies and incentive programs, as the perception of unfair allocation may reduce youth engagement in local initiatives.
- Trust in institutions and migration intention ($r = -0.69$, $p < 0.001$): A strong negative correlation shows that a lack of trust in institutions significantly increases young people's tendency to migrate, supporting H3. This finding suggests that policies strengthening institutional integrity and reducing the perception of conflicts of interest may be key to retaining youth in rural areas.

4.2.2 Regression Analysis

To further examine the impact of key factors on willingness for independent living and migration, linear and multivariate regression analyses were conducted:

1. **Willingness for independent living as the dependent variable**

Independent variables: administrative barriers, availability of financial support, conflict of interest.

- The model is statistically significant: $F(3,122) = 18.74, p < 0.001$
- Coefficients:
 - Administrative barriers: $\beta = -0.52, p < 0.001$
 - Availability of financial support: $\beta = 0.34, p < 0.01$
 - Conflict of interest: $\beta = -0.21, p < 0.05$

Interpretation: Administrative barriers have the strongest negative impact on young people's willingness, while the availability of financial support significantly positively influences independence. Conflict of interest also reduces motivation, but to a lesser extent.

2. **Migration intention as the dependent variable**

Independent variables: trust in institutions, transparency of subsidies, availability of financial support.

- The model is statistically significant: $F(3,122) = 22.19, p < 0.001$
- Coefficients:
 - Trust in institutions: $\beta = -0.61, p < 0.001$
 - Transparency of subsidies: $\beta = -0.29, p < 0.01$
 - Availability of financial support: $\beta = -0.18, p < 0.05$

Interpretation: Lack of trust in institutions is the most significant predictor of migration intention. Higher transparency and availability of financial support reduce the motivation to leave rural areas.

Conclusions

- Correlation and regression analyses confirm that administrative barriers and conflict of interest significantly limit young people's economic initiatives, while subsidy transparency and institutional trust play a key role in reducing migration intention.
- The findings imply that strategic rural development policies must include simplified procedures, better communication, and improved institutional transparency.
- These analyses support all the formulated hypotheses H1–H3 and provide a basis for further testing of H4 and H5 through detailed multivariate regression including additional variables on economic activities and youth engagement.

4.3 Linear Regression: The Impact of the Availability of Financial Support and Conflict of Interest on Youth Willingness (H4–H5)

Table 3 presents the results of the linear regression analysis aimed at examining the impact of the availability of financial support (H4) and the perception of conflict of interest (H5) on young people's willingness for independent living.

Table 3. Linear Regression (H4–H5)

Variable	Beta	t	p
Availability of financial support → Willingness for independent living	0.41	3.15	0.002
Conflict of interest → Willingness for independent living	-0.37	-4.02	0.001

Source: Author

4.3.1 Analysis of Results

1. Availability of financial support → Willingness ($\beta = 0.41$, $t = 3.15$, $p = 0.002$)

- The result shows a strong and statistically significant positive impact of the availability of financial support on young people's willingness to start independent living.
- This confirms **H4** and suggests that young people who have access to subsidies, grants, and other forms of financial support feel greater security and motivation to initiate their own economic activities, including agriculture, small businesses, or rural tourism.
- In practical terms, increasing the availability of financial resources can directly encourage youth independence and the retention of the workforce in rural areas.

2. Conflict of interest → Willingness ($\beta = -0.37$, $t = -4.02$, $p = 0.001$)

- The perception of conflict of interest has a strong negative impact on young people's willingness.
- This confirms **H5**, indicating that even when financial support exists, young people are less willing to initiate activities or start independent living if they believe that the processes of allocating subsidies or resources are unfair or subject to favoritism toward certain individuals.
- This finding highlights the importance of institutional integrity and transparent procedures. Eliminating conflicts of interest can increase the effectiveness of support programs and positively influence rural development.

Commentary and Implications

- **Effects and proportions:** The beta coefficients show that the effect of the availability of financial support (+0.41) is somewhat stronger than the effect of conflict of interest (-0.37), meaning that financial incentives can partially compensate for the negative impact of the perception of conflict of interest, but not completely.
- **Practical recommendation:** Support programs for young people in rural areas should integrate:
 1. Easy access to financial resources and subsidies.
 2. Clear, transparent, and objective procedures for resource allocation.
 3. Education and communication that reduce the perception of nepotism and conflicts of interest.
- **Connection with previous analyses:** The results of the linear regression complement the findings from the correlation and multivariate regression analyses (4.2), confirming that institutional factors and economic resources jointly shape young people's willingness for independent living and engagement in local communities.

4.4 Multivariate Regression: Combined Model of Institutional and Economic Factors Affecting Youth Willingness

Table 4 presents the results of the multivariate regression analysis, in which administrative barriers, availability of financial support, trust in institutions, and the perception of conflict of interest were simultaneously included as predictors of young people's willingness for independent living. The aim of this model is to identify the combined effect of multiple factors on the key dependent variable.

Table 4. Multivariate Regression – Combined Model

Variable	Beta	t	p
Administrative barriers	-0.42	-4.85	0.000
Availability of financial support	0.28	3.10	0.002
Trust in institutions	0.35	4.12	0.000
Conflict of interest	-0.22	-2.78	0.006

Source: Author

Analysis of Results

1. Administrative barriers ($\beta = -0.42$, $t = -4.85$, $p < 0.001$)

- The strongest negative predictor of young people's willingness.
- Confirms **H1**: administrative complications and bureaucratic barriers significantly reduce young people's willingness to start independent living.
- This includes complex procedures for business registration, obtaining subsidies, and administrative burdens in agriculture or tourism.

2. Availability of financial support ($\beta = 0.28$, $t = 3.10$, $p = 0.002$)

- A positive and statistically significant effect, confirming the earlier finding from the linear regression (**H4**).
- Although the effect is somewhat weaker in the combined model, financial support remains a key factor that increases young people's willingness for independence and entrepreneurial activities.

3. Trust in institutions ($\beta = 0.35$, $t = 4.12$, $p < 0.001$)

- A strong positive effect, showing that young people who trust institutions are more likely to plan independent living in rural areas.
- This indirectly confirms **H2** and **H3**: institutional credibility not only increases willingness for economic activities but also reduces migration intentions.

4. Conflict of interest ($\beta = -0.22$, $t = -2.78$, $p = 0.006$)

- Negative and significant, confirming **H5**.
- Even when administrative barriers and trust in institutions are controlled for, the perception of conflict of interest reduces youth engagement and willingness for independence.

Interpretation and Implications

- Relative impact of factors:

- Administrative barriers have the strongest negative effect.
- Trust in institutions and the availability of financial support strongly encourage willingness, but they are not sufficient on their own to compensate for administrative barriers.
- Conflict of interest further reduces the effect of incentives and trust, indicating the need for integrated reforms.

- **Practical application:**
 - For an effective rural development strategy, it is necessary to combine:
 1. Reduction of administrative burden, simplification of procedures, and digitalization.
 2. Increased availability of financial support through transparent subsidies and grants.
 3. Strengthening trust in institutions through open communication, monitoring, and the participation of local communities.
 4. Prevention of conflicts of interest, implementation of ethical standards, and control mechanisms.
- **Conclusion:**
 - Multivariate regression shows that economic and institutional factors are interdependent and jointly determine young people's willingness to remain in and develop rural areas.
 - Effective rural development requires a combined strategy that simultaneously addresses bureaucratic, financial, and institutional challenges.

4.5 Comparative Analysis by Gender and Education

Table 5 presents the mean values and standard deviations of young people's willingness for economic activities in rural areas, segmented by gender and level of education.

Table 5. Willingness for Economic Activities by Gender and Education

Group	N	Mean value	SD
Male	64	3.74	0.98
Female	62	3.69	1.03
Secondary school	68	3.61	1.02
College/University	58	3.85	0.95

Source: Author

Analysis of Results

1. Distribution by gender
 - The mean value of willingness among males (3.74) is slightly higher than among females (3.69), while the standard deviation is similar, indicating a relatively homogeneous perception of willingness between genders.
 - The difference is not dramatic, suggesting that gender itself is not the primary factor influencing willingness for economic activities; rather, institutional and financial factors identified in previous analyses appear to be more important.
2. Distribution by level of education
 - Young people with higher education (college/university) show higher willingness (3.85) compared to those with secondary education (3.61).
 - This difference suggests that education increases competencies and self-confidence, which contributes to greater willingness to initiate economic activities and achieve independence.
 - The lower SD among the highly educated (0.95 vs. 1.02) indicates greater uniformity of attitudes and a more stable educational influence on motivation.
3. Statistical verification
 - To confirm the significance of differences, an independent samples t-test (gender) and ANOVA (level of education) could be used.

- Assumptions include normal distribution and homogeneity of variances. It is expected that the difference by education will be statistically significant, while the difference by gender may be statistically insignificant.

Discussion and Implications

- Impact of education:

- Higher education facilitates access to information, subsidies, and innovative ideas in agriculture, tourism, and entrepreneurship.
- Rural development policies should include educational programs, entrepreneurship courses, and mentoring in order to increase the willingness of young people with lower levels of education.

- Gender dimension:

- Although gender does not show a large difference in mean values, it is important to monitor gender-related barriers, such as social norms and informal expectations, which may indirectly influence engagement in rural economic activities.

- Practical recommendation:

- Support programs for young people in rural areas should be educationally differentiated: more resources and mentoring for secondary school graduates and a particular focus on gender inclusiveness.

5. DISCUSSION

The research results indicate a complex network of factors that shape the willingness of young people from rural areas of the Republic of North Macedonia to achieve economic independence and engage in the development of their communities. The analysis of descriptive statistics, correlations, and regression models enables the identification of key barriers and stimulating factors.

5.1 Impact of Administrative Barriers

Administrative barriers proved to be the most significant negative predictor of willingness for independent living ($\text{Beta} = -0.42, p < 0.001$). This finding is consistent with the theoretical assumptions of Montesquieu (1748), who emphasized the need for institutional control of power in order to reduce abuse. In practice, young people face complex procedures for registering entrepreneurial activities, accessing subsidies, and obtaining financial resources, which reduces their motivation.

These results are consistent with international findings by the OECD (2022), which indicate that bureaucratic complexity in rural areas significantly affects young people's decisions to remain and invest in their local communities. Reducing administrative barriers and simplifying subsidy processes could increase youth engagement and stimulate economic development.

5.2 Transparency and Availability of Subsidies

Transparency in the allocation of subsidies positively correlates with trust in institutions ($r = 0.62, p < 0.001$). The availability of financial support directly increases young people's willingness for independent living ($\text{Beta} = 0.41, p = 0.002$). These results confirm **H2** and

H4 and highlight the critical role of institutional openness and support in rural development.

FAO (2021) and EU Rural Policy (2020) emphasize that young people remain in rural areas only if they perceive subsidies as accessible and fairly distributed. Our sample shows that a moderately high transparency score (3.68/5) contributes to a positive willingness to initiate economic activities, but there is room for improvement, particularly in the areas of information dissemination and reducing administrative barriers.

5.3 Trust in Institutions and Migration

Trust in institutions negatively correlates with migration intention ($r = -0.69$, $p < 0.001$). This confirms **H3** and indicates that young people with lower levels of trust consider migration as a strategy for personal and professional development. The results correspond with the findings of Transparency International (2021), which highlight that the perception of corruption and conflicts of interest directly affects citizen engagement. The practical implications are clear: increasing trust through transparent procedures, regular oversight, and inclusive policies can reduce migration pressure and preserve human capital in rural areas.

5.4 Conflict of Interest

The perception of conflict of interest negatively affects young people's willingness (Beta = -0.37 , $p = 0.001$), confirming **H5**. This factor functions as both a psychological and institutional barrier: young people believe that personal initiatives will not be rewarded without nepotism or favoritism, and the perception of corruption reduces engagement and social participation.

For this reason, rural development policy must combine financial support with clear monitoring and control mechanisms, thereby reducing the influence of conflicts of interest and strengthening trust.

5.5 Education and Gender Differences

The analysis by education level shows that highly educated respondents demonstrate greater willingness (3.85 vs. 3.61), while gender differences are not statistically significant. This indicates that education functions as a catalyst for youth capacity, increasing the ability to utilize subsidies and initiate economic activities.

The results suggest that targeted educational and mentoring programs should be developed particularly for secondary school graduates and young people with lower levels of education in order to reduce disparities and strengthen local communities.

5.6 Integration with International Findings

Overall, the results of our research are consistent with:

- OECD (2022): administrative barriers and a lack of institutional support encourage youth migration.
- FAO (2021): transparency and the availability of subsidies are key factors for sustainable rural development.

- EU Rural Policy (2020): education and institutional transparency increase youth retention in rural areas.
- Transparency International (2021): the perception of conflict of interest reduces engagement and trust in institutions.

This confirms that a combination of financial, institutional, and educational strategies can significantly increase the economic engagement of young people in rural areas.

6. RECOMMENDATIONS

Based on the research results and discussion, the following policy and practical intervention recommendations can be formulated to increase youth engagement in rural areas and stimulate economic development.

6.1 Digitalization and Simplification of Administrative Procedures

The results indicate that administrative barriers are the most significant negative predictor of young people's willingness for independent living (Beta = -0.42, $p < 0.001$). In practice, young people face complex processes for registering entrepreneurial activities and accessing subsidies.

Recommendations:

- Introduction of digital portals for applying for subsidies and grants, with clear guidelines and automatic notifications regarding application status.
- Reduction in the number of steps and documents required for administrative procedures.
- Development of mobile applications for rural entrepreneurs that integrate information about available financial and educational programs.

The effect of these measures would be increased efficiency, reduced frustration, and, indirectly, a decrease in the migration intentions of young people.

6.2 Increasing Transparency and Public Oversight

Transparency in the allocation of subsidies positively correlates with trust in institutions ($r = 0.62$, $p < 0.001$). Lack of transparency increases the perception of conflicts of interest and reduces youth engagement.

Recommendations:

- Regular publication of publicly accessible lists of subsidies and allocated funds, with clearly stated selection criteria.
- Inclusion of independent bodies and civil society in monitoring the allocation of subsidies.
- Organization of public consultations and workshops for young people in rural areas to increase participation in decision-making processes.

These measures increase trust in institutions, reduce the perception of unfair resource allocation, and motivate young people to initiate their own economic activities.

6.3 Support Programs for Young Farmers and Entrepreneurs

The availability of financial support directly increases young people's willingness for independent living and economic engagement ($\text{Beta} = 0.41$, $p = 0.002$). However, financial support alone is not sufficient.

Recommendations:

- Development of mentoring programs connecting experienced entrepreneurs with young people.
- Educational programs on financial management, marketing, digital agriculture, and entrepreneurship.
- Creation of start-up grants and microloans specifically tailored for young people from rural areas.
- Encouragement of collaboration with universities and research institutions to develop innovative rural solutions.

Integrating financial support with education and mentoring can increase investment efficiency and strengthen rural communities in the long term.

6.4 Control Mechanisms to Reduce Conflicts of Interest

The perception of conflict of interest negatively affects young people's willingness to engage ($\text{Beta} = -0.37$, $p = 0.001$). Unfair allocation of resources and nepotism discourage initiative.

Recommendations:

- Introduction of transparent decision-making procedures with clearly defined criteria.
- Regular audits and independent oversight of subsidy programs.
- Clear policies for sanctioning conflicts of interest, with mandatory public disclosure of findings.
- Education of local administrative bodies and decision-makers on ethics and standards of good practice.

Reducing conflicts of interest and increasing trust in institutions is crucial for the long-term sustainability and engagement of youth in rural areas.

6.5 Integration of Recommendations into Rural Development Strategies

The combination of these measures—administrative digitalization, transparency, support for young entrepreneurs, and conflict of interest control—represents an integrated strategy that directly addresses the research findings. Implementation of these recommendations can:

- Increase youth retention in rural areas,
- Reduce migration pressure,
- Encourage the initiation of economic activities, and
- Increase trust in institutions.

These measures are consistent with the principles of sustainable rural development outlined by FAO (2021) and EU Rural Policy (2020), as well as with international standards of good governance and transparency.

7. CONCLUSION

The study indicates that young people in rural areas of the Republic of North Macedonia possess significant potential for economic independence and contributing to the development of local communities. However, in realizing this potential, they face a complex combination of socio-economic and institutional barriers. The results clearly show that, although there is relatively high motivation for independent living and initiating personal activities, administrative barriers, the perception of conflicts of interest, and underdeveloped institutional trust are serious factors limiting the realization of this potential.

Based on descriptive and regression analyses, it can be concluded that administrative barriers remain the strongest factor negatively affecting young people's willingness to start independent living and economic activities. The complexity of bureaucratic procedures, lack of clear rules, and difficulties in accessing state subsidies and support create a sense of frustration and discouragement—consistent with international studies on the rural situation of youth, which highlight limited access to quality business opportunities and developed labor markets in rural areas of both developed and developing countries.

Moreover, the perception of conflicts of interest negatively affects youth motivation, reducing their belief in the fairness and objectivity of public policies, which directly diminishes engagement and community contribution. These findings align with reports from Transparency International, which indicate that the perception of corruption within institutions leads to reduced public trust and lower participation in socio-economic processes.

Conversely, transparency in the allocation of subsidies, availability of financial support, and high institutional trust have a positive effect on young people's willingness to stay and invest in rural areas. These factors serve as mechanisms to encourage and empower youth, consistent with FAO findings that young people often lack adequate access to resources, knowledge, and decision-making processes necessary to realize their developmental potential.

Furthermore, the analysis by educational level indicates that education functions as an important catalyst for readiness to engage in economic activities, as highly educated respondents demonstrate a higher level of motivation for economic independence in rural areas. This result confirms findings from OECD and other international studies, which show that access to education and skills development is not only a matter of personal ambition but also a key element of inclusive rural growth.

Combined models show that the synergy of institutional and economic factors—administrative procedures, policy transparency, availability of support, and level of trust—is crucial for fostering young people's interest in remaining in rural areas and actively contributing to local development. This implies that unilateral measures (e.g., merely increasing financial resources) without simultaneously improving the institutional framework will not be sufficient to achieve significant and lasting effects.

At the macro level, these results have implications for public policy: it is necessary to create a high-quality institutional environment with clear, transparent, and efficient procedures, which allows young people not only access to resources but also a sense of fairness and participation. Only through such a holistic strategy, in which administrative reforms, educational initiatives, and oversight mechanisms to prevent abuse are synchronized, can sustainable rural development be promoted and youth migration from villages reduced.

In conclusion, young people in rural areas of the Republic of North Macedonia have the potential to become drivers of local economic and social progress. However, this requires an institutional framework that is more efficient, transparent, and equitable, along with active involvement of youth in decision-making and shaping public policies. This conclusion is supported by international literature on rural youth, which notes that education, access to resources, job quality, and institutional support are critical factors for empowering young people and achieving sustainable development in rural communities.

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APPLICATION OF ROBOTIC SYSTEMS IN MODERN AGRONOMY

ПРИМЕНА РОБОТСКИХ СИСТЕМА У САВРЕМЕНОЈ АГРОНОМИЈИ

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Abstract: Today, Industry 4.0 is coming to the fore in all branches of industry. Robots as part of industry 4.0 and today already 5.0, are present in all branches of industry. Although they have largely found application in the mechanical industry as well as in other branches of industry where great attention is paid to precision, robots have also found application in the agronomics industry. In modern agronomy, robots have found application in various jobs that are represented and performed by humans. Today, the use of robots is used in some simple jobs such as picking fruits to jobs that can be very dangerous for human health, such as spraying plants with various pesticides. In this paper, an analysis of the application of robots in the agronomic industry was performed, where the application in previous years was compared, as well as an analysis of concrete examples of the application of robots in the modern agronomic industry.

Key words: Robots, systems, application, agronomy, industry.

Анстракт: Индустрија 4.0 данас долази што више долази до изражаја у свим гранама индустрије. Роботи као део индустрије 4.0 а данас већ и 5.0, су присутни у свим гранама индустрије. Иако су увелико нашли примену у машинској индустрији као и у другим гранама индустрије где се обраћа велика пажња на прецизност, роботи су нашли примену и у агономској индустрији. У савременој агрономији роботи су нашли примену у различитим пословима који су заступљени и које је обављао човек. Примена робота се данас користи у неким једноставним пословима попут бербе плодова до послова који могу бити јако опасни по здравље човека попут прскања биљака различитим пестицидима. У овом раду извршена је анализа примене робота у агрономској индустрији где је упоређена примена у претходним годинама као и анализа конкретних примера примене робота у савременој агрономској индустрији.

Кључне речи: Роботи, системи, примена, агрономија, индустрија.

1. INTRODUCTION

Today, agriculture is facing a complex transformation driven by the convergence of socio-economic and environmental pressures. One of the most critical challenges is acute labor

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shortages, a phenomenon further exacerbated by progressive urbanization, the demographic aging of the rural population, and the deep-rooted social stigmatization of agricultural work. The instability of the labor market – characterized by low wages, poor working conditions, and the seasonal nature of employment – has reached a tipping point during the COVID-19 pandemic, exposing the structural vulnerabilities of traditional production models.

At the same time, the sector is under increasing pressure to achieve environmental sustainability due to its significant impact on climate change and the systemic degradation of natural resources through land, air, and water pollution. These negative trends not only threaten the ecological balance, but are also directly linked to food security issues, posing a direct threat to global social stability. In light of these circumstances, conventional approaches are becoming insufficient, requiring an urgent shift to more resilient systems. In the gap between the reduction of the workforce and the need for precise resource management, the implementation of advanced technological solutions and robotics appears as the primary path for future development.

Despite all the challenges, as mentioned, in the modern agronomic industry, modern systems such as robots are increasingly being applied. Robots today can solve various problems such as:

- Solving the workforce deficit, bearing in mind that the use of robots solves problems with reduced workforce in seasonal jobs and enables continuous work 24 hours a day;
- Reduction of costs, bearing in mind that the purchase of a robot enables an initial large investment that pays off over time;
- Enables targeted spraying, bearing in mind that it is possible to spray only those areas where there are weeds and not the entire length;
- Precise fruit harvesting because they allow the fruit to be harvested without damage, as well as to harvest all the crops;
- It allows for an increase in productivity, considering that they can work non-stop;
- Increasing safety and health at work, bearing in mind that they enable work where workers cannot be injured, and also when spraying plants, pesticides are not inhaled by the workers performing the process,
- Enable data collection in real time for further analysis of production and work; ...

The aim of this work is to analyze the application of robotic systems in the agronomic industry. The work consists of two basic parts or parts. The first part of the paper refers to the application and characteristics of robotic systems that are used in the agricultural industry, that is, in this part of the paper, the market and application of robots is analyzed. The second part of the work refers to specific application, where examples of the application of robotic systems in the agronomic industry are presented and explained.

2. APPLICATION OF ROBOTS AND APPLIED ROBOTS

By analyzing different areas as well as the available literature, Figure 1 came up, which shows data on sold robots for professional use in 2024. It is noticeable that despite the fact that it is not the largest number of robots sold for application in agronomy, it is noticeable that this number is around 10%, which again represents a significant figure and the value of sold robots.

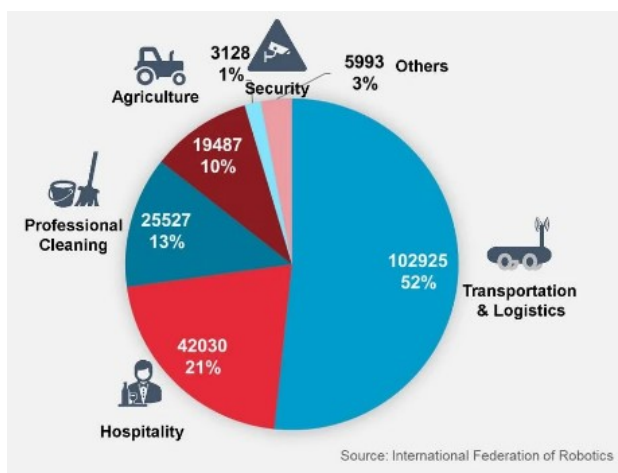


Figure. 1. Application of robots in various fields

Na slici 2 prikazana je analiza i projekcija globalnog tržišta poljoprivrednih robota u periodu od 2020. do 2030. godine, prema podacima agencije Grand View Research. Podaci ukazuju na snažan uzlazni trend sa predviđenom složenom godišnjom stopom rasta (CAGR) od 23,0% u periodu 2025–2030. godine. Analiza globalnog tržišta poljoprivredne robotike u periodu od 2020. do 2030. godine ukazuje na snažan ekspozicioni rast s predviđenom složenom godišnjom stopom rasta (CAGR) od 23,0%, što potvrđuje ubrzanu tranziciju agronomске industrije. Dok segment automatizovane mužnje (Milking) zadržava dominantan udeo zbog rane komercijalizacije, primetan je značajan tržišni uspon robota za upravljanje žetvom, sadnjom i preciznim prskanjem, što direktno korelira s povećanim naučnim interesovanjem za autonomne sisteme zabeleženim u poslednjih pet godina. Ovaj trend, koji projektuje vrednost tržišta daleko iznad 14,7 milijardi USD nakon 2024. godine.

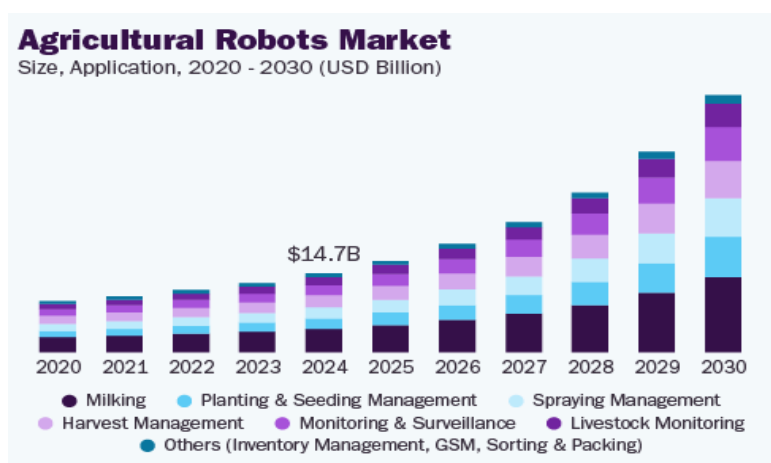


Figure. 2. Application of robots in the agronomic industry

If we look at the scientific papers that were published in the period from 2020 to 2024, it is noticeable that the largest number of works focuses on the navigation of robots that are applied in agronomy. Also, a large number of works focus on the analysis and development

of robots used for product harvesting and harvesting. On the other hand, the biggest increase is research related to crop spraying, planting and sowing of plants, but also the monitoring of crops and plants. For now, the smallest amount of research related to robots to be used in agronomy is related to cropping and pollination of plants. The display of all data is shown in Figure 3.

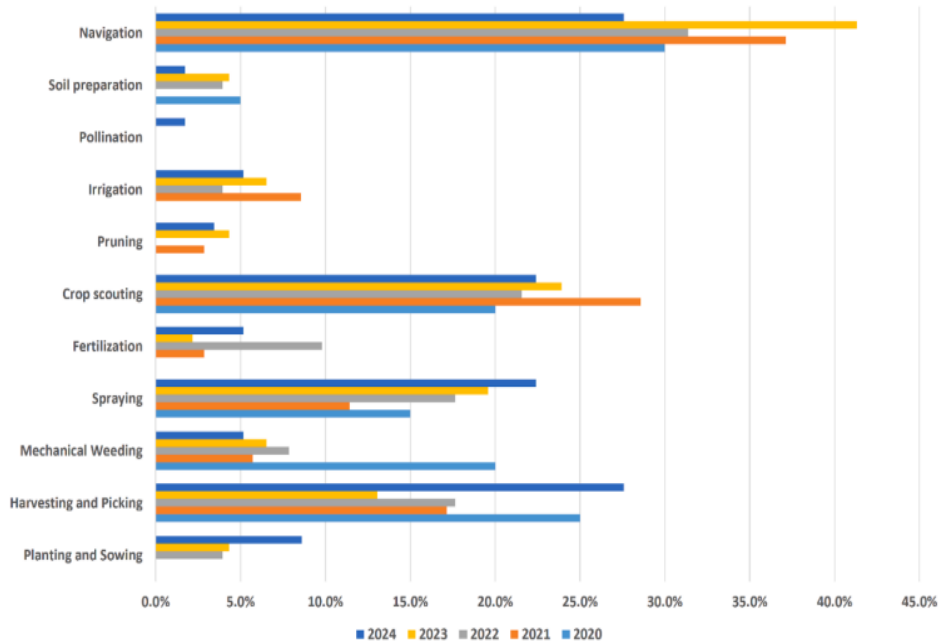


Figure. 3. Frequency of research articles on agricultural operations per year

In one of the studies, commercial robots were analyzed from the aspect of equipment and operations that they can perform. In this study, i.e. machines that are already available on the market - and from scientific sources, which means prototypes developed by research centers and universities. These two categories make up 51% and 39% of all analyzed machines, 3% of robots were developed by startups, while research prototypes and commercial-research hybrids represent 2% and 5% of the total number. This study included a total of 59 robots, of which 11 were from China, 8 from the USA, 7 from France, followed by India, Italy, Spain, Great Britain, ... The most common equipment and sensors they have are navigation equipment (GPS-RTK), RGB cameras that enable plant species recognition, LIDARI for scanning the environment. When it comes to safety, the majority of robots have sensors or other systems that ensure the safety of people around the robot itself to prevent injuries. The analysis conducted in this study identified five main fields of application, namely: vineyards, orchards, open field crops, greenhouses and crops under solar panels. On the other hand, their multiple applications were analyzed, so that the largest number of robots is the type that can be used for only one type of work, the second category is for performing two types of work, and the third category includes the smallest number of robots, where they can be used for only one type of work (Figure 4).

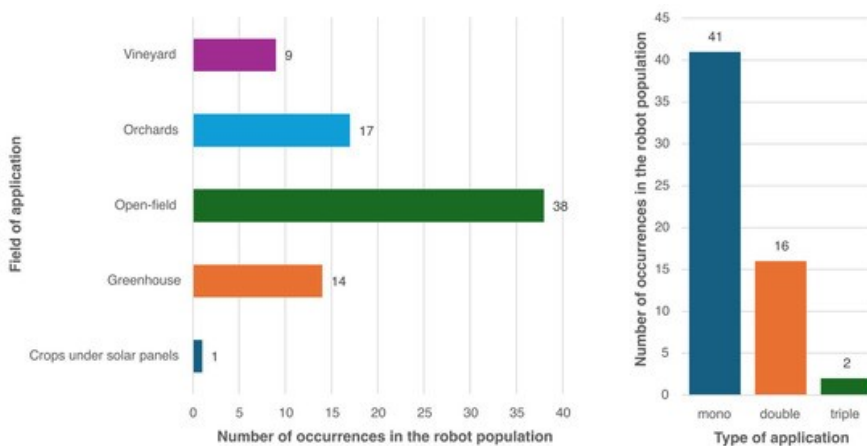


Figure. 4. Number of jobs - operations that robots can perform

3. EXAMPLES OF APPLICATION OF ROBOTS IN AGRONOMY

The application of robots in crop spraying is one of the most important pillars of precision agriculture, because it directly solves the problem of excessive use of chemicals and lack of manpower. Unlike traditional tractor sprayers that uniformly treat the entire surface, robotic systems use a high-tech "see-and-spray" approach. The spraying robots use GPS (RTK) for millimeter precision movement through the rows:

- Reduction of health risks, which is the biggest advantage because it eliminates direct contact of people with toxic chemicals, because the robot performs the operation completely independently;
- Work in difficult conditions because the autonomous systems can work at night or in fog, when the conditions for the evaporation of chemicals are lower, thus increasing the effectiveness of the treatment.



Figure. 5. An example of a plant spraying robot

The use of robots for mechanical weed control and plantation maintenance (Figure 6) is a direct alternative to chemical herbicides. This technology relies on computer vision (Computer Vision) and precise mechanics to remove weeds physically, without damaging the cultivated plant. Advanced robotic units use a variety of intervention mechanisms, including high-precision robotic plucking arms, laser thermo-ablation of weed meristems, or high-voltage electrical pulses. Thanks to the millimeter precision of navigation and sensors, robots enable efficient tillage within the crop row itself, an operation that traditionally required intensive manual work.



Figure. 6. Application of robots in plant maintenance

In modern agronomy, the process of harvesting fruits and vegetables is recognized as a critical point due to the high proportion of manual work and short optimal time frames for exploitation. The development of autonomous picking systems (Figure 7) focuses on solving three basic engineering challenges: identifying ripeness, planning the path of the robotic arm, and preserving the integrity of the fruit. Robotic systems use RGB-D cameras (cameras with depth sensors) and algorithms based on convolutional neural networks (CNN) for fruit detection in complex and inhomogeneous environments. Advanced AI models allow the robot to identify fruits even when they are partially obscured by leaves or branches. One of the key obstacles in harvesting automation is the physical sensitivity of agricultural products. Traditional metal pickers often cause mechanical damage (bruising), which drastically reduces the market value of the fruit. Modern robots use grippers made of flexible materials or silicone that adapt to the shape of the fruit, simulating a human grip. The implementation of pressure sensors on the "fingers" of the robot allows real-time feedback, ensuring that the grip force is sufficient for picking, but below the limit of plant tissue damage.



Figure. 7. Application of robots in the harvesting of plant fruits

Logistics within the field and transportation of the harvested fruits from the harvest site to the warehouse are operations with a high consumption of time and energy. The implementation of autonomous transport robots (ATRs) enables the optimization of these processes by reducing the dependence on the human factor and minimizing soil compaction, as shown in Figure 8. Transport robots use a fusion of sensors, including RTK-GPS, LIDAR and stereo-cameras, to navigate through complex environments such as orchards or greenhouses. The robot identifies the worker (picker) and automatically follows him at a safe distance, serving as a mobile platform for depositing crates. This allows workers to remain focused solely on harvesting, eliminating the need to physically carry loads. Multiple robotic units can work in "swarm robotics", where one robot hands over a full crate to another who transports it to a cold store, while an empty unit returns to the front line. One of the biggest problems of conventional transport is soil compaction due to the weight of tractors and trailers. Thanks to the low center of gravity and all-wheel drive (4WD/4WS), these robots can maneuver in narrow rows where access to standard machinery is impossible, thus increasing the utilization of the cultivated area.



Figure. 8. Application of robots in the transport of plant fruits

4. CONCLUSION

Industry 4.0 has largely entered all branches of the industry, both in other branches and in agro-industry. That's how big the application of robots is today in different areas of agro-industry, thinking about the different jobs that can and are being performed. It is precisely in some of the most critical jobs that robots have found their application. Robots in the agricultural industry have high initial costs, but on the other hand, their application is extremely important when it comes to the health and safety of people. Bearing in mind that e.g. they do not have to expose themselves to work such as spraying which can be very harmful. On the other hand, when e.g. fruit picking can be extremely important when it comes to the safety of the fruits themselves, bearing in mind that they can pick the fruit extremely precisely and with a certain force.

All robotic systems, on the other hand, are equipped with modern sensors that enable monitoring of the robot itself, but also monitoring of the environment for the safety of people. In addition, the robots are equipped with other sensors that enable monitoring of the crops themselves, but the equipment itself and the type of sensor depends solely on the purpose. Robots have found application today in various types of agricultural branches, so today they are used in vineyards, orchards, greenhouses, ...

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SUSTAINABLE DEVELOPMENT OF RURAL AREAS IN THE REPUBLIC OF SERBIA

ОДРЖИВИ РАЗВОЈ РУРАЛНИХ СРЕДИНА У РЕПУБЛИЦИ СРБИЈИ

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Mirko Petković, PhD ³⁶

Abstract: Sustainable development implies the definition of a sustainable development policy and the use of appropriate economic, energy, environmental, and other instruments for the implementation and monitoring of strategic solutions. Rural development represents a highly complex social, political, economic, environmental, and cultural issue, that is, a development issue in a broader sense. Understanding society and its development inevitably requires the analysis of relevant factors that may influence the speed, course, and consequences of social changes in rural areas. The context of rural development requires taking into account the interconnection of different levels of analysis, as well as the significance of the characteristics of rural areas and their populations, which justifies the formulation and application of specific development policies—namely rural, or regional rural development policies. This paper examines in detail the state of rural areas in the Republic of Serbia, the concept of sustainable development in general, as well as the sustainable development of rural environments. In addition, some of the most significant environmental problems faced by such areas will be presented, along with the advantages that rural areas possess.

Key words: sustainable development, rural areas, demography, competitiveness.

Анстракт: Одрживи развој подразумева дефинисање политике одрживог развоја и коришћење адекватних економских, енергетских, еколошких и других инструмената за примену и контролу стратегијских решења. Рурални развој је веома комплексно друштвено, политичко, економско, еколошко, културно... односно развојно питање. Разумевање друштва и његовог развоја неминовно изискује потребу да се анализирају релевантни фактори који могу да утичу на брзину, ток и последице друштвених промена у руралним подручјима. Контекст руралног развоја налаже да имамо у виду повезаност различитих нивоа анализе и значај карактеристика руралних подручја и њихове популације, која заслужује референцирање специфичне политике развоја – руралног, односно, регионалног руралног развоја. У овом раду се детаљно разматра стање руралних средина у Републици Србији, о појму одрживог развоја уопште, али и о одрживом развоју руралних средина. Такође, биће представљени и неке од најзначајнијих еколошких проблема са којима се овакве средине сусрећу, али и предности које руралне средине имају.

Кључне речи: одрживи развој, рурална средина, демографија, конкурентност

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1. INTRODUCTION

In approaching rural development, it is first necessary to acknowledge the view that it represents a long-term social process that differs from previously simplified centralized models of rural development planning. It is closely connected with issues that contemporary social theory seeks to problematize: questions of regional development and decentralization, that is, issues of (neo)endogenous and territorial development; the problem of sustainable development in socio-economic, environmental, and other dimensions; networks of relations among relevant institutions and stakeholders; various strategies of life and work of agricultural holdings and rural households (farming systems); as well as issues related to the level and forms of participation, the role of civil society, social capital, the importance of social inclusion, the fight against (rural) poverty, and similar matters.

Rural development is difficult to define. One of the more comprehensive definitions, in our opinion, was provided by Moseley (Moseley 2003, 4), according to whom rural development is a long-term and sustainable process of economic, social, cultural, and environmental changes designed to increase the long-term well-being of the entire community. Such a definition reveals several key elements of the rural development process. Broadly speaking, it includes several basic dimensions: economic, socio-cultural, environmental, and political (institutional).

In Serbia, the term *rural area* refers to a region whose primary characteristic is the predominant use of land for agricultural production and forestry. If we start from this definition, around 70% of the territory of Serbia can be classified as rural areas. On the other hand, according to the definition of the Organisation for Economic Co-operation and Development (OECD), rural areas are defined as places with a population density below 150 inhabitants per square kilometre. If this definition is taken into account, rural areas cover as much as 85% of the total territory of Serbia, and more than half of the total population lives in these areas. In any case, rural areas concentrate the majority of natural resources, including rich ecosystems and biodiversity, significant forest resources, economic activities, and cultural heritage.

2. THE CONCEPT OF SUSTAINABLE DEVELOPMENT

One of the key characteristics of rural areas, among others, is certainly their heterogeneity in the environmental dimension. The importance of *local* rural development was already highlighted in the late 1980s in a document of the European Commission entitled *The Future of Rural Society*, which pointed to the need for external support (rural development policy) for the endogenous potentials of rural areas. This document emphasizes that: "*Local rural development does not simply mean the implementation of certain measures. It means making the maximum use of all the advantages that a particular rural area possesses: the beauty of space and landscape, high-quality agricultural and forestry products specific to the area, gastronomic specialties, cultural and craft traditions, architectural and artistic heritage, innovative ideas, the availability of labor, industries and services that already exist... all of this should be utilized together with regional capital and human resources, with the idea that what is lacking in terms of capital and coordination, consultancy services, and planning services should be provided to these areas as external assistance*" (EU Communities, 1988, 48).

Development disparities and the demographic picture of Serbia (especially rural Serbia), characterized by migration processes and the demographic growth of a few key urban centers and the inflow of population, the spontaneous creation of transitional zones of suburban settlements, and the demographic passivity and depopulation of rural areas, indicate that these criteria are highly important in the analysis of possible directions and principles of regionalization.

In addition, the question of the possibilities for improving and expanding successful development initiatives can also be considered. From the perspective of regional development, this means that support at the local level should be provided to activities that are: (1) feasible (from the standpoint of existing resources), (2) sustainable, (3) capable of stimulating other (primarily economic) activities in the area, and (4) associated with a range of additional development implications for the wider region. In this context, some authors particularly emphasize that *“rural development requires a regional approach”* (Rauch et al. 2001, 1).

The issue of regional rural development is very clearly linked to territory, which does not necessarily have to be defined by strict administrative boundaries, but rather by functions, a relatively similar and integrated economy, socio-cultural identity, and similar characteristics that constitute its comparative, that is, competitive advantage in relation to other areas—regions. In theory, the concept of *territorial competitiveness* is often used, which, in addition to the economic meaning of "the ability to withstand competition in a market," simultaneously implies ensuring the environmental, social, and cultural sustainability of a particular area. In certain approaches to this issue (Leader 1999, 5), four dimensions of territorial competitiveness are identified: **social competitiveness** (1) – the ability of actors to act successfully together on the basis of shared visions in relation to development projects supported by cooperation between different institutional levels; **environmental competitiveness** (2) – the ability of actors to make the best use of their environment by turning it into a distinctive element of their area, while simultaneously ensuring the preservation and revitalization of their natural resources and heritage; **economic competitiveness** (3) – the ability of actors to create and retain the maximum added value within the area by strengthening inter-sectoral linkages and transforming combined resources into assets that provide advantages aimed at increasing the value and distinctive features of their local products and services; and **positioning in the global context** (4) – the ability of actors to identify the role of their area in relation to other areas and the external world, in such a way as to develop in detail a plan for the development of their territory and ensure its vitality within the global context.

In addition to the basic components of the economic dimension of regional rural development (as one of its primary dimensions), some authors (Rauch et al. 2001, 42) rightly emphasize the improvement of the social protection system for vulnerable rural populations (the elderly, the unemployed, and the extremely poor) as a very important component of economic development, as well as risk management, disaster prevention, and emergency assistance. River overflows, landslides, earthquakes, and similar disasters and natural hazards in Serbia in recent years (e.g., heavy snowfall in 2012, floods in 2014, and fires in 2025) clearly indicate that this component is of great importance in rural development. Neglecting it (that is, neglecting prevention and/or the capacity for an optimal response to such emergency and risk situations, as well as assistance to affected populations) can be extremely dangerous for the economic, environmental, and overall human dimension of social development.

In rural areas, we can certainly speak about resources that go beyond the traditional function of these areas, which is associated with agriculture as an activity and its role in food production. Rural resources or rural “public goods” are not shaped solely by the everyday activities of the agricultural population, but they can be significantly influenced by them (depending on the share of this population and the intensity of agricultural production). In addition to food production, some authors (Bryden, 2006) highlight several other important resources: clean air and water, wind and wave energy, animals, nature and biodiversity, recreational areas, natural beauty and landscapes, culture, archaeology, history, local traditional festivals and other events, local traditional crafts and skills, and similar assets. These goods (created by humans or by nature) “are integrated in a specific way into the new rural economy and the quality of life of the local population through new enterprises, employment opportunities, migration decisions, and similar processes. The nature and functions of these ‘public goods,’ which support the new rural economy and the quality of life in rural areas, are often quite different from those in urban centers (which are guided by an ‘urban regional’ /‘city regions’/ way of thinking)... these goods deserve to be rewarded in a certain way” (ibid.).

2.1 Definition of Sustainable Development

There is no single, universally accepted definition of sustainable development. The most frequently cited definition is the one provided in 1987 by the World Commission on Environment and Development, also known as the Brundtland Commission, established under the United Nations. In its report entitled *Our Common Future*, sustainable development is defined as: “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Brundtland Commission, *Our Common Future*, Final Report of the Brundtland Commission, 1987).

The Brundtland definition of sustainable development includes two fundamental concepts: the concept of needs and the concept of limitations. The first concept refers to achieving or maintaining an acceptable standard of living for all people, while the second concept advocates the use of environmental capacities in accordance with the achieved level of technological development and social organization.

The report of the Brundtland Commission is highly significant for several reasons. First, the concept of sustainable development is understood as meeting present needs without jeopardizing the ability of future generations to meet their own needs. Second, the report highlights the importance of international cooperation, while also pointing to the difficulties involved in achieving such cooperation. Third, the Brundtland Commission emphasized the need to strengthen national environmental agencies, institutions, and organizations. Fourth, the Commission proposed the adoption of a United Nations Programme on Sustainable Development and the organization of an international conference on environment and development.

A comprehensive definition of sustainable development states that: “Sustainable development represents an integral economic, technological, social, and cultural development aligned with the requirements of environmental protection and improvement, which enables both present and future generations to meet their needs and improve their

quality of life” (Report of the United Nations General Assembly on Environment and Development, 1992).

2.2 Dimensions of Sustainable Development

When discussing sustainable development, it can be said that it does not represent merely an environmental issue. It is possible to identify three aspects of sustainable development: (1) economic sustainability, (2) environmental sustainability, and (3) social sustainability. The first aspect implies economic growth and development; the second encompasses the integrity of ecosystems and concern for their capacity and biodiversity; while the third includes values such as equality, empowerment, accessibility, and the participation of individuals in social life.

The dimensions of sustainable development express the fundamental principles of this concept. First, human beings have the right to a healthy and productive life in harmony with nature. Second, states have the sovereign right to use their natural resources in accordance with their own development concepts, but in such a way that they do not cause damage to the environment of other countries. Third, international cooperation is necessary in order to more effectively address environmental problems.

Sustainable development is primarily based on the concept of cleaner production, which includes new methods that should be environmentally cleaner, use significantly less energy, and avoid producing harmful by-products. The aim of this approach is to meet human needs without endangering human life or the ecosystems upon which humanity depends. The main goal of cleaner production is the prevention or reduction of waste generation, as well as the more efficient use of energy and resources. In order to achieve this, it is necessary to adopt new technologies and techniques, together with new values and new ways of meeting the needs of humanity.

3. DIRECTIONS OF SUSTAINABLE RURAL DEVELOPMENT IN CONTEMPORARY CONDITIONS

Sustainable agricultural and rural development implies the preservation of land, water, plant, and animal resources. It must be technically feasible, economically viable, and socially acceptable; in other words, the three pillars of sustainable development previously discussed must be satisfied. It is important to emphasize that the policy of sustainable rural development differs from agricultural policy, that is, it goes beyond it, since it does not relate solely to the development of agriculture but also to the non-agricultural aspects of rural areas.

Sustainable rural development is a very complex concept, especially under contemporary conditions and from the perspective of economic policy makers. It hardly needs to be emphasized how important the proper determination of future directions for the development of villages and agriculture is for the overall socio-economic development of our society. Accordingly, modern policies of sustainable rural development must be based on a territorial and multisectoral integrated approach, the encouragement of networking and the formation of cooperative relationships and partnerships, the promotion of endogenous and mixed development models, the preservation of local identity and social capital while adapting to external changes, and similar principles.

3.1 Rural Tourism and Renewable Energy Sources as Advantages of Rural Areas

In addition to the numerous problems faced by rural areas in Serbia, it is also necessary to highlight the natural beauty and advantages that these regions possess.

The development of rural tourism represents an important challenge for many rural areas in Serbia, particularly when considering their natural and cultural-historical heritage, gastronomy, traditional events and festivals, the hospitality of the local population, as well as many other potentials of these regions. Rural tourism contributes to: providing alternative sources of income for rural households, diversifying the rural economy, reducing unemployment, and revitalizing and promoting the comprehensive development of villages and agriculture. In some parts of the country, rural tourism has already been successfully developing through the integration of tourism, agriculture, and other sectors of the economy. However, due to the very diverse motivations of modern tourists—who demand high-quality services, comfortable accommodation, and a wide range of sports, recreational, cultural, and other entertainment activities—greater investment and the allocation of larger financial resources are still necessary.

The production and use of renewable energy sources (biomass, biogas, biodiesel, solar, wind, and hydropower, etc.) are developing intensively worldwide, primarily ensuring additional income, but also employment opportunities and other economic benefits. Environmental reasons are particularly emphasized as an important motive for the use of such forms of energy.

The energy potential of renewable energy sources in the Republic of Serbia exists, but it remains largely underutilized. Biomass from agriculture in rural areas represents the most significant share of the total renewable energy potential. It is also important to highlight the possibility of using biological waste, that is, organic waste materials. For the production of biodiesel, for example, oilseed rape represents a particularly interesting raw material.

In order to stimulate the wider application of renewable energy sources, it is necessary to create a supportive regulatory framework, subsidize the introduction of appropriate equipment and facilities for the use of these energy sources, provide tax incentives, and educate personnel, given the insufficient knowledge and experience in the production and use of alternative energy sources in our country.

It can be said that only the energy of rivers in Serbia is relatively well utilized, while the use of some other renewable sources still requires considerable development and investment.

4. RURAL DEVELOPMENT POLICY IN SERBIA

Rural development policy in Serbia falls under the jurisdiction of the Ministry of Agriculture, Forestry and Water Management. The Law on Agriculture and Rural Development in Serbia was adopted in May 2009 (*Official Gazette of the Republic of Serbia*, No. 41 of June 2, 2009; No. 10 of January 30, 2013 – other law; No. 101 of December 16, 2016; No. 67 of July 2, 2021 – other law; No. 114 of November 30, 2021; No. 19 of March 6, 2025). In addition to

this law, a whole set of other laws has been adopted addressing specific issues related to rural development, such as the Law on Agricultural Land, the Law on Cooperatives, the Law on Animal Welfare, the Law on Livestock Farming, the Law on Food Safety, and others.

The Law on Agriculture and Rural Development regulates the objectives and implementation of agricultural policy, forms of incentives in agriculture and rural areas, the conditions for exercising the right to incentives, the beneficiaries of incentives, the Register of Agricultural Holdings, as well as the recording and research activities in agriculture and the supervision of the implementation of this Law (*Official Gazette of the Republic of Serbia*, 41/09). Furthermore, this Law establishes the Directorate for Agrarian Payments as an administrative body within the ministry responsible for agricultural affairs.

The most important provisions of the Law in terms of rural development policy relate to the adoption of the Rural Development Programme and the establishment of a new structure of the rural development sector. The department within the Ministry responsible for rural development will be in charge of preparing and amending such future programmes, as well as programming, evaluation, monitoring programme implementation, reporting, coordination, and implementing technical assistance measures for rural development, in accordance with EU requirements.

The implementation of agricultural policy is carried out through the following types of incentives:

1. Direct incentives
2. Market incentives
3. Structural incentives

Direct incentives include: premiums, production incentives, refunds, and support to non-commercial agricultural holdings. Market incentives include: export incentives, storage cost support, and credit support. Structural incentives represent a form of support that includes rural development measures, improvement of the protection and quality of agricultural land, and measures of institutional support.

All the above-mentioned forms of incentives may be determined under different conditions and to different extents, depending on whether they apply to areas with difficult conditions for agricultural activity. These are areas where, due to natural, social, or legal limitations, there are no conditions for intensive development of agricultural production.

The right to use incentives under the conditions established by this Law is granted to agricultural holdings registered in the Register of Agricultural Holdings, units of local self-government, local communities and other forms of local self-government, as well as other persons and organizations in accordance with this Law. The family agricultural holding represents the basic form of organization of agricultural production.

4.1 Rural Development at the Local Level in the Republic of Serbia

In local self-government units in Serbia, Agricultural Support Offices operate in various organizational forms. However, there is no clear connection between the level of development of a particular rural area and the existence of such support offices. Likewise, no clear geographical or regional correlation can be established between rural areas and the presence of these offices.

In most cases, these offices employ only one person, usually a highly educated professional—most often agricultural engineers, veterinarians, or similar experts. A key observation is that with only one employee working in the field of rural development, it is not possible to achieve significant progress in the development of villages or agriculture. The level of financial and professional motivation among these employees is generally quite low. Another major problem is that their job responsibilities are often not clearly defined.

Most local self-government units in Serbia have strategic development plans in which agriculture or rural development is recognized as one of the priorities. However, the main problem with existing strategic plans is that they are not fully developed and do not contain action plans, which makes them largely inapplicable in practice. In most cases, there is also no monitoring or evaluation of the existing plans. Furthermore, many development plans have been prepared without a realistic and detailed assessment of the actual situation in the field, and without a participatory approach during the preparation of strategic documents (Stepanov et al., p. 574, 2016).

4.2 Similarities and Differences between Rural Areas in the Republic of Serbia

Managing rural development in Serbia is a complex issue for several reasons. One of the most striking is that rural areas in the country differ greatly from one another. However, it is very important to recognize that a village and its community should be seen as carriers of potential and societal development—not only through agriculture but also through other activities. On the other hand, the natural and cultural heritage in rural areas has remained relatively preserved, providing a solid foundation on which further rural development can be conceptualized (Stepanov et al., p. 575, 2016).

The terrain in Serbia ranges from volcanic massifs in the south, through limestone mountain chains in the east and west, to the high-quality, fertile plains of the Pannonian Basin in the north.

Through cluster analysis, a typology of rural areas in Serbia has been developed, along with their descriptions, strengths, and weaknesses. This analysis identified four homogeneous groups of municipalities as representative types of rural areas in Serbia (Network for Rural

Development of Serbia, 2010; Action Plan 2011–2015):

1. Highly productive agriculture and integrated economy – Municipalities located in Vojvodina and the northern parts of Serbia along the Sava and Danube Rivers, where high-productivity agriculture is characterized by better farm structures and vertical integration with the agri-food sector.
2. Small urban economies with intensive agricultural activity – This cluster covers rural municipalities along rivers and valleys on main transport routes from Belgrade to Montenegro, Bosnia and Herzegovina, and North Macedonia. These rural municipalities are identified around larger urban centers and offer greater employment opportunities due to a more diversified economy. These areas are referred to as urbanized villages located near major Serbian cities. Market-oriented agricultural production is most intensive here, and the rural economy is diversified.
3. Predominantly mountainous economy oriented toward natural resources – This cluster includes mountainous rural municipalities in southeastern Serbia. It is characterized by lower agricultural productivity, a few industrial activities, tourism

potential, and a higher presence of services. Essentially, this is a rural region with opportunities to utilize rural advantages provided by natural resources, cultural heritage, and the rural environment for tourism development.

4. Large tourism capacity with poor agricultural structure – This cluster, located in western Serbia, has the highest tourism capacity. For example, the number of hotel rooms per 1,000 inhabitants is three times the national average, but agricultural structures are the weakest among all described types. The share of agricultural land and labor productivity is only about half the national level.

The system for planning policies to support the development of agriculture and rural areas in Serbia, in terms of traceability of relevant program documents, can be presented as follows:

1. Law on Agriculture and Rural Development
2. Strategy of Agriculture and Rural Development of the Republic of Serbia 2014–2024
3. National Agriculture Development Program and National Rural Development Program (2018–2020)
4. Annual regulations on the allocation of incentives in agriculture and rural development
5. Strategic and budgetary planning, including EU agreements on the use of IPA funds

(Source: Strategy of Agriculture and Rural Development of the Republic of Serbia for the period 2014–2024, p. 1)

The unevenness of Serbia in regional development is extreme, reflected in rural poverty in the south compared to the relatively developed north. If such heterogeneity persists, it will be impossible to plan a better and more successful future.

4.3 Entrepreneurship and Rural Development

For economic activity in a country to strengthen—and thereby strengthen the country itself—entrepreneurship plays a crucial role. Therefore, emphasis should be placed on promoting entrepreneurship among farmers. This would significantly contribute to strengthening villages and rural areas in Serbia.

The European Union's Common Agricultural Policy encourages entrepreneurship within local communities and rural areas, particularly by supporting innovative initiatives, facilitating knowledge transfer, promoting activities based on local knowledge and resources, and accounting for the specific characteristics of different regions. The European Agricultural Fund for Rural Development provides numerous measures supporting projects aimed at rural entrepreneurship, with approximately 35% of total funds spent on such initiatives during 2013–2019 (EU Rural Development Review, September 2019).

When defining entrepreneurship in the context of rural development, several key elements can be highlighted: creativity, risk-taking and innovative ability, responsibility for resources, and the dynamic process of creating something new. Entrepreneurship is thus defined as a force that mobilizes other resources to meet unmet market demand and the ability to create and build something practically from nothing (Gajić, M., et al., 2000).

For these measures to be effective, support from both national and local institutions is essential. The state must create an environment through its institutional capacity in which entrepreneurs can be most effective, and through actions affecting the broader environment, conditions can be created for the parallel development of villages and entrepreneurship (EU Rural Development Review, 2019).

To this end, the Serbian Academy of Sciences and Arts (SANU), at the scientific conference “*Perspectives of Village Development in Serbia*” held in April 2013, issued several conclusions forwarded to relevant state authorities. Some of these recommendations concerning the development of agriculture in villages are (EU Rural Development Review, 2019):

- Relevant state authorities should, in practice, give greater consideration to proposals from appropriate scientific institutions regarding sustainable village and agricultural development. To this end, these institutions should be reorganized and modernized, including financial and staff consolidation and technical equipment. For the conceptualization of institutional reforms and the development of mid- and long-term strategies for village and agricultural development in Serbia, the National Assembly established a Ministry for Village and Agriculture as a cross-party, independent, and competent body whose expert opinions and legislative proposals significantly influence the existing strategy and ongoing agricultural policy measures.
- Structural adaptation of Serbian agriculture to modern sustainable development primarily involves: 1) technical organization of arable land and consolidation of holdings where possible; 2) regulation of watercourses; and 3) horizontal and vertical organization of farmers.
- Stronger material support from the state is necessary for cooperative forms of organization, strengthening technical, technological, and IT capacities of cooperatives, and especially financial support for securing qualified staff to overcome challenges in existing cooperatives and establish new ones, prioritizing highly skilled, cooperatively oriented personnel.
- Population policy in rural areas should be based on appropriate economic, agricultural, regional development, and cultural policies, fundamentally different from previous approaches that pushed young people out of villages and agriculture. In this context, it is necessary to improve the extremely unfavorable position of agriculture relative to industry, transition to a decentralized model of industrialization and urbanization, invest more in transportation and communal infrastructure in rural areas, improve social security, and modernize education and cultural awareness for young farmers.
- Beyond general education and schooling in rural areas, the professional training of farmers is critical for development. This should primarily be supported through systematic state support of agricultural scientific institutions and the creation of a network of advisory centers to transfer practical expertise in modern agriculture, employing agronomists of various specializations, veterinarians, and similar professionals (SANU: <http://www.sanu.ac.rs/Inicijative/2013OdborZaSelo>).

Infrastructure is key in villages with young people, as it reduces isolation, helps retain young residents, and accelerates the economic development of rural areas.

5. SUSTAINABLE RURAL DEVELOPMENT IN SERBIA

Sustainability is a relatively recent concept. As the term itself implies, it represents the capacity to endure and persist. Today, this term is frequently used in various contexts, giving rise to expressions such as sustainable growth, sustainable economy, sustainable society, sustainable agriculture, and so on. In fact, the concept of sustainability is difficult to explain when used outside a specific context, so in this section, we will attempt to explain it through the lens of rural development in Serbia.

By its very nature, sustainable agriculture is opposed to efficient intensive agricultural production, which relies on the exploitation of the productive capacities of land, plants, and animals, all in pursuit of low prices without accounting for the damage to the environment.

Today, sustainability is no longer a matter of choice but a matter of necessity. If sustainability is properly understood and applied, there is the potential to transform the deficiencies of rural Serbia into certain advantages. Progress and sustainable development in our country must begin with the rehabilitation of a sustainable way of life, meaning the full recognition of traditional, ethnically based knowledge, skills, norms, and institutions. Only through such an approach can a non-violent process of negotiation regarding future economic and environmental rights and responsibilities among various stakeholders begin.

Rural development in Serbia also largely depends on the strengthening of awareness among people that primary agricultural production and the exploitation of natural resources alone cannot sustain the rural economy at an acceptable level (Šunjka, Stepanov, 2018).

5.1 Actors in Sustainable Rural Development in Serbia

Organizations and institutions that play a significant role in the policy and strategy of rural development, as well as its implementation at the national level, include various ministries and government bodies, led by the Ministry of Agriculture, Forestry, and Water Management, which holds primary responsibility for rural development. Other ministries with a direct interest in rural development include those responsible for economy and regional development, finance, infrastructure, education, environment, labor and social policy, tourism, local self-government, among others. National agencies and bodies responsible for small and medium enterprise development, infrastructure, environmental protection, development funds, poverty reduction, etc., also play an important role in rural development. Additionally, institutions such as Chambers of Commerce, the Standing Conference of Towns and Municipalities, tourism organizations, and various academic institutions contribute to the rural development process.

At the local level, actors include civil society organizations, citizen associations, business associations, farmers, tourism organizations, retail businesses, the wood industry, and other representatives of local communities.

Significant differences between rural areas often result from the varying strength of citizen associations in those regions. Some areas have active associations that enjoy certain advantages in terms of the capacity of the rural population to take initiative and play an active role in improving the entire region. On the other hand, other regions have weakly developed civil society, mainly due to centralized governance.

The role of the non-governmental sector in rural development in Serbia remains limited. Only a small number of organizations are truly focused on comprehensive rural development, although many have the capacity and interest to engage in rural development initiatives. These are primarily environmental and social organizations, farmer associations, and initiatives related to rural development and education.

5.2 European Union Support for Rural Development in Serbia

Almost all of us expect that all our problems, including environmental ones, will be resolved through the country's accession to the EU. However, this transition is far from simple and, in fact, requires the opposite: that all problems must be addressed for the country to join the EU. Rural development, as one of the most complex issues of the transition, is an area that requires special attention.

The enormous funds that candidate and potential candidate countries expect during the pre-accession period also include access to national funds, which serves as tangible evidence of the recognition that rural development is indeed a national priority. To this end, the European Union adopted a Council Regulation encompassing five components:

1. Assistance in the process of transition and institution building
2. Support for cross-border cooperation
3. Assistance for regional development
4. Support for human resource development
5. Assistance for agriculture and rural development (Popović, Nikolić, 2014).

Until Serbia received candidate country status at the end of 2011, it could only use the first two components, while today it is entitled to all five.

In order to utilize the available funds, the country must create appropriate capacities and fiscal space. Experience from many countries shows that timely and proper public information represents an important tool for generating demand for pre-accession funds.

6. CONCLUSION

Sustainable rural development is one of the economic, social, and environmental priorities in contemporary society. For this reason, the European Union provides strong support for social and territorial cohesion of rural areas and seeks to ensure more efficient valorization of local development potentials in accordance with the principles of sustainable development. At the same time, it is essential to preserve and enhance the economic, cultural, social, and environmental functions of rural communities, especially considering that rural communities in the Republic of Serbia have been facing numerous structural and socio-economic challenges for decades.

The sustainable development of rural areas in Serbia largely depends on the activities of all key development actors at all levels, as well as on the proper identification of strategic development directions and their practical implementation in line with contemporary market challenges that cannot be avoided.

The survival and rehabilitation of small-scale agriculture represent tasks of crucial importance for the sustainable development of rural Serbia. This agricultural production provides ecosystem services to various rural areas of Serbia and is vital for the preservation of biodiversity.

The rural economy should be adapted to available natural resources, and logic dictates a return to a range of diverse activities that reconnect rural communities with their immediate environment in a traditional way. For this reason, local communities need to be interested and actively participate in the decentralization process.

Based on all of the above, it can be concluded that Serbian villages are currently at a crossroads between disappearance and survival. The process of rural degradation is very intensive and manifests itself in various forms. To halt these negative trends in Serbian villages, a new and proactive rural development policy is required. Villages are no longer merely production regions but also places for living, residence, leisure, tourism, and recreation. European experiences should serve as lessons in rural development policy, which must be adapted to local resources and initiatives.

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METHOD FOR CALCULATING INTEGRAL INDICATORS OF ECOSYSTEM STATUS BASED ON THE CHARACTERISTICS OF BIOLOGICAL OBJECTS

МЕТОД РОЗРАХУНКУ ІНТЕГРАЛЬНИХ ПОКАЗНИКІВ СТАНУ ЕКОСИСТЕМИ НА ОСНОВІ ХАРАКТЕРИСТИК БІОЛОГІЧНИХ ОБ'ЄКТІВ

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Abstract: Natural and anthropogenic factors affect biological organisms through multiple pathways. The strength of their influence also varies greatly. However, to identify negative impacts, the biological organism (BO) itself can serve as a measurement tool. The paper proposes to use the characteristics of biological objects (in particular, mass) as integral indicators of the impact of the environment on the ecosystem. Integral indicators take into account the presence of stochastic changes in environmental characteristics, as a result of which a method for calculating the distribution of biological objects by their masses is given. Formulas are given for finding model coefficients from experimentally measured characteristics.

Key words: biological organism, environment, impact, integral indicator, distribution by masses.

Анотація: Природні та антропогенні фактори впливають на біологічні організми кількома шляхами. Сила їхнього впливу також дуже різниться. Однак для виявлення негативного впливу сам біологічний організм (БО) може служити інструментом вимірювання. У статті пропонується використовувати характеристики біологічних об'єктів (зокрема, масу) як інтегральні показники впливу навколишнього середовища на екосистему. Інтегральні показники враховують наявність стохастичних змін характеристик навколишнього середовища, в результаті чого наведено метод розрахунку розподілу біологічних об'єктів за їх масами. Наведено формули для знаходження модельних коефіцієнтів за експериментальними характеристиками.

Ключові слова: біологічний організм, навколишнє середовище, вплив, інтегральний показник, розподіл за масами.

1. INTRODUCTION

Within the framework of ecology, the main attention is paid to the study of the relationship between a biological organism (BO) and the environment at the levels of both individual organisms and their aggregates. The use of the entire BO as a single whole or a given set of BOs as a detector of the influence of the external environment seems promising. In this case,

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there is a need to find parameters that could most informatively indicate the specifics of the interaction of the BO and the environment.

The work is devoted to the development of a method for using the distribution function (probability density) of BOs by mass as a characteristic of the degree of interaction between a system of homogeneous BOs and their environment. The BOs themselves are considered at the level of a set of individual whole organisms. They can be both unicellular and multicellular, both plants and animals.

This allows us to simultaneously take into account the factors of influence on the biological community of both natural and anthropogenic origin. In this case, it is possible to identify such characteristics of the distribution function that correspond to the “reference” state of the environment. (Shiyan, 1997) Then it will be possible to whiten the contribution of anthropogenic factors at the level of the “reference” state of the environment.

Using populations of unicellular organisms, it will be possible to study the influence of human anthropogenic activity on the functioning of the genome. Since the generations of unicellular organisms change quite quickly, the methods described below will allow us to predict changes in the genomes of multicellular biological communities. As a result, this will allow us to take proactive measures to counteract the negative impact of factors of various natures and ensure the sustainable and safe existence of biological communities (including humans).

The importance of such a characteristic as mass for ecological problems is evidenced by the widespread use of allometric formulas that express the dependence of morphological or functional characteristics of BS on their mass. (Peters, 1991; Zaika, 1983) The appearance of the distribution of BO by mass is due to the influence of both variability (fluctuations) in trophic chains and fluctuations in environmental parameters. For example, for plants, this may be fluctuations in illumination or temperature, for animals, this may be due to the variability of the characteristics of the food base. For predators, this is especially obvious, since the hunting process itself is stochastic. Some of the BOs - e.g., animals - due to their motor activity are natural “averagers” of fluctuations in the spatial characteristics of the external environment (which are manifested primarily through the spatial distribution of food). Diversity in the phenotypic manifestation of the genotype leads to the fact that there will be an optimum for the search (food) motor activity of animals. Therefore, a component caused by this will also appear in the distribution of BO by mass. When the environmental conditions change, the characteristics of such an optimum will also change, and therefore the parameters of the experimental mass spectra of $P_e(m)$.

In the general case, the distribution of BO by mass can be represented as a superposition of two (generally speaking, nonlinear) components: a constant component caused by genotypic features, which is manifested in the phenotype (both at the morphological and functional levels), and a variable component caused by the influence of environmental variability.

2. QUANTITATIVE DESCRIPTION OF THE CHARACTERISTICS OF THE DISTRIBUTION OF BO BY MASS

Following (Shiyan, 1997), we describe a class of models that can be used to quantitatively describe the parameters of the distribution of BO by mass.

The dynamics of the change in the mass of a single BO can be described by the equation.

$$\frac{dm}{dt} = cm^a - dm^b, a < 1, a < b \quad (1)$$

Here, a , b , c , and d are some parameters that characterize this type of BS (Shiyan, 1997; Zaika, 1983)

For example, for hydrobionts (Zaika, 1983): *Artemia salina*: $a=2/3$, $b=1$, $c=0.27$, $d=0.182$ (m – measured for dry mass, t – day); *Orchestia bottae*: $a=3/4$, $b=1$, $c=2.304$, $d=0.0572$; *Xatho hydrophilus*: $a=0.773$, $b=1$, $c=9.24$, $d=0.0176$ (the last two: m – measured for wet mass, t – day).

The first term on the right in (1), $Q = cm^a$, corresponds to the rate of mass gain due to food consumption, with the coefficient a being found experimentally and assumed to be constant for individuals of a given population. (Zaika, 1983) The coefficient c is proportional to the so-called food digestibility coefficient (Zaika, 1983) (i.e., the ratio of digested food to consumed food) and therefore can fluctuate due to reasons both genetic (e.g., individual variability in the degree of food digestibility) and those caused by the variability of the external environment (determining, e.g., the amount of food consumed itself).

The second term, $R=dm^b$, expresses the rate of energy expenditure for life support in the BO and energy expenditure with respiration, (see Peters, 1991; Zaika, 1983; Ecological systems, 1986) with the coefficient b , like a , also assumed to be constant and characterizes the BO of a given population.

In general, the hierarchical and fractal structure of the BO should find its expression in the parameters a and b . The fractal properties of the BO are revealed, for example, in the dependence $m=kL^n$, where L is the characteristic linear dimensions of the BS itself or its organs, $k=const$. Thus, for the squid *Stehonoteuthis pteropus*, we have (Zaika, 1983) $m=0.0199L^{3.766}$, where m is the raw mass, and L is the length of the mantle. Note that equation (1) is invariant with respect to the group of transformations $m=kL^n$ at $n>0$, the relations obtained in the work will also be valid for L .

The values $a=2/3$ and $b=1$ are most often used to process experimental data on the growth of BO (see, (Zaika, 1983) where extensive material on hydrobionts is given)). It should be noted that, probably due to the fractal nature of the indices a and b , attempts to assign a clear biological meaning to the parameters a , b , c , and d have so far been unsuccessful (see, e.g., Zaika, 1983).

Thus, for the population under study, a and b can be considered constants. The parameter d is part of the complex that describes the process of respiration - the oxidation of protein compounds to the simplest forms, which occurs almost the same in all individuals of the population, and therefore we can put $d=const$ (e.g., this assumption is characteristic of coenosis that exist at a constant temperature).

The parameter c , as indicated above, has a fluctuation component caused by the variability of the external environment, and therefore (1) should be written in the form of a stochastic equation.

The parameter c , as indicated above, has a fluctuation component caused by the variability of the external environment, and therefore, (1) should be written in the form of a stochastic equation.

$$\frac{dm}{dt} = \lambda m^a - m^b + \xi_t \cdot m^a \quad (2)$$

Here $\tau=dt$, $\lambda=c_0/d$, $\xi_t=(c_t/d)/_{t=\tau/d}$. The value $c_0=const$ specifies the average rate of mass gain due to food consumption, and c_t is determined by the variability of both the phenotype and the external environment.

The specificity of (2) is given by the type of noise ξ_t . Since $a < b$, the stationary state is always achieved. Then in the general case, equation (2) can be characterized by the time-dependent probability density of the mass distribution $P(m,t)$, which tends to the stationary $P_s(m)$ over time. (Horsthemke, Lefever, 1984)

Next, we consider the analytically exactly solvable case when the fluctuations ξ_t are white noise of intensity $\langle \xi_t^2 \rangle = \sigma^2$. This approximation correctly describes the main contribution of short-correlated external actions (Horsthemke, Lefever, 1984) (both temporal and spatial - in the latter case, such an approximation can be justified with spatial sampling of the BO and the interpretation of the experimental distribution $P_e(m)$ as a characteristic of the entire region from which the BOs are sampled).

From (2) one can construct the Fokker-Planck equation for the distribution $P(m,t)$ in the Stratonovich interpretation corresponding to our case, (see Horsthemke, Lefever, 1984) the stationary solution of which is as follows.

$$P_s(m) = \frac{N}{m^a} \cdot \exp \left[\frac{2\lambda m^{1-a}}{(1-a)\sigma^2} \left(1 - \frac{1-a}{\lambda(b+1-2a)} \cdot m^{b-a} \right) \right] \quad (3)$$

Here, N is the normalization constant.

The extremes of the probability density are found as solutions to such an equation.

$$\lambda - m^{b-a} = \frac{1}{2} a \sigma^2 m^{a-1} \quad (4)$$

It is easy to see that for $\sigma^2 < \sigma_c^2$, where

$$\sigma_c^2 = \frac{2}{a} \cdot \left(\frac{\lambda}{y^x + y^{x-1}} \right)^{\frac{1}{x}}, y = \frac{1-a}{b-a}, x = \frac{1-a}{b+a-2a} \quad (5)$$

the probability density $P_s(m)$ has a maximum and a minimum, and for $\sigma^2 > \sigma_c^2$ it decreases monotonically. This behavior of the probability density is called a noise-induced transition. (Horsthemke, Lefever, 1984)

Expression (3) can be rewritten in self-similar form with respect to the deterministic (“definitive” - in the terminology of (Zaika, 1983)) value of mass $m_0 = \lambda^{1/(b-a)}$:

$$P_s(M) = \frac{N(m_0, \alpha)}{M^a} \cdot \exp \left[\frac{a(y^x + y^{x-1})^{\frac{1}{x}} \cdot M^{1-a} \alpha^2}{(1-a)} \left(1 - \frac{1-a}{b+1-2a} \cdot M^{b-a} \right) \right] \quad (6)$$

where indicated $M = m/m_0$ i $\alpha^2 = \sigma_c^2 / \sigma^2$, and

$$N(m_0, \alpha) = A(\alpha) \cdot m_0^{a-1} \quad (7)$$

$$A^{-1}(\alpha) = \int_0^\infty dM \cdot M^{-a} \cdot \exp \left[\frac{a(y^x + y^{x-1})^{\frac{1}{x}} M^{1-a} \alpha^2}{(1-a)} \left(1 - \frac{1-a}{b+1-2a} M^{b-a} \right) \right]$$

3. INTERPRETATION

Using (3)–(7) of the experimentally measured $P_e(m)$, the following characteristics can be determined. First of all, for given (known) values of a and b , σ_e^2 and m_0^e can be determined, which will allow us to conclude both the nutritional value of a given environment and the degree of intensity of the adaptive capabilities of a given type of BO for given properties of the environment. The latter can be described by the complex $\alpha^2 = \sigma_c^2 / \sigma^2$, the numerical value of which can be found from □2e and $m_0^e = \lambda_e^{1/(b-a)}$ (see (5)) and which invariantly characterizes the structure of the mass distribution $P_s(m)$. Note that since the distribution $P_s(M)$ in the form of (6) is determined only by the values of a and b , it becomes possible to compare the sensitivity to external actions for different types of BO, but in which the values of the parameters a and b are equal.

The variability of the parameters of the external environment can be considered as containing fluctuation parts with intensities $\sigma_i^2 = \langle \xi_i^2 \rangle$ for the i -th parameter characterizing the external environment (assuming, of course, that the correlation time of such fluctuations is negligible and therefore they can be approximated by white noise). While as a model relation connecting the degree of mass variability σ_e^2 with the vector $\hat{\sigma}^2 = \{\sigma_i^2\}_{i=1}^N$, the formula can be used

$$\sigma_e^2 = \sigma_g^2 + \sum_{i=1}^N A_i \sigma_i^2 = \sigma_g^2 + \langle \hat{A}, \hat{\sigma}^2 \rangle \quad (8)$$

Here, σ_g^2 characterizes the distribution of CO masses due to the genetic heterogeneity of the population. This value can be measured, for example, either in laboratory conditions or by taking some ecosystem — e.g., in a certain reserve — as a “standard” (note that for genetically homogeneous populations — e.g., cohorts of plants — it is expected that the value σ_g^2 is negligible compared to the rest of the values in (8)). The vector $\hat{A} = \{A_i\}_{i=1}^N$ characterizes the “sensitivity” of the distribution of masses of a given CO type to the intensity of fluctuations in the corresponding environmental parameters (e.g., hydrobionts have a

pronounced sensitivity of the parameter to changes in environmental temperature (Zaika, 1983)). As a rule, the sensitivity vector $\hat{A}$ can be found in laboratory conditions, and then the relation (8) can be used to experimentally find the vector $\hat{\sigma}^2$ for a previously studied BO type (which opens up new possibilities in environmental monitoring). Interestingly, the proposed method of interpreting experimental data allows us to distinguish several types of different ecosystems in a given area - provided that there is a corresponding number of peaks in the experimentally obtained $P_e(m)$.

The relation (8) is qualitatively consistent with ecological data. (Shiyan, 1997)

Thus, the mass spectrum of BO (the probability density of the distribution of BO by mass) can serve as an important integral characteristic of the influence of the external environment on biological organisms in the ecosystem.

An important circumstance is that factors of both natural and anthropogenic origin are simultaneously (integrally) taken into account here.

Moreover, using microorganisms that have a short generational change period, it is also possible to study the manifestations of changes at the genetic level.

This method can also be used to develop new indicators of a medical nature. For example, in (Shiyan, 1999) the above method was used to quantitatively describe the size distribution indicators for the system of lymphocytes, both single and their aggregates.

Experimentally, the parameters of model (1), a , b , c , and d , can be found as follows. The first term in the differential equation (1) describes the intensity of the increase in the number of BO mass, and the second term describes the limit on the increase in mass.

Therefore, at the stage of mass growth, when the second term in (1) is small and can be discarded in the first approximation, the increase in the number of supporters can be described by the following formula.

$$m = \frac{m_0}{[1 - m_0^{1-c}(1-c)at]^{1/(1-c)}} \approx m_0(1 + m_0^{1-c}at), \text{ if: } m \ll M. \quad (9)$$

Here, m_0 is the initial mass.

From (9) it is clear that to fulfill the requirement of the growth of the number of supporters, it is necessary that the requirement $0 < c < 1$ is fulfilled. The last approximation is valid when the condition $m_0^{1-c}(1-c)at \ll 1$, is fulfilled, that is, for small values of the observation time.

It is possible to experimentally determine the quantitative values of the quantities a and c from the experimental data, using, for example, the method of least squares. Of course, the conditions specified in (9) must be fulfilled.

The quantitative values of the characteristics of the term in (1), which are responsible for limiting the growth of the mass (which occurs under the condition $m_0 > M$), can be found from the following relation.

$$m = \frac{m_0}{[1+m_0^{d-1}(d-1)bt]} \approx m_0(1 - m_0^{d-1}bt), \text{ if: } m_0 \gg M. \quad (10)$$

From (10) it is clear that to fulfill the requirement of mass reduction, the relation $d > 1$ must be fulfilled. The last approximation is valid when the condition $m_0^{d-1}(d-1)bt \ll 1$, is fulfilled, that is, at small values of the observation time.

Relations (9) and (10) can be used at the beginning of the change in the initial mass of the BO, revealing the quantitative values of the parameters that are specific to it.

The coefficient a can also be found from the ratio between the mass and lifespan of given BOs.

We give a summary, following the article. (Alexander, 1971)

Problems related to the lifespan of living organisms have both clearly expressed fundamental and applied aspects. Among the first, one can single out a range of problems related to the identification of the causes that limit the life of animals, but there are more than 300 hypotheses that cannot yet link this parameter with any physical factors. The importance of such a parameter for applied problems is due primarily to the fact that the productivity of living organisms can be expressed in terms of their lifespan: for example, for hydrobionts, this dependence has the form $C = kT^n$, where C is the specific productivity of animals, T is their lifespan, $k > 0$, and $n > 0$ are coefficients.

Recently, a large amount of material has shown the existence of a close correlation between the lifespan T and mass for a large number of species of living organisms, both plants and animals. However, the reasons leading to this correlation remain unclear.

Method.

We will proceed from the equation for the evolution of the mass of living organisms, accepted in modern biology, written in the form (1).

Equation (1) allows us to introduce the concept of the “definitive” mass for these living organisms m_0 , which is found from the stationary solution (1) as

$$m_0 = \left(\frac{c}{d} \right)^{\frac{1}{b-a}} \quad (11)$$

Obviously, the value of the definitive mass m_0 is achievable only when $b > a$ - we will consider this relation to be fulfilled in the following.

As a rule, the “initial” (e.g., after birth for mammals) and definitive masses for living organisms are related by the relation

$$m_{\text{nat}} \ll m_0 \quad (12)$$

Therefore, the characteristic time τ_0 required to reach the definitive mass can be estimated as

$$\tau_0 = \frac{m_0^{1-a}}{(1-a)c} \quad (13)$$

In fact, the time τ_0 represents a characteristic (but not complete) growth time of these living organisms - it is at this time that their most intensive growth continues.

If we accept the following Assumption (A):

The life span T for living organisms is directly proportional to the characteristic time τ_0 required to reach their definitive mass,

then we arrive at the relation

$$T = A m^p \quad (14)$$

where indicated

$$p = 1 - a \quad (15)$$

4. RESULTS AND DISCUSSION

Assumption (A) actually means that the natural discrete quantity for measuring the lifespan T of living organisms is the characteristic duration θ of the stage of their ontogenesis. This is supported by the fact that the characteristic periods of the initial physiological cycles of mammals and birds are presented in the form (5) with an exponent practically coinciding with p . (Alexander, 1971; Lindstedt, Calder 1981)

It is also interesting that the assumption about the relationship of the dependence of the form (14) between the lifespan of eukaryotes and the mass of living organisms, expressed in, (Metelsky, 1995) finds its direct confirmation in formula (6).

Assumption (A) also leads to the following relation for pre-exponential factors

$$\frac{T}{\tau_0} = A \cdot c = Q \quad (16)$$

where $Q = \text{const}$, and in the general case, can depend on the type of living organisms. The relation (16) can be naturally identified with the number of complete cycles of "renewal" in the life process. Such an interpretation of the institution provides ample opportunities for achieving the highest possible interpretation with existing models for aging mechanisms and allows us to propose new multi-valued approaches for processing experimental data (this will be described in more detail in a separate paper).

In, (Metelsky, 1995) based on extensive experimental material, the value $p=0.3$ in expression (14) was found. This value corresponds to $a=0.7$, which is close to the value $a_{\text{theor}}=2/3$ proposed by Bertalanffy. (Zaika, 1983)

Thus, the available experimental information on the numerical values of the parameters a and p , summarized by independent methods, allows us to verify the conclusion (15) we have drawn. The data in the table indicates the good performance of this system. Some explanations of the table are given below.

Table 1. Testing the fulfillment of the relation $p=1-a$ from. (Shyian, 2022)

N	Groups of living organisms	a_{exp} , [source]	p_{theor} , calculation from $p_{theor}=1-a_{exp}$	p_{exp} , [source]
1.	General to the superkingdom of eukaryotes	$0,78 \pm 0,08$ ^{*38}	0,22-0,08	0,30-0,02 ³⁹
2.	General for plants	$0,77 \pm 0,09$ ⁴⁰	0,23-0,09	0,29-0,03** ⁴³
3.	Animals	0,76 *** ⁴⁴	0,24	0,27-0,01**** ⁴³
4.	Mammals (except primates)	0,898 ⁴¹	0,102	----
5.	Primates	0,787 ⁴⁵	0,213	----
6.	Brood birds	0,75 ⁴⁵	0,25	0,206-0,064 ⁴² [0,25-0,03 ⁴³
7.	Nestling birds	0,861 ⁴⁵	0,139	0,13 < $p_{эксп} < 0,15$ ⁴³
8.	Insects	$a_{exp}=1-p_{эксп}=0,61 \pm 0,08$	---	0,39-0,08 ⁴³

Note:

* - obtained under the assumption that the growth rate of living organisms is proportional to their effective surface area;

** - trees and shrubs;

*** - poikilothermic animals;

**** - animals in general.

In conclusion, we note that the relation (6), which relates the power indices depending on the mass for various morphological and functional characteristics of living organisms, is probably one of the few in modern biology.

5. DISTRIBUTION OF BO BY LIFE SPAN

For a given biological species, as noted above, we can set $Q=const$. Then the variability of the parameter A , which is included in the relations (14) and (16), within a given biological species will be due only to the variability of the coefficient, which determines the intensity of the mass gain process. The presence of variability in A is evidenced, for example, by the results of experimental data. (Gavrilov, 1995) It is interesting that the variability in the social

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³⁹ Metelsky S. T., (1995). Relationship between the life span of eukaryotes (animals and plants) and some of their physical characteristics. Journal of General Biology. V.56, N 6. p. 723-735.

⁴⁰ Alimov A. F., (1992). Characteristics of populations, communities of hydrobionts and mass of animals. Reports of the Russian Academy of Sciences. V.323, N3. p. 588-591..

⁴¹ Zaika V. E., (1983). Comparative productivity of hydrobionts. Kyiv: Naukova Dumka.

⁴² Gavrilov V. V., (1995). Association of maximum lifespan with social organization in free-living waders (CHARADPII, AVES). Journal of General Biology. V.56, N5. p. 529-538.

organization of waders studied in (Gavrilov, 1995) is directly reflected in the peculiarities of chick feeding - and, therefore, leads to variability in the coefficient (we note that significant differences in A were observed precisely in such social structures that differed in the feeding regimes of chicks).

Taking this into account, instead of (1), we arrive at the stochastic equation (2) to describe the dynamics of the mass of living organisms of a given biological species

The analytically exactly solvable case of white noise leads to formula (2).

Equations (1) – (2) are invariant with respect to the group of transformations $m=kT^{1/p}$, where $k>0$ and $p>0$ are some constants. This means that the form of the distributions (3) is also preserved for the distribution by lifetime T , but with changed parameter values.

Thus, for the distribution of living organisms of the same biological species by life time using relation (6) we obtain the formula

$$P_s(T) = N_2 \cdot \exp \left\{ \frac{2T}{T_0 \cdot \sigma_T^2} \left[1 - \left(\frac{T}{T_0} \right)^{\frac{b+p-1}{p}} \cdot \frac{p}{b+2p-1} \right] \right\} \quad (17)$$

where N_2 is a normalized factor, and σ_T^2 is the dimensionless noise intensity, T_0 is the “definitive” (by analogy with mass) life span for a given biological species, and b is the power exponent in equation (1) for the mass dynamics of living organisms of this biological species (since $b=1$ is often assumed, (Zaika, 1983) the distribution (17) degenerates into a Gaussian distribution).

It would be extremely interesting to compare formula (17) with experimental data. Note that the derivation of this formula implements an example of a transition from a distribution according to one morphological or functional characteristic of living organisms to another.

6. CONCLUSION

The paper proposes to use the characteristics of biological objects as integral indicators of the impact of the environment on the ecosystem. Integral indicators take into account the presence of stochastic changes in environmental characteristics, as a result of which a method is given for calculating the distribution of biological objects by their masses. Formulas are given for finding the model coefficients by experimentally measured characteristics.

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THE ORGANIZATION AS A FUNCTION OF STRATEGIC MANAGEMENT, TOWARDS A SUSTAINABLE AND EFFICIENT TOBACCO PRODUCTION PROCESS

ОРГАНИЗАЦИЈАТА КАКО ФУНКЦИЈА НА СТРАТЕГИСКИОТ МЕНАЏМЕНТ, ВО НАСОКА НА ОДРЖЛИВ И ЕФИКАСЕН ТУТУНОПРОИЗВОДСТВЕН ПРОЦЕС

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Abstract: Organization is a managerial function that defines the role of the individual in the organizational structure and provides the inflow of necessary funds, i.e. resources, to create a complete functional whole, which will enable the proper operation of all segments of activity. Organizing is a phase in managerial work, necessary to create favorable conditions for the work of successful teams. By forming the organizational structure, the tasks that employees should perform must be defined, according to their ability and motivation. It is necessary to systematize organizational units and, if possible, provide a description of each job, thereby creating an administrative management scheme. The organizational structure does not only serve to determine positions between the people covered by it, it has many more effects on the communication, functioning and effectiveness of the various business functions in the business itself. Good organizational setup and coordination is of primary importance in all spheres of social life and functioning, including agriculture and of course tobacco production in all its phases. That is why a successful manager should establish such an organizational structure of the operation that will provide the expected results, i.e. achieve the following goals: timely inflow of financial resources, timely provision of the necessary mechanization in the production process, quality location selection, timely supply of raw materials, provision of quality and professional human potential (managerial and non-managerial), provision of working conditions, that is everything that is necessary for the smooth functioning and development of the production process as a functional whole. The modern way of managing tobacco production, especially through the development of a modern family business, imposes the need for developed management of all activities and appropriate motivation of the engaged members. In this way, greater efficiency, reduced costs, increased productivity and maximum utilization of existing resources are achieved.

Key words: organization, efficiency, planning, motivation, sustainability

Анотација: Организацијата е менаџерска функција која ја дефинира улогата на поединецот во организациската структура и обезбедува прилив на потребни средства, односно ресурси за создавање на комплетната функционална целина, која ќе овозможи правилно работење на сите сегменти на дејствување. Организирањето претставува фаза во менаџерското работење,

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потребна за создавање поволни услови за работење на успешни тимови. Со формирање на организациската структура мора да се дефинираат задачите што треба да ги извршуваат вработените, според нивната способност и мотивираност. Потребно е организациските единици да се систематизираат и по можност да се даде опис на секое работно место, при што се создава управно раководна шема. Организациската структура не служи само за определувањена позиции помеѓу луѓето опфатени со неа, таа има многу повеќе ефекти врз комуникацијата, функционирањето и ефективоста на различните бизнис функции во самиот бизнис. Добрата организациска поставеност и координираност има примарно значење во сите сфери на општественото живеење и функционирање, вклучувајќи го и земјоделството и секако тутунопроизводството во сите негови фази. Точно поради тоа успешниот менаџер треба да воспостави таква организациска поставеност на работењето што ќе му ги обезбеди очекуваните резултати, односно ќе ги постигне следниве цели: навремен прилив на финансиските средства, навремено обезбедување на потребната механизација во процесот на производство, квалитетен избор на локација, навремен дотур на сировини, обезбедување на квалитетен и професионален човечки потенцијал (менаџерски и неменаџерски), обезбедување на услови за работа, односно се што е потребно за непречено функционирање и одвивање на производствениот процес како една функционална целина. Современиот начин на стопанисување во тутунопроизводството, особено преку развивање на современ семеен бизнис, наметнува потреба од развиен менаџмент со целокупните активности и соодветна мотивација на ангажираните членови. На таков начин се постигнува поголема ефикасност, намалени трошоци, зголемена продуктивност и максимална искористеност на постоечките ресурси.

Клучни зборови: организација, ефикасност, планирање, мотивација, одржливост

1. INTRODUCTION

A well-structured organization will always outperform others, achieve better performance, and continuously strive to elevate its capabilities to a higher level. A successful and dedicated manager who has established a sound organizational structure should always ask the following questions:

“In what were we better today than yesterday?”

“What did we learn, and where do we need to improve?”

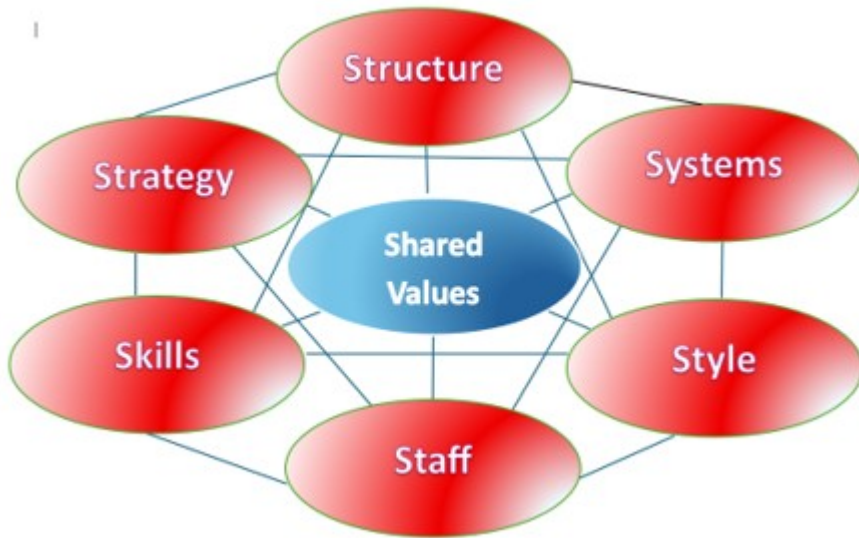
“Is our work professional and efficient?”

“Did we achieve the expected results?”

A well-organized work process consistently provides positive answers to these and similar questions, as it continuously works on improving its performance. However, the dilemma still remains: how do we create a good organization?

Globally, the McKinsey 7 “S” model is often applied, which includes seven elements of a well-structured organization. Therefore, the seven basic elements of a well-structured organization are:

Figure 1. Elements of the Organizational Structure



The organizational structure is established according to a strict hierarchy, with clearly defined rules for advancement. The structure and organization are clear to all employees; the “rules of the game” are known, and every employee understands their place within the organization as well as their prospects. All employees are replaceable and accountable for their work, regardless of their position.

The system represents the way work processes are carried out. Systems of communication, reporting, planning, analysis, quality control, etc., must be aligned with the overall strategy of the organization.

Strategy represents a mix of general measures and activities that need to be implemented in order to achieve the set goals.

Shared values are both a distinct quality and a particular challenge for every business. If a competitive climate is created in which employees are evaluated based on what kind of car they drive, what kind of suit they wear, or where they travel, then the business is in an unfavorable position. However, if a competitive climate oriented toward the market and competitors is established, and employees are evaluated based on the quality of their work, openness, and cooperation, then the business will genuinely progress.

The selection of capable and talented employees has become an imperative for successful companies. A well-selected and trained employee, placed in an appropriate position, can deliver up to five times better results compared to an unselected employee. If employees are selected based on criteria other than their abilities, then there will be no top performers, and consequently no high-performing team capable of achieving outstanding results.

Employee skills are of great importance. If employees possess diverse skills, they will be able to perform a wider range of tasks. This reduces the need for external collaborators and makes the work process more efficient.

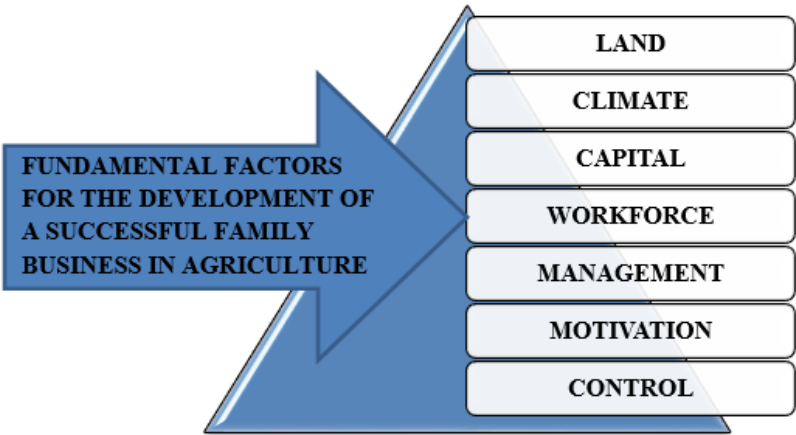
Style represents a recognizable characteristic of a particular company or business, whether it is production- or service-oriented. It differentiates the business from others. Style refers to the way work is carried out, the system of communication within and outside the organization, behavior patterns, and the execution of assigned tasks. It is adapted to team spirit, the willingness to help other employees, and the commitment to give one’s best as a team or community.

In joint operations, everyone involved in the production process must know their role and perform it correctly, as defined. Staffing falls within the domain of the staffing function, but aspects of this issue are also included in organizing, which creates an overlap between organizing and staffing. For this reason, many authors view organizing and staffing as a single activity. However, despite certain common elements, it is useful to distinguish between these functions, since organizing only partially addresses human resources, while the staffing function analyzes all aspects of managing human potential (how to recruit, train for proper performance, manage, promote, dismiss, etc.).

2. THE ROLE OF MANAGEMENT AND ITS FUNCTIONS IN THE SUSTAINABILITY OF TOBACCO PRODUCTION AS A FAMILY BUSINESS

Unlike general management, management in a family business engaged in tobacco production focuses on how the owner organizes the factors of production—land, labor, and capital—adapts the activity to the specific environment, and manages the resulting product—tobacco—in a way that generates maximum profit, while at the same time preserving the integrity of the fundamental production factors.

Figure 2. Fundamental Factors for the Development of a Successful Family Business in Agriculture



The development of a modern family business primarily engaged in tobacco production must rely on well-developed management, along with all its accompanying elements such as planning, work organization, production management, and control, supported by appropriate motivation of the involved members. Only in this way can greater efficiency and effectiveness in operations be achieved, along with reduced production costs, increased productivity, and improved business results.

When it comes to family businesses in tobacco production in Macedonia, it can be said that these are individual producers who have invested their own resources in tobacco production and use either their own land or leased land. In terms of labor, they rely on the engagement of family members or other individuals, regardless of gender.

Most tobacco producers today are primarily focused on the production process itself, rather than on planning, organizing, managing production, keeping records of income and expenses, controlling costs, and managing the risk of negative business outcomes. This approach may have been sufficient in the past, but in today's globalized market with strong competition in every field, the traditional approach to managing rural tobacco farms—characterized by high production costs, low efficiency, and small cultivated areas—must change. It is necessary to transition to a completely new, modern way of managing a family business in tobacco production. This approach should certainly include planning, organizing work, controlling operations and costs, managing human resources and their motivation, as well as the application of new technologies through the use of modern machinery, information technology, and bioengineering.

The development of a successful family business in tobacco production must rely on well-developed agromanagement, which represents the achievement of defined agricultural production goals under specific production conditions and the efficient use of limited resources. Management in tobacco production essentially means achieving strategic goals through the use of available human resources. Management is not only about decision-making; its essence lies in taking action. Based on these decisions, the family business is directed toward the desired goal. The objective is to coordinate all work activities so that they are carried out efficiently and effectively with the help of others.

The owner of a family business in tobacco production has two roles:

- to take care of production and create a quality product, and
- to manage the family business.

As a manager, they must perform certain functions, roles, and possess specific skills. They are expected to carry out the following functions—planning, organizing, leading, and controlling production—in order to effectively and efficiently coordinate the work of others. There are numerous interrelated managerial roles, most commonly grouped around interpersonal relations, information transfer, and decision-making.

Figure 3. Management functions



Managers also require certain skills to perform their duties: technical skills (knowledge in a specific field or area), human skills (the ability to work with other people, both individually and in groups), and conceptual skills (the ability to develop concepts for abstract and complex situations).

The acquisition of specific knowledge and skills is most often linked to education. However, the level of education among the population involved in agriculture is relatively low. This percentage is lower than in other sectors, not only in our country but also in the EU-28.

Table 1. Level of Education in the Non-Agricultural and Agricultural Sectors in the European Union and in Our Country in 2024

Степен на образование	Вкупно			Земјоделски сектор		
	Ниско	Средно	Високо	Ниско	Средно	Високо
ЕУ-28	17,9%	48,0%	34,1%	40,8%	50,3%	8,9%
Македонија	19,2%	54,5%	26,3%	54,8%	41,3%	3,9%

Source: Eurostat

The data are even more worrying in terms of age structure. They are given in the following table for the EU-28 and Macedonia:

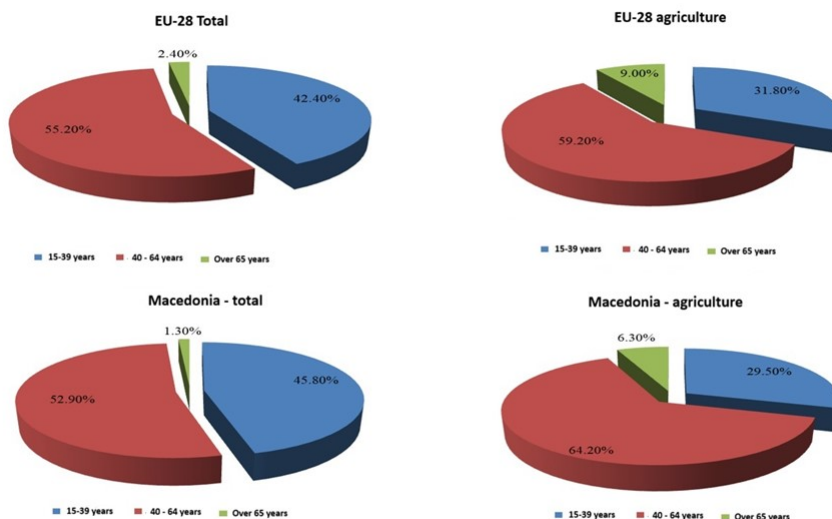
Table 2. Percentage of population by age group in the EU-28 and Macedonia in and outside agriculture in 2024

Старосна структура	Вкупно			Земјоделски сектор		
	15-39 г.	40-64 г.	Над 65 г.	15-39 г.	40-64 г.	Над 65 г.
ЕУ-28	42,4 %	55,2%	2,4%	31,8%	59,2%	9,0 %
Македонија	45,8%	52,9%	1,3%	29,5%	64,2%	6,3%

Source: Eurostat

Graphically, these data can be presented as follows:

Chart 1. Percentage of population by age group in the EU-28 and Macedonia in and outside agriculture



The manager, that is, the owner of a family business, using the skills and knowledge they possess, should begin with planning the family business as the first and most important step when intending to start a tobacco production business. This step is influenced by many external and internal factors that affect, first, the successful establishment of the business, and later its gradual development into a well-established and successful family enterprise. During the planning process, the manager should consider two alternatives:

Whether to be a tobacco producer who cultivates only tobacco on larger areas, involving family members or hired labor; and

Whether to be a part-time tobacco producer (someone who has another job in agriculture or outside it), with income from tobacco serving as a supplement to the family budget.

For planning to be successful, the manager must first:

- Define the goals of the family business in tobacco production;
- Assess the available resources (internal scanning), i.e., evaluate internal factors (labor force, size, structure and quality of the land, availability of water and irrigation systems, availability of appropriate machinery, etc.);
- Conduct an environmental analysis in the form of external scanning, including the purchasing conditions offered by buying companies, possibilities for obtaining advances, etc.;
- Identify and select strategies for achieving the set goals; and
- Implement the selected strategies.

After defining the goals of the family business in tobacco production, assessing resources, conducting environmental analysis, and selecting strategies for achieving the set goals, the next step is to formulate short-term objectives. The manager of the family business must define action steps, set a timeframe for their proper execution, and continuously monitor their implementation. This automatically means setting specific short-term (tactical and operational) goals in order to measure progress toward long-term objectives.

Defining goals in tobacco production is not simple because:

- conditions are uncertain and unpredictable; and
- it requires a significant amount of time to establish appropriate goals.

The complexity in defining goals lies in the fact that tobacco production, as a primary activity for the owner of a family business, is often also a way of life. Thus, while in most businesses the primary goal is profit maximization, in agriculture (tobacco production) this is not necessarily the main objective due to the integration of lifestyle and profession. The goals of these family business owners can therefore be described as the pursuit of profit, provided that it does not come at the expense of their way of life (i.e., the survival of the business).

In the context of the above, we can conclude that the foundation of management lies in planning and organization. This is the basis upon which modern management in tobacco production is built. Planning must assess where the family business currently stands and where it is heading. It determines the course of action. In other words, planning defines the way in which various activities can be carried out in an effective sequence and in a precise chronological order. It creates the framework within which the different factors of production (land, capital, and labor) will be organized, allocated, and controlled in order to achieve the goals in tobacco production. It is closely related to the effort to answer the question of how to carry out tasks efficiently and effectively. Efficiency means doing things right, while effectiveness means doing the right things.

The second task of management, after planning, is organization. Once plans and budgets are established, the family business in tobacco production must be organized in a way that enables their implementation. For plans to succeed, it is necessary to identify the various tasks, and those that are carried out together can be combined. Therefore, organization is defined as determining the different tasks that need to be performed, grouping those that go together into functions, and establishing good relationships among those responsible for carrying out these functions and tasks, so that everyone knows their responsibilities and their role within the family business. As a managerial function, organization includes two activities: creating an organizational structure and managing human resources. Both organization and planning within a family tobacco production business have their specific characteristics. These are primarily due to the fact that the manager is often not only a supervisor but also directly involved in production or in certain production activities, just like other workers. This makes organization, particularly the delegation of clearly defined tasks, more difficult—not only for the manager but also for all employees or participants in the family business. As a result, the possibility of narrow specialization of human resources within the family business is reduced.

Within the scope of organization also falls the successful management and planning of human resources. In this regard, motivation, communication, and workforce training are among the key issues that owners of family tobacco production businesses must not neglect. In certain situations, only family labor will be used; in others, there will be a need for hired labor; and

in some cases, even external expertise and the use of services from consultants or specialists will be required—whether for tobacco diseases, the introduction of new machinery, legal advice, and similar matters.

Motivation is, in essence, the process of activating human behavior, that is, directing activity toward the achievement of specific goals. Motives are the reasons for initiating certain behaviors or activities. The motivation of an individual owner of an agricultural holding to engage in tobacco production may stem from existential reasons—which is very common, especially in rural areas—from family tradition, since it is a fact that in the world, Europe, and in our country, the inheritance of agricultural professions is much more common than in other sectors; from a lack of other skills and education, as a low level of education is characteristic of the population engaged in agriculture; or from the need to secure additional financial resources to improve the family budget.

Macedonian farmers lag behind the European average in terms of education level. When it comes to managerial skills and competencies, the situation is even less favorable. The number of farm managers/owners in the EU-28 amounted to 12,247,850 in 2024; of these, only 7.5% are under 35 years of age, 39.4% are between 35 and 64 years old, and as many as 53.2% are over 65. At the EU level, the number of managers who have attended management training is as follows:

Table 3. Farm Managers in the EU Who Have Undertaken Management Training in the Past 12 Months, 2024

Managers in the EU-28	Total	men	women
under 35 years old	89.100	76.110	12.990
35 to 44 years old	178.730	152.710	26.020
45 to 54 years old	230.400	197.980	32.420
55 to 64 years old	145.770	125.700	20.070
over 65 years old	60.070	49.590	10.480
Total managers who have undergone management training in the last 12 months	704.070	602.090	101.980

Source: Eurostat 2024.

Of this number, only 194,980 have completed full management training, while 221,100 have only practical experience, and 287,990 have basic training.

Once the plans are finalized and the family business in tobacco production is organized, it is necessary to ensure the implementation of these plans, which must be monitored. Control is the fourth function of management, through which the manager keeps the family business in tobacco production on the right track. It should be both preventive and ongoing. Any untimely execution of control puts the continued operation of the business at risk. Control is inseparably linked to planning and organization, which means the manager must oversee activities and monitor them to ensure they are carried out according to plan.

The control process includes the following four steps:

- Establishing standards;
- Measuring actual performance;
- Comparing actual performance with planned standards; and

- Taking corrective action.

Considering all that has been presented regarding the management of a family tobacco business, we can conclude that good management is of critical importance for a family tobacco business and includes the following elements:

- Making decisions;
- Implementing those decisions; and
- Accepting responsibility for the decisions made.

To accomplish all of this, the manager/owner must possess:

- Integrity and a sense of responsibility;
- Practical experience;
- Business acumen;
- Technical knowledge; and
- Information about the family business related to costs, yields, the status of production factors, and many other elements.

In the context of successfully organizing agricultural activities, and specifically tobacco production, it is particularly important to apply tactical management of the family business, which is a key aspect for the effectiveness and sustainability of agricultural enterprises. This type of management involves planning, organizing, leading, and controlling all activities related to production and resource management.

Within the organizing function, tactical management is of great importance and includes:

1. Identifying and defining the problem or opportunity;
2. Identifying alternative solutions;
3. Collecting data and information;
4. Analyzing alternatives and making a decision;
5. Implementing the decision;
6. Monitoring and evaluating results; and
7. Accepting responsibility.

Following these steps will not guarantee that every decision will be perfect, but it will help the manager act in a logical and organized manner when faced with a particular problem.

3. CONCLUSION

Strategic decisions of management in agribusiness must be based on internal considerations of costs, technology, risks, financial planning and managerial resources, as well as external considerations of synergies, differentiation, market positioning and marketing strategies. Today, in agribusiness, which includes tobacco production, changes are constant and increasingly rapid, so managers must use a new management approach to the way of management, an attitude that will favor flexibility, faster innovation, the integration of challenges arising from constant changes in operating conditions.

Maintaining the long-term productivity of the land, protecting the environment, protecting the health of the entrepreneur and workers, as well as maintaining financial independence are issues that affect the plan of an agricultural organization. The type, quality and quantity of available resources determine which activities can be taken into account when drawing up a

plan for the organization, and which are not feasible. First of all, land should be considered as a complex and limited resource with characteristics that affect the type and number of activities considered, then facilities, that is, a list of all structures should be included, along with their condition, capacity and potential uses. Mechanization can be a fixed resource in the short term, and the number, size and capacity are also important in the development of the plan, while capital is a limiting resource and its lack or limited access can affect the size and choice of activity. The workforce should be analyzed in terms of quantity and quality. Quantity can be measured in months of labor currently available to the business, while the quality of the workforce is a little more difficult to measure, but any specialized skills, training and experience that will affect the possible success of a particular activity should be noted. In this regard, the organization as a function of strategic management envisages the best possible utilization of all available resources: land, labor, capital, and entrepreneurship in order to achieve the set goals, therefore it is a practical process that should ensure the best management of available resource.

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DIGITALIZATION IN RURAL AREAS AND STATE CONTROL: ASSISTANCE OR SURVEILLANCE?

ДИГИТАЛИЗАЦИЈА В СЕЛСКИХ РАЙОНАХ И ГОСУДАРСТВЕННЫЙ КОНТРОЛЬ: ПОМОЩЬ ИЛИ НАДЗОР?

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Abstract: Precision agriculture and the integration of smart technologies represent a significant transformation of the Macedonian rural economy. This paper explores the paradox of digital agriculture as a tool for both economic and ecological progress, while also serving as a potential instrument for state and corporate surveillance. Through examples from precision farming, smart technologies, and national programs for rural modernization, it analyzes how digital infrastructure affects farmers' autonomy, access to technologies, and the distribution of economic power. Particular emphasis is placed on the digital divide between large farms with access to sensors, drones, and analytical platforms, and small farmers who are limited in resources and digital literacy. The paper proposes strategies for ethical, inclusive, and politically balanced development of digital agriculture in Macedonia, aiming to maximize benefits for rural communities while minimizing risks of power concentration and technological dependency.

Key words: precision agriculture, smart technologies, digital agriculture, state surveillance

Анотација: Точное земледелие и интеграция умных технологий представляют собой значительную трансформацию македонской сельской экономики. В данной работе исследуется парадокс цифрового земледелия как инструмента экономического и экологического прогресса, а также как потенциального средства государственного и корпоративного надзора. На примерах точного земледелия, умных технологий и национальных программ модернизации сельских районов анализируется, как цифровая инфраструктура влияет на автономию фермеров, доступ к технологиям и распределение экономической власти. Особое внимание уделяется цифровому неравенству между крупными хозяйствами, имеющими доступ к датчикам, дронам и аналитическим платформам, и мелкими фермерами, ограниченными в ресурсах и цифровой грамотности. Работа предлагает стратегии этического, инклюзивного и политически сбалансированного развития цифрового земледелия в Македонии с целью максимизации выгод для сельских сообществ и минимизации рисков концентрации власти и технологической зависимости.

Ключевые слова: точное земледелие, умные технологии, цифровое земледелие, государственный надзор

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1. INTRODUCTION

In recent decades, digitalization has radically reshaped the agricultural sector globally, becoming not only a driver for the modernization of rural areas but also a field of political and economic competition. Precision agriculture and smart technologies, which include IoT sensors, drones, geolocation systems, and big data analytics, offer extraordinary opportunities to increase productivity, optimize resources, reduce costs, and promote economic sustainability and innovative business models.

In an ideal world, these technologies should strengthen the agricultural sector and reduce historical inequalities in rural regions. However, reality is far from ideal. Precision agriculture is not merely a technological advancement. It represents a potential tool for state surveillance and corporate domination, altering the power dynamics within rural communities. Digital platforms and data collection systems, when in the hands of the state or large corporations, can create new forms of dependency, inequality, and economic marginalization for small farmers. (Zuboff, 2019) In regions with limited digital infrastructure, these technologies risk becoming a hidden mechanism of control, compromising the traditional concept of farmer autonomy.

The aim of this paper is to explore the dual nature of digital agriculture: as a tool for economic and ecological progress and, simultaneously, as a potential means of power concentration, state oversight, and corporate domination. Does digital agriculture increase the autonomy and productivity of rural communities, or does it transform the agricultural sector into a space of political and economic control?

2. MATERIAL AND METHODS

This paper is based on a qualitative research approach, employing the analysis of secondary data and relevant scientific and professional literature. The research utilizes sources from international organizations, as well as academic publications related to the digitalization of agriculture, precision agriculture, and the concepts of the digital economy and algorithmic governance.

Methodologically, the paper relies on theoretical analysis and a comparative approach, through which global trends in digital agriculture and their applicability to the Macedonian context are examined. Additionally, a critical analysis is applied to explore the implications of digital technologies on the distribution of economic power, farmers' autonomy, and the potential emergence of new forms of surveillance.

The analysis also includes practical examples and national initiatives related to the digitalization of agriculture in Macedonia, aiming to illustrate the real situation and challenges in implementing these technologies.

3. RESULTS AND DISCUSSION

3.1 Precision Agriculture as a Technological Paradigm and a New Production Regime

In contemporary agricultural literature, precision agriculture is considered one of the most significant technological transformations in agricultural production in recent decades. It is defined as an integrated system of digital technologies, data platforms, and automated

processes that enable detailed analysis and optimization of agricultural activities. (Wolfert, et al., 2017) Within this technological paradigm, agriculture is gradually transforming from a traditional production model, based on local experience and empirical knowledge, into a data-driven production system where decisions are made based on complex analytical algorithms and digital platforms.

The integration of technologies such as IoT sensors, satellite navigation, unmanned aerial vehicles (drones), geospatial information systems, and advanced analytical tools enables continuous monitoring of agricultural ecosystems. In the Republic of Macedonia, these technologies are present but their application is still limited, mainly occurring through pilot projects, international initiatives, and individual commercial farms. For example, digital solutions such as drone imaging and crop analysis are applied in certain regions, such as Kumanovo and Strumica, primarily as part of private precision agriculture services.(Agfutura.com)

At the same time, national and international programs, supported by institutions such as the FAO, are working on developing digital infrastructure through platforms like e-agriculture, which provide farmers and institutions with access to agrometeorological and spatial data. (United Nations, North Macedonia)

However, despite these initiatives, advanced technologies such as IoT sensors and analytical systems remain limited to pilot projects and have low prevalence, especially among small farms, indicating significant digital inequality in the agricultural sector.(Stojkov Pavlović et al., 2025)

IoT sensors allow for measuring soil moisture and the nutritional status of crops, while drones capture crop conditions and identify areas with potential risk of disease or stress. Geospatial information systems integrate these data into digital maps, enabling more precise management of water, fertilizer, and pesticide use. This approach contributes to optimizing productivity and reducing the ecological footprint of agriculture. Research indicates that precision agriculture can reduce water use by approximately 20–40% and fertilizer uses by around 15-30%, with potentially higher effects depending on technology and local conditions.(AgriEconomist)

Theoretically, this transformation is linked to broader processes of digitalization and automation that characterize the modern economic system. Precision agriculture fits into the concept of the “fourth agricultural revolution,” in which digital technologies become a key driver of productivity and innovation in the agricultural sector. In North Macedonia, the state and private actors are gradually supporting this transformation through pilot projects for soil data analysis, agrometeorological systems, and the development of digital platforms for managing agricultural production. These initiatives involve the use of mobile applications, sensors, and drones to monitor crop conditions, although their application is still limited and unevenly distributed across different types of farms.

Supporters of this perspective argue that digitalization is a crucial mechanism for ensuring global food security and addressing climate challenges.

However, technological transformation is not exclusively a technical process, but also a structural change in power relations within the agricultural economy. Through digital infrastructure, control over production processes gradually shifts from individual farmers to technological platforms and companies that own and manage this infrastructure. In this sense,

precision agriculture can be interpreted not only as a means of modernization but also as a new regime of technologically mediated production, where algorithms and data play a central role in managing agricultural activities.

From this perspective, there is a warning that the digitalization of agriculture may lead to a new form of technologically mediated dependency, in which control over production processes is concentrated in the hands of a limited number of technology companies that own the platforms, algorithms, and data processing infrastructure. This concentration of digital infrastructure raises broader questions about power asymmetry in the global agri-tech system. Thus, a fundamental question arises as to whether digitalization truly leads to the democratization of agricultural production or, conversely, creates a new form of technological dependency in which farmers become part of digitally organized production systems over which they have limited control.

3.2 Data as a New Form of Agricultural Power

One of the most controversial aspects of digital agriculture is the transformation of data into a key economic resource. Within the contemporary digital economy, information on soil, production processes, climatic conditions, and market trends becomes strategic capital with significant economic value.

In this perspective, the agricultural sector becomes part of a broader process of “datafication,” i.e., the transformation of physical and biological processes into digital data that can be analyzed, processed, and monetized. (Couldry, Mejias, 2019) Every aspect of agricultural production from the chemical composition of the soil to crop growth dynamics can be digitally recorded and integrated into algorithmic systems for analysis and prediction. This process creates a new economic reality in which data becomes a form of agricultural power.

Such concentration of data resources can create a new type of digital agrarian capitalism, in which control over production information becomes as important as control over land or resources. Companies with large data sets and analytical capacities gain a significant advantage in managing production, predicting market trends, and optimizing agricultural processes. Global trends show that digital technologies are concentrated in specific regions and farm types. For example, about 62% of farms in North America use precision agriculture technologies, while their adoption is significantly lower in many regions of Africa and Asia. (Lowenberg-DeBoer, Erickson, 2019)

At the same time, studies show that less than 15% of smallholder farms (Food and Agriculture Organization) worldwide have access to these technologies, even though small farmers make up approximately 80% of all farmers globally. (Ricciardi et al. 2018)

In North Macedonia, although digital platforms are still in pilot stages, a similar dynamic is already emerging. Large farms in Macedonia are more likely to use digital platforms and technologies such as sensors and drones to optimize irrigation, fertilization, and disease monitoring. Small farmers, who make up a significant portion of the country’s agricultural holdings, often lack access to these technologies or advanced analytical services, creating asymmetry in economic benefit and control over data.

The key issue in this transformation is the question of ownership and control over data. In many cases, digital platforms collecting agricultural data are owned by large technology companies or multinational agribusiness corporations. Although farmers generate the data, they often lack full control over its use, analysis, or commercialization. As a result, an asymmetric power structure emerges in which farmers become data producers, while the economic value of that data is accumulated by entities controlling the digital infrastructure. Some authors describe this phenomenon as a form of digital value extraction, in which information generated in rural areas is turned into an economic resource for global tech markets.

3.3 Precision Agriculture in the Macedonian Context

In North Macedonia, the digitalization of agriculture is beginning to develop as a concrete, pragmatic process, supported by state and international initiatives, although it is not yet fully integrated into everyday agricultural practices. In recent years, the Ministry of Agriculture, Forestry, and Water Economy, in cooperation with the Food and Agriculture Organization (FAO) and other partners, introduced a national e-agriculture platform (e-zemjodelstvo.mk) aimed at centralizing the latest spatial, climate, and market data in one place, making it accessible to institutions, researchers, and farmers themselves. This platform integrates systems such as the Agribusiness Market Information System (AMIS) and national agrometeorological data, enabling a more complex understanding of production conditions and market trends.

One of the most significant innovations in the country's digital transformation is the project to install approximately 500 advanced soil sensors, designed to collect data every 15 minutes in major agricultural regions. These sensors record soil mineral characteristics and moisture dynamics, and the data are transmitted wirelessly to a central database, where they can be analyzed and visualized via mobile applications or web interfaces. Although the project is in its initial phase, its implementation already serves as a foundation for further efforts to introduce technologies such as satellite monitoring, drones, and smart irrigation systems, aiming to improve productivity and reduce the ecological footprint of agriculture.

These technological monitoring systems and digital platforms not only provide more data but also create a basis for better national-level agricultural policy planning. For example, through the e-agriculture platform, farmers can access up-to-date market information, while state institutions can use the data to develop strategies for addressing climate change, adapting production, and increasing competitiveness according to European Union standards. This approach reflects an effort to link digital information with strategic objectives in the national agro-sector as part of harmonization with European standards and the Sustainable Development Goals.

However, the practical application of digital technologies on Macedonian farms faces significant structural challenges. The average farm size in the country is relatively small and fragmented, limiting their capacity to invest in sensors, drones, and high-cost digital solutions, particularly for small family farms without stable capital inflow. A small farm can hardly afford the implementation of IoT technologies or data analytics software, putting them at a disadvantage compared to larger farms already investing in these technologies.

In addition, digital literacy among farmers is still limited. Many producers continue to communicate with state authorities and access subsidy systems in traditional ways, through physical counters, as digital application systems, though officially introduced, are still perceived as complex and difficult to use for those without prior experience with advanced digital tools. This digital barrier creates an additional gap between technologically equipped and unequipped farms, meaning that some farmers remain dependent on intermediaries or assistance from local officials to physically enter data into national systems.

Overall, the digitalization of agriculture in North Macedonia represents a complex, multi-layered process that simultaneously brings new opportunities for productivity, sustainability, and innovation, while also facing structural constraints related to financial capacity, digital literacy, and access to technology. These challenges indicate that a full digital transformation of the agricultural sector will require a coordinated effort by the state, the education sector, farmers' organizations, and international partners to ensure fair distribution of benefits and reduction of digital inequality.

4. CONCLUSION

Digital agriculture represents a significant transformation of the rural sector, with the potential to increase productivity, optimize resources, and support sustainable agricultural practices. Precision technologies, sensors, drones, and analytical platforms provide closer control and insight into production processes, which can improve farmers' outcomes and reduce the ecological footprint. In the Macedonian context, national initiatives such as e-zemjodelstvo.mk create a foundation for greater coordination, awareness, and modernization of the agricultural sector, enabling access to data that is critical for planning, adapting to climate change, and aligning with European standards.

In conclusion, digital agriculture can be understood as a paradoxical phenomenon: on one hand, a tool for economic and ecological progress, and on the other, a potential mechanism for technological dependency and political concentration of power. To realize its true potential, inclusive and transparent policies are necessary, ensuring fair access to technology, educational programs for digital literacy, and active participation of farmers in the decision-making process. Only through such a balanced approach can digital agriculture become an instrument for sustainable development, innovation, and democratic participation, rather than turning into a means of centralized control and a new form of agricultural inequality.

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<https://www.agrieconomist.com/transforming-farming-with-precision-agriculture>

ANTHROPOMETRIC AND BIOCHEMICAL EXAMINATIONS AMONG OBESE MILITARY PERSONNEL FROM THE REPUBLIC OF KOSOVO

АНТРОПОМЕТРИСКИ И БИОХЕМИСКИ ИСПИТУВАЊА КАЈ ДЕБЕЛИ ВОЕНИ ЛИЦА ОД РЕПУБЛИКА КОСОВО

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Abstract: *The problem of obesity has been an existing and complex health issue associated with increased levels of cardiometabolic risks and physical functionality. This problem has been observed in the military population. Changes in the structure of jobs and modern lifestyles and eating habits are among the factors that contribute to an increased number of people with obesity in the armed forces. This has significant implications for the health of the military. The objective of this study was to examine the physical characteristics and clinical findings of the military population with issues of excess weight. The study participants included 29 male soldiers from the Republic of Kosovo. Their ages varied from 22 to 54. For each participant, the study team obtained physical measurements and carried out blood pressure and blood tests. The blood test included a count of blood cells and other biochemical and lipid tests. The study also included the examination of the link between the levels of blood glucose and triglycerides and the BMI. The study findings indicated that the group had excess weight and average blood pressure levels that were slightly above normal. Hematological values were generally maintained within the range, while biochemical and lipid values had considerable variations. The correlation analysis revealed a moderate positive relationship between BMI and blood glucose, indicating increased metabolic risk factors. The study reveals that the extra weight in the military population is associated with increased cardiometabolic risk, as evidenced by increased blood glucose and prehypertension blood pressure values. In the future, there is a need to focus on lifestyle interventions*

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and health monitoring to reduce the metabolic risk factors in order to increase the readiness of the military personnel.

Key words: Nutrition, military population, body mass index, metabolic risk, anthropometry

Анстракт: Проблемот со дебелината претставува постоечки и комплексен здравствен предизвик поврзан со зголемени нивоа на кардиометаболни ризици и намалена физичка функционалност. Овој проблем е забележан и кај воената популација. Промените во структурата на работните задачи, како и современиот начин на живот и навиките во исхраната, се меѓу факторите што придонесуваат за зголемување на бројот на лица со дебелина во вооружените сили. Ова има значајни импликации врз здравјето на воениот персонал. Целта на ова истражување беше да се испитаат физичките карактеристики и клиничките наоди кај воената популација со проблеми со прекумерна телесна тежина. Во студијата беа вклучени 29 машки војници од Република Косово, на возраст од 22 до 54 години. За секој учесник беа направени физички мерења, како и мерења на крвниот притисок и лабораториски анализи на крвта. Крвните анализи опфатија број на крвни клетки, како и други биохемиски и липидни параметри. Студијата исто така ја испитуваше поврзаноста помеѓу нивото на гликоза во крвта, триглицеридите и индексот на телесна маса (BMI). Резултатите од студијата покажаа дека испитуваната група има прекумерна телесна тежина и просечни вредности на крвен притисок кои се малку над нормалните граници. Хематолошките вредности генерално беа во референтните граници, додека биохемиските и липидните параметри покажаа значителни варијации. Корелациската анализа откри умерена позитивна поврзаност помеѓу BMI и нивото на гликоза во крвта, што укажува на зголемени метаболни ризик-фактори. Студијата укажува дека прекумерната телесна тежина кај воената популација е поврзана со зголемен кардиометаболен ризик, што се потврдува со покачени вредности на гликоза во крвта и вредности на крвен притисок во рамките на предхипертензија. Во иднина, потребно е да се стави акцент на интервенции во начинот на живот и континуирано следење на здравствената состојба со цел намалување на метаболните ризик-фактори и зголемување на подготвеноста на воениот персонал.

Клучни зборови: исхрана, воена популација, индекс на телесна маса, метаболички ризик, антропометрија

1. INTRODUCTION

Generally, obesity is a long-standing and multifactorial state characterized by excessive body fat and a notably increased risk for cardiovascular disease, type 2 diabetes, metabolic syndrome, and decreased physical performance (Ng et al., 2014; World Health Organization, 2023). The rise in obesity across the world is now regarded as one of the most alarming issues in this modern age and has ripple effects that extend beyond individual-level health and into socioeconomic structures and institutions. While the military has long been synonymous with physical fitness, discipline, and strict body type ideals, modern militaries are struggling to combat a rising rate of overweight and obese personnel in the military (Knapik et al., 2015; Bray et al., 2018). The move towards modernized military operations, sedentary roles, increased hours of work, psychosocial factors, and the availability and quality of food are all contributing factors to this phenomenon (Chapman et al., 2019; Smith et al., 2020). Obesity is of particular concern in the military because it directly impacts the military's readiness, endurance, speed, and agility in both combat and day-to-day operations (Knapik et al., 2015). In addition, obese service members are more likely to experience musculoskeletal injuries, rehabilitation, and absences, which can be costly for the military healthcare system (Jones et al., 2010). According to studies, it is clear that the increased prevalence of energy-dense diets characterized by saturated fat and refined carbohydrate intake, coupled with decreased physical activity and irregular meals, is a major contributing factor to the increased prevalence of obesity in soldiers (Chapman et al., 2019; Mozaffarian et al., 2016). This is because these types of dietary habits are often accompanied by unfavorable body and blood parameters such as increased BMI, waist size, dyslipidemia, insulin resistance, and increased

inflammation markers (Hu, 2013; Schwingshackl et al., 2019). Although there is an increase in studies about obesity in the military across the world, there is still limited information about the body measurements and biochemical parameters of obese soldiers in the Republic of Kosovo. The scarcity in relevant research makes it difficult to precisely target within the military healthcare system. In this study, we have specifically targeted some of the important physical and biochemical markers in obese soldiers from Kosovo. In this regard, this study aims to identify and highlight some of the important risk factors by specifically examining body mass index and lipid and blood sugar profiles in obese soldiers and provide some evidence-based recommendations in nutrition-related interventions that may be helpful in enhancing military personnel’s health and combat readiness.

2. MATERIALS AND METHODS

This study was conducted both as an observational study and an interventional study, specifically within a military setting. Its main purpose was to determine anthropometric, clinical, laboratory, and behavioral characteristics, while assessing the potential impact of an educational intervention on knowledge, attitudes, and practice related to nutrition and lifestyle factors. A total of 29 active military men, ranging in age from 22 to 54 years, were recruited from the Republic of Kosovo. All participants were fully informed about the study’s purpose, procedures, and benefits, thus providing their voluntary consent to participate. Among the anthropometric parameters, body weight and height were measured, from which body mass index was derived using the following formula: $\text{body mass index} = \text{body weight} / \text{height}^2$.

Resting blood pressure while sitting was measured using a sphygmomanometer, and both systolic (SBP) and diastolic (DBP) pressure were recorded. For laboratory investigations, venous blood samples were collected from all subjects after fasting overnight. A complete blood count (CBC) was done to determine various parameters such as leukocytes, erythrocytes, hemoglobin, hematocrit, and platelet counts. Biochemistry tests included liver function tests such as ALT, AST, GGT, renal function tests such as serum creatinine, urea, blood glucose, and direct bilirubin. In addition, total cholesterol, triglycerides, LDL, and HDL were included in the lipid profile. All these tests were done in an accredited laboratory using conventional clinical-biochemical methods.

3. RESULTS AND DISCUSSION

3.1. Anthropometric and Biochemical Assessments

The basic characteristics of the studied population are presented in Table 1.

Table 1. Basic characteristics of the studied population

Parameter	Average	SD ±	Minimum	Maximum
Age (years)	38.9	10.4	22	54
Weight (kg)	90.4	13.9	70	146
Height (cm)	180.7	5.4	170	192
SBP (mmHg)	133	20.7	100	180
DBP (mmHg)	85	8.9	70	100

All participants were male, with a mean age of 38.9 ± 10.4 years, ranging from 22 to 54 years. The average body weight was 90.4 ± 13.9 kg, with a minimum of 70 kg and a maximum of

146 kg. Height ranged from 170 cm to 192 cm, with a mean value of 180.7 ± 5.4 cm. Blood pressure measurements showed an average systolic blood pressure (SBP) of 133 ± 20.7 mmHg and diastolic blood pressure (DBP) of 85 ± 8.9 mmHg. The highest recorded systolic and diastolic pressures were 180 mmHg and 100 mmHg, respectively, while the lowest values were 100 mmHg (SBP) and 70 mmHg (DBP). These results indicate that, although the average blood pressure values fall within the prehypertensive range according to international guidelines (Whelton et al., 2018), some participants exhibited elevated values that require monitoring and potential lifestyle interventions. All participants underwent laboratory blood tests. The values of the complete blood count (CBC), presented in Table 2, were within the normal recommended ranges for healthy adults (McPherson & Pincus, 2017). This indicates that, despite the presence of excess body weight and elevated blood pressure in some participants, there were no apparent hematological abnormalities in this population.

Table 2. Complete blood count in the studied population

Parameter	Average	SD $\pm$	Minimum	Maximum
WBC ($\times 10^3/\mu\text{L}$)	6.0	1.3	3.8	9.0
RBC ($\times 10^6/\mu\text{L}$)	4.8	0.7	2.9	6.2
HCT (%)	43.1	6.3	27.2	51.8
HGB (g/dL)	14.4	2.2	8.7	17.5
PLT ($\times 10^3/\mu\text{L}$)	187.9	49.1	118	312

The anthropometric and clinical data indicate that the studied population predominantly consists of middle-aged individuals with excess body weight, with an average BMI suggesting pre-obesity. The wide range of body weights, including individuals with significantly higher weight (up to 146 kg), highlights the variability in body composition and the potential metabolic risk. Elevated systolic and diastolic blood pressure values in some participants are consistent with trends observed in populations with excess body weight, indicating a higher prevalence of prehypertension or hypertension (Kearney et al., 2005). Normal complete blood count values suggest that, at present, there are no significant hematological complications, such as anemia or leukocytosis, associated with obesity in this population. However, considering the well-established relationship between obesity, hypertension, and metabolic disturbances, these individuals may be at an increased risk of developing cardiovascular disease and metabolic syndrome in the future (Lavie et al., 2014). The findings underscore the importance of regular health monitoring and highlight the potential need for lifestyle interventions, including dietary modification, physical activity, and stress management, to reduce cardiovascular and metabolic risk among military personnel. The mean white blood cell count (WBC) was $6.0 \times 10^3/\mu\text{L}$ (SD ± 1.3), red blood cell count (RBC) $4.8 \times 10^6/\mu\text{L}$ (SD ± 0.7), hematocrit (HCT) 43.1% (SD ± 6.3), hemoglobin (HGB) 14.4 g/dL (SD ± 2.2), and platelet count (PLT) $187.9 \times 10^3/\mu\text{L}$ (SD ± 49.1) (Table 2). Maximum and minimum values were within clinically acceptable ranges, although individual extremes were observed (e.g., HGB as low as 8.7 g/dL and PLT up to $312 \times 10^3/\mu\text{L}$). These findings indicate that, on average, hematological parameters were within normal reference ranges (McPherson & Pincus, 2017). Minor deviations in some participants may reflect individual physiological variations, minor subclinical conditions, or lifestyle influences such as diet, physical activity, and stress levels (Pejic et al., 2018). Importantly, no significant cytopenias or hematological disorders were detected, suggesting that the participants, despite excess body weight or elevated blood pressure, generally maintain a normal hematological status.

The biochemical panel, which included liver enzymes, kidney function tests, and glucose levels, is shown in Table 3. The mean values for the liver enzymes alanine aminotransferase (ALT), aspartate aminotransferase (AST), gamma-glutamyltransferase (GGT), direct bilirubin (DB), and creatinine (CRE), as well as glucose levels (GLU) and urea levels, were as follows: ALT - mean = 27.3 U/L, SD $\pm$ 12.2; AST - mean = 27.2 U/L, SD $\pm$ 8.4; GGT - mean = 21.6 U/L, SD $\pm$ 7.9; DB - mean = 5.2 μ mol/L, SD $\pm$ 1.2; CRE - mean = 92.4 μ mol/L, SD $\pm$ 14.7; GLU - mean = 5.1 mmol/L, SD $\pm$ 0.7; urea - mean = 6.4 mmol/L, SD $\pm$ 5.3. The greatest deviations from the mean values were noted for ALT and CRE. This may indicate that some participants have increased liver enzyme activity or decreased kidney function. Although the mean values for these tests are within normal ranges, these deviations may be signs of early metabolic problems or liver or kidney strain due to certain lifestyles, such as diet and level of activity (Kleiner et al., 2019; Levey et al., 2009). Regular monitoring of these parameters is recommended, especially in populations with excess body weight and increased cardiovascular risk, as early detection may prevent progression to more severe metabolic or organ dysfunction.

Table 3. Biochemical analyses in the studied population

Parameter	Average	SD $\pm$	Minimum	Maximum
ALT (U/L)	27.3	12.2	12.5	60.8
AST (U/L)	27.2	8.4	16.0	51.1
GGT (U/L)	21.6	7.9	8.9	36.3
DB (μ mol/L)	5.2	1.2	3.5	8.1
CRE (μ mol/L)	92.4	14.7	62.3	126.6
GLU (mmol/L)	5.1	0.7	4.3	7.4
UREA (mmol/L)	6.4	5.3	3.0	30.3

The lipid levels of the participants in the study have been summarized in Table 4. The average lipid levels of the participants were found to be 5.1 mmol/L (SD $\pm$ 1.1) for cholesterol, 1.8 mmol/L (SD $\pm$ 1.3) for triglycerides, 2.0 mmol/L (SD $\pm$ 0.5) for LDL, and 0.8 mmol/L (SD $\pm$ 0.3) for HDL. The range of lipid levels indicates that while some of the participants had lipid levels within normal limits, the lipid levels of the rest of the participants were abnormal. The abnormal lipid levels indicate that the participants had low HDL and high triglycerides. These lipid levels are known risk factors for heart disease (Grundy et al., 2018). The range of lipid levels indicates the need for a tailored approach to improve lipid levels. The approaches that could be used to improve lipid levels include diet, exercise, and the use of drugs. The results of the study have provided a good foundation for the development of a preventive and health promotion program for the military.

Table 4. Lipid Profile in the studied population

Parameter	Average	SD $\pm$	Minimum	Maximum
CHOL (mmol/L)	5.1	1.1	3.2	7.7
TG (mmol/L)	1.8	1.3	0.6	6.7
LDL (mmol/L)	2.0	0.5	1.3	3.3
HDL (mmol/L)	0.8	0.3	0.5	1.5

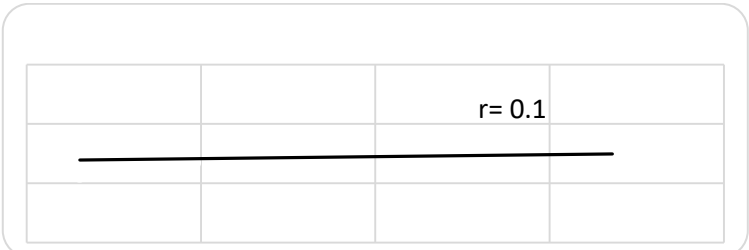
Lab tests indicate that overall, the group is in a normal state in terms of their blood and chemical composition. However, there is a clear indication that there is variability in liver enzymes, kidney functions, and cholesterol/triglyceride levels. This indicates early metabolic changes in the people’s bodies, likely due to their state of being overweight. The plan is to implement measures aimed at reducing health risks through improved nutrition, increased exercise, and monitoring liver enzymes, kidney functions, and lipid profiles.

3.2. Correlation analyses between triglycerides, blood glucose and BMI

To investigate metabolic associations in the studied population, correlations were analyzed between triglyceride levels (TG), blood glucose levels (GLU), and body mass index (BMI).

3.2.1. Triglycerides and BMI

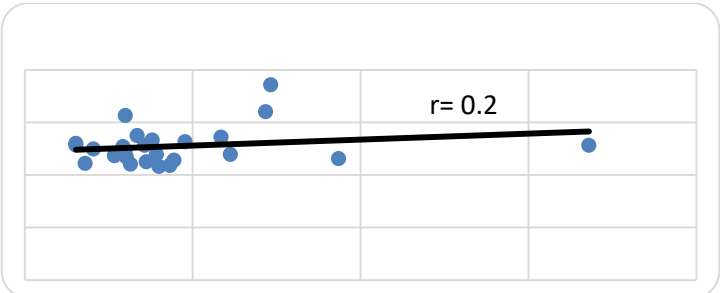
The correlation between TG and BMI showed a low positive association ($r = 0.1$) (Graph 1). This indicates that individuals with higher BMI tend to have slightly elevated TG levels. This finding is consistent with previous research linking excess body weight, a sedentary lifestyle, and dietary habits to increased triglyceride levels (Grundy et al., 2018; Pejic et al., 2018).



Graph 1. Correlation between triglyceride levels and BMI ($r = 0.1$).

3.2.2. Triglycerides and blood glucose

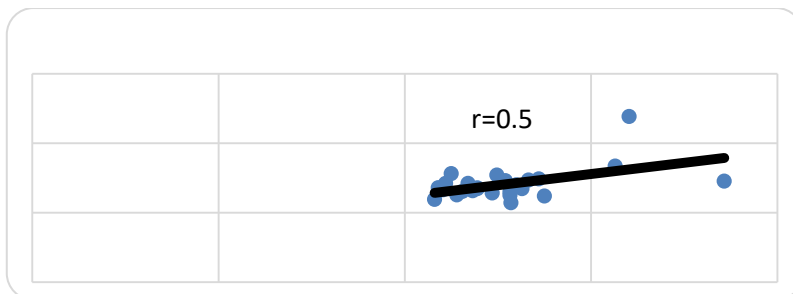
Analysis of the association between TG and GLU indicated a modest positive correlation ($r = 0.2$) (Graph 2). Although the association is weak, it indicates a potential link between lipid and glucose metabolism, supporting the idea that metabolic disturbances may be multifactorial. These disturbances are influenced by lifestyle-related factors and are recognized contributors to the risk of chronic non-communicable diseases (Levey et al., 2009; Kleiner et al., 2019).



Graph 2. Correlation between triglyceride levels and blood glucose ($r = 0.2$).

3.2.3. Blood glucose and BMI

The correlation between GLU and BMI showed a moderate positive association ($r = 0.5$) (Graph 3), representing the strongest association observed in this study. This finding reflects the relationship between increased BMI and impaired glucose regulation. Statistical analysis using the t-test for correlation confirmed significance at $p < 0.01$. Specifically, the tabular t-value of 0.471 was lower than the calculated t-value of 3, indicating a significant difference between BMI and blood glucose levels in the studied population.



Graph 3. Correlation between blood glucose and BMI ($r = 0.5$, $p < 0.01$).

These results suggest that higher BMI may be associated with impaired glucose and lipid metabolism. The low to moderate correlations emphasize the importance of lifestyle factors, dietary habits, and other risk determinants for metabolic health. These findings highlight the significance of early monitoring and targeted interventions to reduce the burden of metabolic disturbances.

4. CONCLUSION

This study provides a general overview of the body measurements and clinical findings of the military personnel studied, helping to understand the health condition and potential cardiometabolic risk of the active-duty personnel. The results of the study indicate that the majority of the population were middle-aged and had excess body weight. The average blood pressure of the population was found to be in the prehypertensive range. This is important because it is known that having excess body weight and increased blood pressure is a potential risk factor for the development of cardiometabolic risk. Although the hematological parameters of the population were within the normal reference range, there were variations in the biochemical and lipid parameters. This may indicate the potential risk of metabolic changes in the population, even in the absence of any clinical condition.

This is consistent with previous studies that have found metabolic issues to develop gradually, sometimes beginning with changes in biochemical parameters before progressing to more overt issues. One of the main takeaways from this study is the moderate positive relationship between body mass index (BMI) and blood glucose levels. This is consistent with the well-known association between increased body mass and metabolic control, which may represent one of the first steps in the process leading to insulin resistance and metabolic disease. Finally, the low-to-moderate levels of intercorrelation between triglycerides, glucose, and BMI support the view that metabolic disease is multifactorial, resulting from a complex interplay of physiological, behavioral, and environmental factors. Lifestyle factors such as diet, exercise, occupational demands, and psychosocial stressors may all play a

significant role in metabolic disease in military populations, so these data should be viewed within the context of military lifestyle factors.

This study, therefore, points out the significance of early detection of cardiometabolic risk factors in military personnel. It emphasizes the need for a comprehensive, integrated, and cohesive health prevention program, which incorporates health education, health checkups, and well-structured lifestyle modification programs, in order to reduce the risk of cardiometabolic risk factors, promote health, and sustain the health of military personnel in top form.

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EFFECTS OF VITAMIN C AND D SUPPLEMENTATION ON PULMONARY FUNCTION, SYMPTOMS AND INFLAMMATORY PARAMETERS IN NON-OBSTRUCTIVE CHRONIC BRONCHITIS

ЕФЕКТИ ОД СУПЛЕМЕНТАЦИЈАТА СО ВИТАМИНИ Ц И Д ВРЗ БЕЛОДРОБНАТА ФУНКЦИЈА, СИМПТОМИТЕ И ВОСПАЛИТЕЛНИТЕ ПАРАМЕТРИ КАЈ НЕ-ОПСТРУКТИВЕН ХРОНИЧЕН БРОНХИТИС

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Abstract: Non-obstructive chronic bronchitis (NCB) is characterized by chronic productive cough without spirometric obstruction ($FEV_1/FVC \geq 0.70$), although patients often experience pronounced symptoms, functional impairment, and signs of systemic inflammation. Oxidative stress and immune dysregulation play an important role in the pathophysiology of the disease, suggesting a potential benefit from antioxidant and immunomodulatory interventions. The aim is to assess the effects of high-dose vitamin C and vitamin D supplementation on pulmonary function, symptoms, functional capacity, and inflammatory status in patients with NCB. Material and Methods: In this cross-sectional observational study, 62 adult patients with non-obstructive chronic bronchitis (NCB) were included and divided into a control group (standard therapy) and an intervention group that additionally received vitamin C (2 g/day) and vitamin D (100,000 IU monthly) for a period of six months. Symptom burden was assessed using the COPD Assessment Test (CAT), functional capacity was evaluated using the six-minute walk test (6MWD), and systemic inflammation was measured through serum C-reactive protein (CRP). Group comparisons were analyzed using independent t-tests or Mann–Whitney U tests, with a level of statistical significance set at $p < 0.05$. Results and discussion: Patients receiving vitamin supplementation showed significantly lower CAT scores ($p = 0.005$), significantly greater 6MWD distance ($p = 0.003$), and lower serum CRP levels ($p = 0.044$) compared to the control group. These results indicate reduced symptom burden, improved functional capacity, and reduced systemic inflammation. Conclusion: Supplementation with high doses of vitamin C and D in patients with non-obstructive chronic bronchitis leads to significant improvement in symptoms, physical endurance, and inflammatory status.

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Key words: Chronic bronchitis, pulmonary function, C-reactive protein, vitamin C, vitamin D.

Анстракт: Вовед: Не-обструктивниот хроничен бронхитис (NCB) се карактеризира со хронична продуктивна кашлица без докази за спироетриска опструкција, но често е придружен со изразени симптоми, намален функционален капацитет и појава на воспаление. Овие симптоми не се секогаш адекватно објаснети со класичните функционални тестови, што укажува на потреба од проширена системска проценка. Целта е да се проценат ефектите од суплементацијата со високи дози витамин С и витамин D врз симптомскиот товар, функционалниот капацитет и системската инфламација кај пациенти со не-обструктивен хроничен бронхитис. Материјал и методи: Во оваа пресечна опсервациска студија беа вклучени 62 возрасни пациенти со NCB, поделени во контролна група (стандардна терапија) и интервенциска група која дополнително примаше витамин С (2 g/ден) и витамин D (100.000 IU месечно) во период од шест месеци. Симптомскиот товар беше оценет со COPD Assessment Test (CAT), функционалниот капацитет со шестминутниот тест за одење (6MWD), а системската инфламација преку серумски C-реактивен протеин (CRP). Групните споредби беа анализирани со независни t-тестови или Mann-Whitney U тестови, со ниво на статистичка значајност $p < 0.05$. Резултати и дискусија: Пациентите кои примаа витаминска суплементација покажаа значително пониски CAT резултати ($p = 0.005$), значително поголема дистанца на 6MWD ($p = 0.003$) и пониски серумски нивоа на CRP ($p = 0.044$) во споредба со контролната група. Овие резултати укажуваат на намален симптомски товар, подобрен функционален капацитет и редуцирана системска инфламација. Заклучок: Суплементацијата со високи дози витамин С и D кај пациенти со не-обструктивен хроничен бронхитис доведува до значајно подобрување на симптомите, физичката издржливост и воспалителниот статус.

Клучни зборови: хроничен бронхитис, белодробна функција, C реактивен протеин, витамин С, витамин D.

1. INTRODUCTION

Non-obstructive chronic bronchitis (NCB) is defined by chronic productive cough and sputum expectoration lasting for at least three months in two consecutive years, in the presence of preserved spirometry, specifically a ratio of forced expiratory volume in the first second to forced vital capacity equal to or greater than 0.70 ($FEV_1/FVC \geq 0.70$) (Global Initiative for Chronic Obstructive Lung Disease–GOLD, 2023). Although these patients do not exhibit fixed airway obstruction, they frequently experience substantial morbidity manifested by persistent cough, increased sputum production, reduced exercise tolerance, recurrent respiratory infections, impaired quality of life, and an increased risk of progression to chronic obstructive pulmonary disease (COPD).

Recent research indicates that, despite normal spirometric findings, patients with NCB demonstrate significant pathophysiological alterations, including chronic airway inflammation, oxidative stress, mucus dysfunction, and immune dysregulation. Such impairments can be objectively assessed using tests such as the six-minute walk distance (6MWD), as well as through elevated scores on symptom assessment instruments such as the COPD Assessment Test (CAT).

Micronutrient supplementation, particularly with vitamin C and vitamin D, has been explored as a potential adjuvant strategy for modulating inflammatory processes, oxidative stress, and impaired immune defense in chronic respiratory diseases. Vitamin C is a water-soluble antioxidant that plays an important role in neutralizing reactive oxygen species (ROS), maintaining epithelial barrier integrity, and supporting both innate and adaptive immune

responses. Although direct clinical evidence regarding its effects in NCB is limited, available data suggest that vitamin C may reduce oxidative stress and enhance respiratory immune defense, which may indirectly contribute to improvement in symptoms and inflammatory status in chronic respiratory conditions (Wu et al. , 2022).

Vitamin D is a fat-soluble secosteroid hormone with well-established immunomodulatory and anti-inflammatory properties. Clinical studies and meta-analyses conducted in patients with COPD have demonstrated that vitamin D supplementation is associated with improvements in lung function (FEV₁), reductions in exacerbation frequency, decreased symptom burden as measured by the CAT score, and enhanced functional capacity, as reflected by increased six-minute walk distance (6MWD) (Zendeleg et al. , 2015; Liu et al. , 2019). Furthermore, vitamin D plays a key role in regulating inflammatory responses, which may also be reflected in reductions in systemic inflammatory markers such as C-reactive protein (CRP) (Lehouck et al. , 2012; Domej et al. , 2014; Martineau et al. , 2017).

In this context, combined supplementation with vitamin C and vitamin D represents a biologically plausible strategy for improving pulmonary function, reducing symptom burden, enhancing functional capacity, and modulating the inflammatory response in patients with NCB (Schrumpf et al. , 2020; Sluyter et al. , 2021).

2. MATERIALS AND METHODS

2.1 Study Design and Participants

This cross-sectional observational study was conducted in 2025 and included 62 adult participants diagnosed with non-obstructive chronic bronchitis (NCB). Inclusion criteria were current or former smokers with a smoking history of more than 20 pack-years and age between 32 and 68 years. Participants were recruited through outpatient clinics, physician referrals, and public announcements distributed in clinical and community settings. All participants were fully informed about the purpose and procedures of the study and provided written informed consent prior to enrollment. The study protocol was reviewed and approved by the local ethics committee (Ref. No. 14211).

2.2 Grouping

Participants were divided into two groups based on whether they received vitamin supplementation (vitamin C and/or vitamin D). The control group received standard care for NCB without micronutrient supplementation, whereas the intervention group received high-dose supplementation consisting of vitamin D (100, 000 IU every four weeks) and vitamin C (2 g/day, administered as 500 mg four times daily) for a period of six months, in addition to standard care (Hemilä, 2017).

2.3 Symptom Assessment

Symptom burden and the impact of disease on daily functioning were assessed using the COPD Assessment Test (CAT). CAT is a simple, validated, self-administered questionnaire widely used in clinical practice to evaluate the impact of chronic respiratory diseases on quality of life and to monitor disease progression. The questionnaire consists of eight items,

each scored on a scale from 0 to 5. The items cover various disease-related domains, including respiratory symptoms (such as cough, sputum production, and dyspnea), sleep disturbances, energy levels, and limitations in daily physical and social activities. The total CAT score ranges from 0 to 40, with higher scores indicating greater symptom burden and more pronounced impairment of quality of life (Jones et al. , 2009).

CAT is a practical tool for routine clinical monitoring, as it is easy to complete, requires minimal time, and allows early identification of changes in clinical status. In this study, a CAT score ≥ 10 was considered indicative of clinically significant symptom burden and was used as a threshold to identify patients with pronounced symptoms. The entire procedure was conducted under the supervision of qualified healthcare personnel, in accordance with ethical principles ensuring participant safety and respect (Lee et al. , 2021).

2.4 Assessment of Functional Exercise Capacity (6MWT)

Functional exercise capacity was assessed using the Six-Minute Walk Test (6MWT), with the six-minute walk distance (6MWD) taken as the primary outcome measure. The test was performed in accordance with the recommendations of the American Thoracic Society (ATS) and represents a simple, validated, and widely used functional test for evaluating cardiorespiratory capacity and exercise tolerance, particularly in patients with chronic pulmonary and cardiovascular diseases.

The 6MWT was conducted in an indoor, flat, straight corridor with a standard length of 30 meters. Participants were instructed to walk at a self-selected pace that they could maintain for six minutes, aiming to achieve the maximum possible distance. During the test, short rest periods were allowed if necessary; however, participants were encouraged to resume walking as soon as they felt able, without stopping the timing of the test. Subjective symptoms such as fatigue, dyspnea, or other discomforts were recorded if they occurred during the test.

The 6MWT provides an objective assessment of patients' ability to perform daily physical activities and represents a clinically relevant indicator of functional status. In addition, the test is used to monitor disease progression and to evaluate the effectiveness of therapeutic interventions, including pharmacological and adjunctive strategies, in patients with chronic respiratory diseases (Jones et al. , 2013).

2.5 Assessment of Inflammatory Status

Systemic inflammation was assessed by measuring serum levels of C-reactive protein (CRP), a sensitive and widely used biochemical marker of acute and chronic inflammatory activity. CRP is synthesized in the liver in response to pro-inflammatory cytokines and is commonly used in clinical practice to assess the intensity of inflammatory responses in chronic respiratory diseases.

Blood samples were obtained from peripheral venous blood under routine laboratory conditions using standard aseptic techniques. Collected samples were analyzed in serum using a validated biochemical method, in accordance with laboratory protocols. CRP values were expressed in milligrams per liter (mg/L) and used as an indicator of the presence and degree of systemic inflammation.

To minimize the influence of acute inflammatory conditions, no active infection or acute respiratory exacerbation was documented in participants at the time of blood sampling. The obtained CRP values were included in the analysis as a continuous variable and compared between the vitamin and control groups in order to evaluate the potential effect of vitamin C and vitamin D supplementation on systemic inflammatory activity in patients with non-obstructive chronic bronchitis.

2.6 Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics for Windows, version 27. Descriptive statistics were presented as means and standard deviations (SD) for continuous variables and as frequencies (%) for categorical data. Data distribution was assessed using the Shapiro–Wilk test.

Depending on data normality, independent t-tests or Mann–Whitney U tests were used to compare pulmonary function parameters between the vitamin and control groups. Statistical significance was set at $p < 0.05$.

3. RESULTS AND DISCUSSION

This study investigated the effects of combined supplementation with high-dose vitamin C (2 g/day) and monthly high-dose vitamin D (100,000 IU) on symptom burden, functional exercise capacity, and systemic inflammation in patients with non-obstructive chronic bronchitis (NCB) over a six-month period.

3.1 Assessment of Symptom Burden (CAT)

Symptom burden, assessed using the COPD Assessment Test (CAT), was significantly lower among participants receiving vitamin supplementation (Table 2). The mean CAT score was 11.29 ± 2.25 in the vitamin supplementation group compared with 13.77 ± 4.06 in the control group, with median values of 11 and 13, respectively. CAT scores ranged from 5 to 23 in the control group and from 6 to 18 in the vitamin group. The difference between the groups was statistically significant (independent t-test, $P = 0.005$), indicating a significantly reduced symptom burden among participants receiving vitamin supplementation.

Table 1. Comparison of CAT scores between the group without vitamins and the vitamin supplementation group.

CAT	Without vitamins	With vitamins	Total
N	31	31	62
Mean	13.77	11.29	12.53
Median	13	11	12
SD	4.06	2.25	3.49
Min-Max	5 – 23	6 – 18	5 – 23
Range	18	12	18
Independent samples t-test	$P = 0.005$		

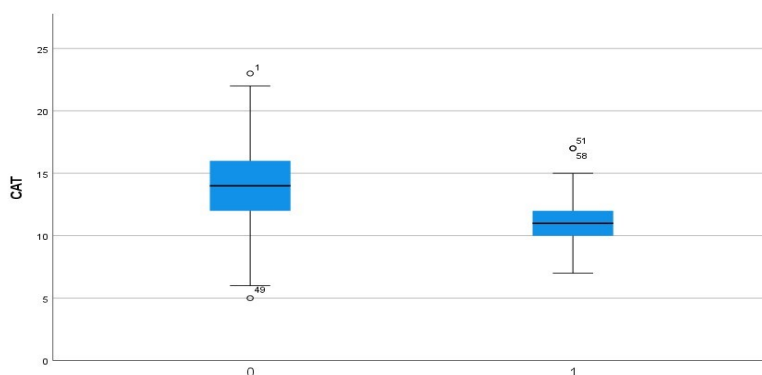


Figure 1. Comparison of CAT scores between the non-vitamin group and the vitamin-supplemented group (independent samples t-test: $p = 0.005$)

One of the main findings of this study is the significant reduction in symptom burden among patients who received vitamin supplementation, as evidenced by lower CAT scores. This indicates an improvement in subjective symptoms and quality of life, which represents a key clinical goal in patients with non-obstructive chronic bronchitis (NCB), as symptoms in these patients are often persistent and substantially affect daily functioning. The reduction in CAT scores suggests that vitamin supplementation may have a positive effect on the overall clinical burden of the disease, independent of traditional functional parameters.

3.2 Functional Exercise Capacity (6MWD)

Functional exercise capacity, assessed using the six-minute walk distance (6MWD), was significantly better in the vitamin-supplemented group (Table 4). The mean walking distance over six minutes was 407.61 ± 47.61 m in the supplemented group, compared with 362.77 ± 66.16 m in the control group. Median values were 407 m and 383 m, respectively. Walking distance ranged from 195 to 535 m in the control group and from 320 to 487 m in the vitamin group. This difference was statistically significant (independent t-test, $p = 0.003$), indicating a significantly improved functional exercise capacity among participants receiving vitamin supplementation.

Table 2. Six-minute walk distance (6MWD) by group

6MWD	Without vitamins	With vitamins	Total
N	31	31	62
Mean	362.77	407.61	385.19
Median	383	407	385
SD	66.16	47.61	61.47
Min–Max	195 – 535	320 – 487	195 – 535
Range	340	167	340
Independent samples t-test	$P = 0.003$		

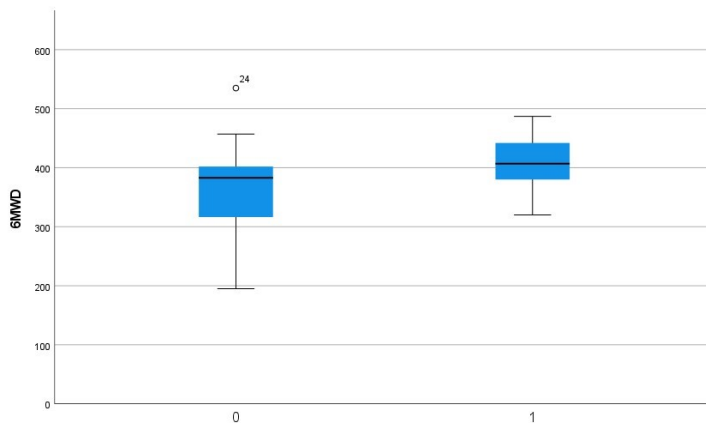


Figure 2. Comparison of 6MWD between the non-vitamin group and the vitamin-supplemented group (independent samples t-test: $p = 0.003$)

Functional exercise capacity, assessed using the six-minute walk test, was significantly improved in the vitamin supplementation group. The increase in 6MWD indicates improved exercise tolerance and more efficient cardiorespiratory adaptation, which has direct clinical relevance for patients' ability to perform daily activities.

This finding is particularly important in non-obstructive chronic bronchitis (NCB), where reduced functional capacity is often present despite the absence of spirometric obstruction and may be associated with chronic inflammation, reduced physical activity, and the occurrence of fatigue.

3.3 Inflammatory Status (CRP)

Serum levels of C-reactive protein (CRP) were significantly lower in the vitamin-supplemented group compared with the control group (Table 5). The mean CRP value was 2.51 ± 2.43 mg/L in the supplemented group versus 3.92 ± 2.92 mg/L in the non-vitamin group, with median values of 1.8 mg/L and 3.9 mg/L, respectively. CRP values ranged from 0 to 11.5 mg/L in the control group and from 0 to 9.3 mg/L in the vitamin group. The difference between groups was statistically significant (independent t-test, $p = 0.044$), indicating a significantly lower systemic inflammatory burden among participants receiving vitamin supplementation.

Table 3. Comparison of serum CRP values between groups

CRP	Without vitamins	With vitamins	Total
N	31	31	62
Mean	3.92	2.51	3.21
Median	3.9	1.8	2.6
SD	2.92	2.43	2.75
Min–Max	0 – 11.5	0 – 9.3	0 – 11.5
Range	11.5	9.3	11.5
Independent samples t-test	$P = 0.044$		

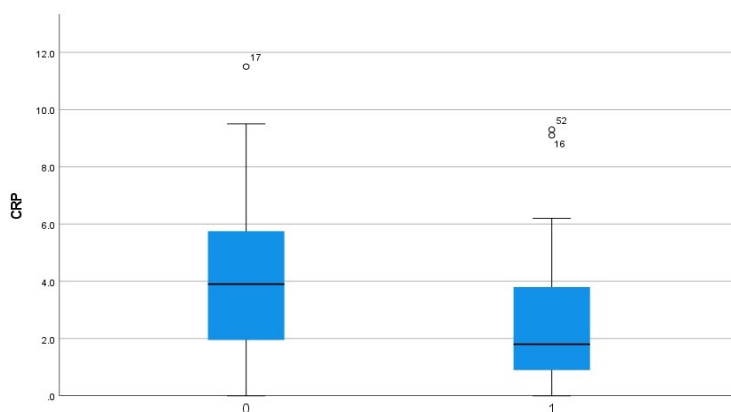


Figure 3. Comparison of CRP values between the non-vitamin group and the vitamin-supplemented group (independent samples t-test: $p = 0.044$).

Regarding systemic inflammation, patients in the vitamin supplementation group exhibited significantly lower serum levels of C-reactive protein (CRP) compared with the control group. This finding suggests a potential anti-inflammatory effect of combined vitamin C and vitamin D supplementation. The reduction in CRP provides biological support for the observed clinical improvements and indicates that part of the positive effects may be attributable to a decrease in chronic low-grade systemic inflammation, which is characteristic of chronic bronchitis.

The combined administration of vitamin C and vitamin D is biologically justified, given their complementary mechanisms of action. Vitamin C contributes to the reduction of oxidative stress, which is pronounced in smokers and in patients with chronic airway inflammation, while vitamin D has well-documented immunomodulatory and anti-inflammatory effects. These mechanisms may result in improved symptoms, enhanced physical endurance, and reduced systemic inflammation, without necessarily affecting classical parameters of pulmonary function.

4. CONCLUSION

The results of this study demonstrated that supplementation with high-dose vitamin C (2 g/day) and monthly high-dose vitamin D (100,000 IU) was associated with significant clinical improvements in patients with non-obstructive chronic bronchitis (NCB).

Patients receiving vitamin supplementation showed a significant reduction in symptom burden, assessed using the COPD Assessment Test (CAT), indicating an improvement in subjective clinical status and quality of life.

Functional exercise capacity, evaluated using the six-minute walk test (6MWD), was significantly improved in the vitamin supplementation group. The increased walking distance indicates enhanced physical endurance and better tolerance of daily activities, which has a direct positive impact on functional independence and overall patient well-being.

Regarding inflammatory status, the supplemented group exhibited significantly lower serum levels of C-reactive protein (CRP), suggesting a reduction in systemic low-grade inflammation. This finding provides biological support for the observed clinical

improvements and indicates that part of the positive effects may be attributable to the anti-inflammatory and immunomodulatory actions of combined vitamin supplementation.

These results have important clinical implications. Although patients with NCB have preserved spirometric measurements without airway obstruction, they often experience substantial symptom burden, reduced physical endurance, and impaired daily functioning. Introducing a low-cost, easily accessible, and relatively safe intervention, such as vitamin C and D supplementation, may represent an effective strategy to improve clinical and functional outcomes in this population.

In conclusion, the findings suggest that vitamins C and D may play a significant therapeutic role in patients with NCB, contributing to symptom reduction, improved functional capacity, and decreased systemic inflammation through mechanisms that extend beyond conventional spirometric assessment.

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LEGAL LIABILITY FOR DAMAGE OF COOPERATIVE BODIES TOWARDS THE COOPERATIVE

ЗАКОНСКА ОДГОВОРНОСТ ЗА ШТЕТУ ОРГАНА ЗАДРУГЕ ПРЕМА ЗАДРУЗИ

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Abstract: *The research covers relevant issues of liability for damage of cooperative bodies towards the cooperative: conceptual definition of the subject legal form of liability; assumptions of liability for damage (parties in a legal obligation, harmful action, damage caused, illegality, established causal link between the action and harmful consequences and the fault of the harmdoer); exclusion of liability; joint and several liability and implementation of the procedure for compensation for damage in practice. This work has as its subject exclusively one type of legal liability - liability for damage, and in terms of the subject of liability, exclusively the cooperative bodies as separate and collegial, i.e., their members as natural persons. The research is based on a normative and theoretical approach. The aim of the paper is to point out domestic and foreign legislative solutions on the liability for damage of cooperative bodies towards the cooperative, on the one hand, and theoretical positions on this issue, on the other hand.*

The purpose of the paper is to determine whether there are contemporary tendencies regarding the responsibility of cooperative bodies towards the cooperative and, if so, what they reflect.

Key words: *legal liability for damage, subjective liability, presumptions of liability for damage, cooperative bodies, cooperative.*

Апстракт: Предметним истраживањем обухваћена су релевантна питања одговорности за штету органа задруге према задрузи: појмовно одређење предметног правног облика одговорности; претпоставке одговорности за штету (стране у облигационо-правном односу, штетна радња, проузрокована штета, противправност, утврђена узрочна веза између радње и штетне последице и кривица штетника); искључење одговорности; солидарна одговорност и спровођење поступка за накнаду штете у пракси. Овај рад има за предмет искључиво једну врсту правне одговорности - одговорност за штету, а у погледу субјекта одговорности - искључиво органе задруге као инокосне и колегијалне, односно њихове чланове у својству физичких лица. Истраживање је заснивано на нормативно-теоријском приступу. Циљ рада је да се укаже на домаћа и страна законодавна решења о одговорности за штету органа задруге према задрузи, с једне стране, и на теоријске ставове по овом питању, с друге стране. Сврха рада је да се утврди да ли постоје савремене тенденције у погледу одговорности органа задруге према задрузи и, ако постоје, у чему се огледају.

Кључне речи: *законска одговорност за штету, субјективна одговорност, претпоставке одговорности за штету, органи задруге, задруга*

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1. INTRODUCTION

Liability constitutes one of the fundamental legal institutions and is, above all, a legal concept—legal liability. At the same time, liability represents a core principle of every democratic society. It is studied across various fields and disciplines, including ethics, philosophy, sociology, anthropology, theology, law (including cooperative law), as well as economics and politics. In general, liability in law (legal liability), including within the field of cooperative law, presupposes a breach of a rule of conduct (disposition) and the subjection of the offender to a sanction. Both natural and legal persons may be held liable, while natural persons may bear liability either individually (personally) or collectively (collegially).

Natural persons engaged in work within a cooperative, as well as those performing specific functions within the bodies of cooperatives and cooperative unions, have the right and duty to perform their entrusted tasks conscientiously and in accordance with the law. There exists an interest on the part of these individuals, cooperatives and cooperative unions, as well as a general societal interest, that their activities and tasks be carried out in compliance with the law and other regulations. In practice, such persons may undertake actions contrary to the law or fail to act despite having a legal duty to do so. This constitutes a violation of legal rules by individuals engaged in work or exercising certain functions within cooperatives and cooperative unions, where their conduct in the course of and in connection with work is regulated. Depending on whether such actions contain elements of a disciplinary breach, a misdemeanor, an economic offense, or a criminal offense, and whether damage has been caused by such acts or omissions, these individuals may potentially incur different forms of legal liability—disciplinary, misdemeanor, economic offense, criminal, or liability for damages. Only certain natural persons engaged in cooperatives and cooperative unions may additionally be subject to two specific types of liability—political and, potentially, professional liability. Each type of liability has its own legal nature and content. These forms of liability are not mutually exclusive and may run concurrently for the same punishable act or unlawful conduct, subject to certain exceptions. However, not every act or unlawful conduct gives rise to all types of liability; as a rule, it gives rise to one, two, or more (e.g., disciplinary and liability for damages; criminal, disciplinary, and liability for damages).

When referring to liability in the field of cooperative law, specific legal types of liability are implied. Unlike non-legal responsibility, legal liability entails the accountability of a subject of law (natural or legal person) for a committed legal delict.⁵² Legal liability arises when a person (natural or legal) violates a legal norm, i.e., commits a legal delict, and is subjected to a sanction.⁵³ (Tripković, 2018). The notion of a delict encompasses all unlawful and culpable conduct (acts, omissions, or abstentions) of legal subjects. In cases of disciplinary liability, norms of labor law are violated; in liability for damages, norms of civil law; and in penal liability, norms of criminal law—whether criminal offenses, economic offenses, or misdemeanors. Depending on the type of legal norm that has been violated by the committed delict, legal liability may take different forms. Each type of delict entails a corresponding type of liability. (Radišić, 2004).

⁵² By “delict” here is meant a violation of any legal norm, not only a violation of a criminal law norm.

⁵³ Responsibility necessarily implies a sanction, because there is no responsibility without a sanction.

This research has as its subject exclusively one type of legal liability - liability for damage, and in terms of the subject of liability - exclusively the bodies of the cooperative as separate and collegial, that is, their members as natural persons. The research is based on a normative (legislative) and theoretical approach.

2. CONCEPTUAL DEFINITION OF STATUTORY LIABILITY FOR DAMAGE CAUSED BY COOPERATIVE BODIES TO THE COOPERATIVE

The general regime of liability for damages in comparative legal systems is governed by the rules of civil law contained in civil codes or other statutes, while in Serbia it is regulated by the Law on Obligations. (Law on Obligations). However, certain issues relating to this specific type of liability are also subject to regulation under special legislation. This is the case with the examined cooperative legislation, as certain issues concerning the liability for damages of cooperative bodies and members of such bodies vis-à-vis the cooperative are regulated by a specific law on cooperatives, with a reference to the “appropriate application” (“application”) of another statute—namely, the law governing the legal status of commercial companies. Consequently, the rule of precedence of special over general provisions applies to liability for damages of cooperative bodies towards the cooperative, in accordance with the principle *lex specialis derogat legi generali*.

For illustration, in Serbian cooperative law, the legal liability for damage of cooperative bodies towards the cooperative is regulated by the imperative norms of the law governing cooperatives, with reference to the provisions of the Law on Business Companies, “in the part regulating special duties towards the business company”, unless otherwise provided by the parent law. (Law on Cooperatives) In Serbian company law, duties of care (duty of care) in the conduct of company affairs relate to a specific circle of persons. The legislator has encompassed these duties through several legal institutions (persons having special duties towards the company, related parties, duty of care, conflict of interest, personal interest, business secret, prohibition of competition) and regulated them under the title “special duties towards the company” (special duties in the conduct of company affairs). (The Law on Business Companies). In Croatian cooperative law, reference is not made to appropriate application, but rather to the application of the provisions of the Companies Act, (Law on Cooperatives), and not specifically to the part regulating special duties towards the company, but to the relevant provisions of that Act. (Companies Act).

In the examined cooperative legislation, it is only generally prescribed that members of bodies “are liable for damages”, without a more precise determination of the manner of their liability. Therefore, the applicable rules for this issue are those of civil law. As a rule, the cooperative is entitled to compensation for both actual damage and loss of profit, and compensation is effected by restoring the damaged object to its previous condition. If this is not possible, the damage caused to the cooperative is assessed and compensated in monetary terms. (Law on Obligations, Art. 189 et seq.).

Liability for damages of cooperative bodies towards the cooperative presupposes the establishment of an obligation-law (debtor–creditor) relationship in which one party—the body or members of the body of the cooperative—has caused damage to the cooperative and

is obliged to compensate it to the other party, i.e., the cooperative itself, to which the compensation belongs. The obligation of the tortfeasor to compensate the damage corresponds to the subjective right of the injured party to claim such compensation. This is a claim asserted by the cooperative against members of its body on the basis of fault for the damage caused.

Liability for damages of cooperative bodies or their members towards the cooperative is established on the principles of fault-based (subjective) liability. Serbian legislator has established the general principle of liability for damages under civil law: “whoever causes damage to another shall be obliged to compensate it, unless he proves that the damage occurred without his fault”. (Law on Obligations, Art. 154th st. 1.)

The fact that liability for damage caused to the cooperative by its bodies or their members is regulated by law, and that the source of the obligation does not arise from a contract but from the law itself, indicates that this is statutory (delict/tort, non-contractual) liability. More precisely, this liability for damage presupposes a mandatory legal obligation to compensate the damage.

Cooperative bodies are not subjects of law and therefore do not possess their own will or property; consequently, they cannot be held directly liable for damage caused to the cooperative. Cooperative bodies and their members consist of natural persons who have legal personality and through whom the bodies express their will.

In conclusion, the characteristics of statutory liability for damages of cooperative bodies or their members towards the cooperative are as follows: it is a specific type of legal liability; it differs in content and legal nature from other forms of legal liability (e.g., disciplinary, misdemeanor, criminal); it is of a pecuniary nature, as it affects the property rather than the personality of the body or its members; it is autonomous and independent, yet not mutually exclusive with other forms of liability, and may coexist concurrently (e.g., with criminal liability); it is primarily governed by the law on cooperatives and by the application of company law, and subsidiarily by general rules of civil law; it is fault-based (subjective), as bodies and their members are liable on the basis of fault; it is statutory (delict/tort, non-contractual) liability, as the source of the obligation arises from the law, i.e., from a delict; it is personal, direct, individual or joint and several (solidary) for the body or its members; liability for damages arises when legally prescribed conditions (special prerequisites) are met; sanctions for causing damage are of a pecuniary nature; it is determined in a legally prescribed procedure before a competent court; and others.

3. GENERAL REMARKS ON LIABILITY FOR DAMAGES

Liability for damage assumes property liability for a committed civil tort, the consequences of which are reflected in the causing of damage, which is why it is also called civil, civil, patrimonial, property or material. It should be borne in mind that liability for damage includes compensation for damage, and not every compensation constitutes liability. (Radišić, 2004)

When causing damage, the question arises: what is the basis of liability? In the historical context, the principle of fault was first accepted as the basis of liability – subjective liability. The later development of technology and engineering led to the emergence of liability for dangerous goods, on the basis of which the owner or holder of a dangerous thing as well as

the perpetrator of a dangerous activity become liable for the damage caused, without determining their guilt – objective liability. The legal basis for liability for damage by cooperative bodies is fault, which is why we continue this research in the field of subjective liability of cooperative body members.

The two fundamental forms of civil liability for damages in legal theory have been accompanied by the development of two doctrines—the theory of unity and the theory of dualism. Unlike the theory of unity, the dualistic approach distinguishes between contractual (contractual) and non-contractual (delict/tort, statutory) liability. The main criterion for their distinction lies in the source of obligations. The first form of liability is governed by contract and, as a rule, applies to the contracting parties. Contractual liability for damages arises from a breach of the principle of autonomy of the will of the contracting parties. The second form of liability is regulated by law and extends to all persons (natural and legal) covered by a general legal norm. It does not arise from the non-performance of an obligation, but from a delict. For that reason, stricter liability is often advocated in this context. The former may be excluded or limited, as it is based on the will of the contracting parties; however, it cannot be excluded in cases of more serious forms of fault—*dolus* and *culpa lata*. The latter is based on mandatory legal norms, which the parties cannot modify by their will. Both forms of liability ultimately aim at compensating the injured party for the damage suffered. (Krulj, 1959). Based on the foregoing, the question arises: to which form of liability does the liability for damages of cooperative bodies belong? Such liability is non-contractual, as its source lies in the law. (Popović, 1983).⁵⁴

4. PRESUMPTIONS OF LIABILITY FOR DAMAGE OF COOPERATIVE BODIES TOWARDS THE COOPERATIVE

In order to address statutory liability for damages of cooperative bodies towards the cooperative, certain prerequisites (specific conditions) must be fulfilled, such as: the parties to the obligation-law relationship (the tortfeasor—the body or members of the cooperative body, and the injured party—the cooperative, i.e., the parties to the dispute); a harmful act; the occurrence of damage; unlawfulness; the existence of a causal link between the act and the harmful consequence; and the fault of the tortfeasor.

Parties to the obligation-law relationship – There are two parties in the debtor-creditor relationship in cases of liability for damages of cooperative bodies towards the cooperative: the tortfeasor or the subject of liability (liable person), and the injured party or the cooperative (injured person). The liable person is the body or members of the cooperative body whose actions cause damage to the cooperative. The injured party is the cooperative that has suffered the damage.

On the side of the liable party appear the cooperative bodies. Cooperative bodies are established on the principles of cooperative democracy and equality of members for the

⁵⁴ Non-contractual liability for damage is regulated differently in comparative law. However, the different systems sometimes have similar starting ideas, and in recent history, faced with the challenges of the industrial revolution, they have given similar answers to the demands of modern society. The three systems analyzed (French, German and English) represent examples with particular characteristics. Each of them is also a progenitor, since it has exerted an influence beyond the country in which it was founded.

purposes of governance, supervision, and management of the cooperative's activities. Equality of cooperative members in the governance of the cooperative presupposes both active and passive voting rights, including the right of control and supervision over the cooperative's operations, based on the traditional cooperative principle—"one member, one vote", subject to certain exceptions. For example, in German cooperative law, employees also participate in the governance of the cooperative.

As a rule, cooperative bodies are designated and regulated by the law on cooperatives, although the law may allow members, based on the principle of freedom of contract, to establish and regulate additional bodies through cooperative rules (statute). Furthermore, cooperative bodies are generally classified by law as mandatory or optional. In addition, with regard to their composition, cooperative bodies may be collegial or individual.

Based on the nature of the functions performed by cooperative bodies, they may be classified as follows: the assembly, as the body of members and the highest governing body; the management board, as the governing body of the cooperative; the supervisory board, as the body responsible for oversight of operations and business activities; and the director, as the body responsible for representation and management of the cooperative. (Henry, 2001).⁵⁵ The terminology used for these bodies may differ depending on the cooperative system to which they belong. As a rule, bodies and their members are elected from among cooperative members, but may also be chosen from among employees of the cooperative or from among natural persons outside both the membership and employment structure of the cooperative.

In the example of Serbian cooperative legislation, the bodies of a cooperative are: the assembly, the management board, the supervisory board, and the director. As follows from their designation, the first three bodies are collegial, while the fourth is a single-person (individual) body. (Cooperative Union of Serbia).⁵⁶

⁵⁵ Unlike companies, the operation of a cooperative depends on the participation of its members, who must strive to effectively influence the operation of the cooperative. However, as a legal entity, a cooperative must maintain a certain independence from its members. Therefore, the internal organization, the division of powers (competences) between the various bodies, the selection of the administration, and the making of important decisions must reflect on all members of the cooperative, regardless of their financial contribution. Issues related to the cooperative's associative nature should be placed under the responsibility of the assembly, and those related to the enterprise should be placed under the responsibility of the board of directors, while the day-to-day issues related to the enterprise should be placed under the responsibility of the board of directors to the (professional) manager.

⁵⁶ In cooperative law, the mandatory bodies are: in Germany: the assembly, the management board (board of directors) and the supervisory board; in Slovenia: the assembly, the president of the cooperative and the supervisory board, and a cooperative with ten or more members also has a board of directors; in Croatia: the assembly, the supervisory board and the manager; in Austria: the assembly and the management, while the supervisory board is optional, except in cooperatives with more than 40 full-time employees; in Switzerland: the assembly, the management board and the supervisory body (one or more auditors); in Greece: the assembly, the management board and the supervisory board; in Italy: the assembly, the management board and the supervisory board; in France: the assembly, the management body (in the form of a management board or directory) and the supervisory board, and an agricultural cooperative whose annual income exceeds the amount of money established by law must

The Assembly of the Cooperative – Bearing in mind that the assembly is “the highest governing body”, that it consists of “all members”, and that within it “members exercise mutual control”, it is not expected that members, through their participation in the assembly, would cause damage to the cooperative, i.e., act “to their own detriment”. These considerations explain why Serbian, as well as other legislators, have generally refrained from explicitly regulating the liability of the assembly for damages caused to the cooperative. On the other hand, the legislator justifiably addresses and regulates this issue with respect to other cooperative bodies—namely, members of the management and supervisory boards and the director. These bodies, and their members, due to their position within the cooperative, are in a situation where their actions may cause damage to the cooperative. Therefore, it has been necessary to establish, through mandatory legal provisions, their liability for damages caused to the cooperative whose bodies they constitute. Unfortunately, as will be analyzed later in this paper, the Serbian legislator has opted to remain at a general and largely uniform level of regulation, without providing more specific rules for individual bodies. This approach was likely guided by the existence of a legal solution providing for the appropriate application of the provisions of the Law on Companies, as well as the subsidiary application of civil law rules. It is useful to note here a more specific solution concerning the liability of the president and members of the management board for damages caused to the cooperative “by their decisions”, which was contained in the previously applicable Law on Cooperatives. (Law on Cooperatives, Official Gazette of the FRY, No. 41/1996 and 12/1998 and Official Gazette of the Republic of Serbia, No. 10172005 – other law and 34/2006, Art. 39.).⁵⁷ In German cooperative law, the liability of members of the management board is based on the standard of due care of a diligent and prudent cooperative manager, while the liability of members of the supervisory board is based on the standard of due care of a diligent and prudent cooperative supervisor. (Cooperative regulations in some European countries).⁵⁸

Management Board – In Serbian cooperative law, the management board is the executive body of the general assembly of the cooperative. Its members are “elected by the general assembly of the cooperative” “from among the cooperative members”. (Law on Cooperatives, Art. 40, paragraph 3.)

In addition to regulating its composition, election, and competences, the legislator has also addressed the issue of the “liability” of the members of the management board. In this regard, it has prescribed the following: “Members of the management board are obliged to perform

have one or more controllers; in Spain: assembly, management board and one or more auditors; in Portugal: assembly, management and supervisory board; in Bulgaria: general assembly, management board, president of the cooperative (also president of the management board) and supervisory board; in the Czech Republic and Slovakia: assembly, management board and control commission; in Montenegro: assembly, management board, supervisory board and director; in Bosnia and Herzegovina: assembly, management board and supervisory board; in Republika Srpska: assembly, management board, supervisory board and director. See: Cooperative Federation of Serbia, *Regulations on Cooperatives in Some European Countries*, Belgrade, 1995, pp. 3-135.

⁵⁷ The president and members of the board of directors are jointly and severally liable for the damage they cause by their decisions if the decision was made with gross negligence or with the intent to cause damage. The aforementioned persons were not liable for the damage if they were against the decision and if they set out their opinion in the minutes.

⁵⁸ “Cooperative Law in the Federal Republic of Germany: 100 Years of Cooperative Law”, *Regulations on Cooperatives in Some European Countries*, p. 131.

their function conscientiously, honestly, and responsibly towards the cooperative, with the due care of a prudent businessperson and in accordance with the interests of the cooperative.” This general statutory formulation establishes several principles upon which the liability of management board members in the performance of their function is based, in relation to all specific types of legal liability, including their liability for damages towards the cooperative. However, the legislator also found it necessary to regulate liability for damages of management board members through a general provision: “Members of the management board shall be liable, in accordance with the law, for the damage they cause to the cooperative”. (Law on Cooperatives, Art. 42) It is also useful to refer to the solution adopted by the Hungarian legislator, in comparison with the solution contained in the previously applicable law in Serbia.⁵⁹ (Vig, Doklešić, 2009)

In Italian cooperative law, on the basis of the Civil Code of 1942, as subsequently amended, members of the management board are liable for damage suffered by the cooperative, its creditors, members, or third parties “due to their wrongful acts”. (Cooperatives in Italian Law General Questions, Regulations on Cooperatives in Some European Countries, p. 76.) Under the Austrian Cooperative Act, members of the executive board who act in their own name beyond the limits of their authority or contrary to the provisions of the Act or the cooperative’s statute are personally, jointly and severally, and individually liable for any damage caused. (Unofficial Translation of The Austrian Cooperative Societies Act, paragraph 23.) Under the General Law on Cooperatives of Bosnia and Herzegovina and the Law on Agricultural Cooperatives of the Republic of Srpska, the president and members of the management board are jointly and severally liable for damage caused by their decisions if such decisions were adopted with gross negligence or with intent to cause damage. (General Law on Cooperatives and Law on Agricultural Cooperatives)⁶⁰

Supervisory Board – In Serbian cooperative law, the supervisory board is the supervisory body of the general assembly. Its members are also “elected by the general assembly of the cooperative” “from among the cooperative members”. (Law on Cooperatives, Art. 43, paragraph 3.) In addition to regulating its composition, election, competences, and powers, the legislator has also addressed the issue of the “liability” of the supervisory board. As with the regulation of the liability of management board members, the legislator repeated the general provision establishing the principles on which their liability is based, with the

⁵⁹ The Hungarian law on cooperatives contains provisions on liability very similar to ours (Law on Cooperatives, "Official Gazette of the Socialist Federal Republic of Yugoslavia", No. 41/1996, 12/1998 and "Official Gazette of the Republic of Serbia", 101/2005, 34/2006). However, in Hungarian legislation, members and the chairman of the board of directors (or director) are required to exercise the care of a "good businessman" when performing the tasks of managing the cooperative, which is a higher degree of liability than that required of persons holding the same positions in our law. In addition, Hungarian law stipulates that these persons must inform the supervisory board of any disagreement with the decisions of the majority in the management board, and here it is not enough for the disagreement to be noted in the minutes as a basis for exemption from liability (MZZ - Act on Cooperatives ("Official Gazette of the Republic of Hungary", No. 10/2006), Art. 33. Such a solution also increases the level of legal certainty, so it should be included in our legislation.

⁶⁰ See: General Law on Cooperatives (Official Gazette of BiH, No. 18/2003), Art. 39. and Law on Agricultural Cooperatives (Official Gazette of the Republika Srpska, No. 73/2008, 106/2009, 78/2011), Art. 39.

addition of one more principle: “and all its members”. (Law on Cooperatives, Art. 46, paragraph 1.) Furthermore, the Serbian legislator has, by using the same formulation as for the members of the management board, regulated a specific form of liability of supervisory board members—liability for damage caused to the cooperative.

Under the Austrian Cooperative Act, members of the supervisory board are liable for damage caused by failure to perform their duties. (Unofficial Translation of The Austrian Cooperative Societies Act, paragraph 24e. paragraph 6.) Due to the lack of more detailed rules for determining liability for damages of supervisory board members, general rules of civil law will apply in practice. Members of the supervisory board are persons entrusted with special powers within the cooperative, and are therefore obliged to protect business secrets and are liable for damage that the cooperative may suffer as a result of a breach of this duty. Furthermore, lack of professional expertise of supervisory board members does not constitute grounds for exemption from liability. (Cooperative Union of Serbia, 1995).⁶¹ Under the Bulgarian Law on Cooperatives, under the heading “liability of members of the supervisory board”, it is prescribed that members of the supervisory board are jointly and severally liable for damage caused to the cooperative through their fault. (Cooperatives Law, <https://lex.bg/laws/ldoc/2134696966>)

Under the Croatian Law on Cooperatives, the liability of supervisory board members for damage caused to the cooperative by their actions or omissions is governed by the relevant provisions of the Companies Act. (Law on Cooperatives, Art. 25.) In the context of earlier Croatian cooperative legislation (Law on Cooperatives, “Narodne novine”, Nos. 36/1995, 67/2001, and 12/2002), which did not contain provisions on liability, legal doctrine held that supervisory board members are liable to the cooperative under general rules for damage caused by their conduct. It has been emphasized that supervisory board members do not perform their duties as professionals, but as an additional activity, and that they do not manage the cooperative’s business but only supervise it. The standard applied is how an average supervisory board member would perform such duties. (Barbić, 2002)

Director – “This body is mandatory within the cooperative and is the only single-person body”. (Vitez, 2000. p. 235.) The director is the body responsible for organization, management, and representation of the cooperative; he or she is the executive body of the general assembly, the management board, and the supervisory board, as well as the body responsible for the legality of the cooperative’s operations. “The director of the cooperative does not have to be a member of the cooperative”, and is elected by the “competent body of the cooperative”, meaning that the cooperative is free to determine which body appoints the director. (Law on Cooperatives, Art. 47.) In addition to regulating issues of composition and election, competences, acting appointments, grounds for dismissal, limitations on appointment, and prohibition of competition, the Serbian legislator has, through a single general provision—identical to that applicable to members of the management and supervisory boards—regulated a specific form of liability of the director, namely liability for damage caused to the cooperative. (Law on Cooperatives, Art. 50, paragraph 2.)

⁶¹ "Cooperatives according to Austrian regulations", Regulations on cooperatives in some European countries, p. 16.

In Croatian cooperative law, under the heading “liability of the manager”, it is prescribed that the liability of the manager for damage caused to the cooperative by his or her actions or omissions is governed by the relevant provisions of the Companies Act. (Law on Cooperatives, Art. 29.) In the context of earlier Croatian cooperative legislation (Law on Cooperatives, “Narodne novine”, Nos. 36/1995, 67/2001, and 12/2002), which did not contain provisions on liability, legal doctrine held that the manager is liable to the cooperative under general rules for damage caused by his or her conduct. It has been emphasized that the manager acts as a professional whose primary occupation is managing the cooperative’s business. (Barbić, 2002. p. 697)

Under the cooperative legislation of Bosnia and Herzegovina and the Republic of Srpska, “the director of the cooperative also bears material liability for decisions he or she has adopted which result in material damage to the cooperative”. (General Law on Cooperatives of BiH, Art. 45, paragraph 3.) This legislative solution has been criticized in legal doctrine as being too narrow, on the grounds that practice has shown that there are numerous more refined forms of conduct by which a legal entity, including a cooperative, may be harmed, and that such conduct does not necessarily consist solely of adopted decisions. Furthermore, it does not cover the liability of the director for erroneous or improper proposals of decisions submitted to the general assembly, management board, or supervisory board. (Vitez, 2000, p. 235)

On the side of the injured party appears the cooperative as the primary economic entity within the cooperative (social) sector. (Dabić, 2018. p. 126-150)

How do legislators define a harmful act in the examined cooperative legislation? The Austrian legislator has indirectly defined harmful acts of the executive board that cause damage to the cooperative. It provides that members of the executive board are liable for any damage caused if they have undertaken actions “beyond the limits of their authority” or “contrary to the provisions of the AZG or the statutes of the cooperative”; (Unofficial Translation of The Austrian Cooperative Societies Act, paragraph 23.) while members of the supervisory board are liable for damage caused by the “failure to perform their duties.” (Unofficial Translation of The Austrian Cooperative Societies Act, paragraph 24e. paragraph 6.) The Slovenian legislator stipulates that the president of the cooperative, members of the management and supervisory boards, as well as the inspector and the director, are liable for damage “caused to the cooperative by their actions and omissions.” (Law on Cooperatives, Art. 32.) Serbian and Montenegrin legislators impose on members of the management board the duty to perform their function conscientiously, honestly, and responsibly towards the cooperative, “with the diligence of a prudent businessman and in accordance with the interests of the cooperative.” (Law on Cooperatives, Article 42, paragraph 1.) Otherwise, by undertaking harmful acts, they expose themselves to the risk of causing damage to the cooperative and being held liable. This general legal formulation establishes several principles on which the liability of members of the management board is based in the performance of their functions, in relation to all specific forms of legal liability, including their liability for damage caused to the cooperative.

In Portuguese cooperative law, the legislator has found it necessary to list, by way of example, certain impermissible acts. (Portuguese Cooperative Law, Cooperative Regulations in Some European Countries, p. 95) ⁶²

Damage Caused – In the specifically examined cooperative legislations, damage is merely mentioned, without further definition. These legislations refer to the causing of damage, the subject who caused it, or the cooperative that suffered it, but without specifying damage as a prerequisite for the liability of cooperative bodies towards the cooperative. In such cases, the general rules of civil law apply.

In Serbia, damage is defined as the reduction of someone's property (ordinary damage) and the prevention of its increase (loss of profit), as well as the infliction of physical or psychological pain or fear on another (non-material damage). (Law on Obligations, Art. 155.) The Draft Civil Code of Serbia proposes a slight expansion of this definition by including "violation of guaranteed personal rights" within non-material damage, or alternatively, by providing a new definition of damage. (The Government of the Republic of Serbia) ⁶³ From the legal definition it follows that damage may be material or non-material. Material damage may consist of ordinary (actual) damage (*damnum emergens*) and loss of profit (*lucrum cessans*). Claims for compensation of different types of damage are not mutually exclusive, and the injured party may, where the conditions are met, claim compensation for all three types of damage – actual damage, loss of profit, and non-material damage.

In the context of the existence of material and non-material damage, it may be noted that in cooperative law "as a rule, the damage for which members of the management board are liable appears only as pecuniary damage." (Marković, 1938, p. 97.) Unlike contemporary law, historical legislation found it necessary to provide examples in which the management board is liable for damage caused to the cooperative. ⁶⁴ Pecuniary damage consists of the reduction (difference) between the state of assets that would have existed had the damaging event not occurred and the state after its occurrence.

For a cooperative body to be liable for damage caused, certain conditions must be met, including that the damage has actually occurred. The final word on this issue may only be given by a competent court deciding in a dispute for damages. By way of illustration, in

⁶² The Cooperative Law lists the following impermissible actions: performing tasks, on behalf of the cooperative, that do not correspond to their purpose, i.e. interests, or agreeing to such tasks; making payments without legal basis, i.e. agreeing to it; distributing fictitious surplus, i.e. distribution contrary to the law and the rules of the cooperative; abusing the mandate for the purpose of achieving personal benefit, i.e. benefit for other individuals and legal entities. "Portuguese Cooperative Law", Regulations on Cooperatives in Some European Countries, p. 95.

⁶³ Commission for the Drafting of the Civil Code, Preliminary Draft, Civil Code of the Republic of Serbia (second book) – Obligatory Relations, Belgrade 2009, Art. 168 (p. 64).

⁶⁴ These examples are as follows: disposal of the cooperative's property or making a payment contrary to the Law on Cooperatives or its rules; making any payment after the time when bankruptcy should have been filed; concluding transactions contrary to the legal order; irregular maintenance of business and other books, lists of cooperative members or incorrect and incomplete preparation of annual financial reports. Law on Economic Cooperatives, Belgrade 1937, para. 17, paragraph 2.

German cooperative law it is stipulated that the cooperative cannot claim damages from members of the supervisory board if the general assembly has previously approved their report, unless they provided inaccurate or incomplete information and thereby misled the members of the cooperative. Likewise, subsequent approval by the general assembly results in a waiver of the claim for damages. (Cooperative Law in the Federal Republic of Germany: 100 Years of Cooperative Law, Cooperative Regulations in Some European Countries, p. 131.)

Unlawfulness – Unlawfulness exists when the injurer's act violates a legal rule prescribed by applicable regulations. In the subject matter of this research, unlawfulness exists on the part of the injurer – the bodies or members of the bodies of a cooperative – when, by their actions, they violate a relevant legal norm from cooperative legislation or the rules of the cooperative. Unlawfulness is assessed independently of unlawfulness as an element of criminal or misdemeanor liability. Therefore, in civil law it is understood more broadly, as conduct contrary to moral rules or customs.

This may be illustrated by certain legal solutions in the examined legislation. Under the AZZ, members of the executive board act unlawfully “if they undertake actions beyond the limits of their authority” or “contrary to the provisions of the AZZ or the statutes of the cooperative,” in which case they are liable for any damage caused. (Unofficial Translation of The Austrian Cooperative Societies Act, paragraph 23.) Under the Law on Cooperatives of Montenegro, the president and members of the management board are liable to the general assembly for damage caused by performing or failing to perform their function “by acting contrary to the law or the rules of business of the cooperative.” (Law on Cooperatives, Art. 43. paragraph 2.) Their unlawfulness is reflected in actions that are illegal or contrary to cooperative rules. Under the General Law on Cooperatives of Bosnia and Herzegovina, the president and members of the supervisory board are liable for damage caused by their decisions “if such decisions were made with gross negligence or with intent to cause damage.” (General Law on Cooperatives of BiH, Art. 42.)

Causal Link – In civil law, the causal link (causal nexus) refers only to the connection between the unlawful act for which a person is liable and the consequence of that act in the form of damage. The Law on Obligations does not define the concept of a causal link, leaving its determination to judicial practice and legal theory. In domestic theory, the theory of adequate causation is accepted, according to which the cause of a phenomenon is considered to be only that circumstance which is legally relevant and capable of producing the consequence in the form of damage. (Karanikić, 2005, p. 995.)⁶⁵ According to this theory, the causal link must be continuous and uninterrupted; it is not presumed, but must always be proven. The burden of proof lies with the injured party. In the context of this research, it is the link between the act of the cooperative body or its members and the resulting damage suffered by the cooperative.

⁶⁵ "According to the theory of adequate causation, the cause of damage can only be that event whose regular effect corresponds to the specific damage. Only an event that is adequate, corresponding to the damage that has occurred, can be considered the cause of that damage." Karanikić, M., "Normative in the understanding of causation as a condition for civil liability", *Pravni život*, no. 10/2005, p. 995.

The necessity of a causal link in establishing liability for damage of cooperative bodies towards the cooperative may be illustrated by the following provisions: “members of the supervisory board are liable for damage caused by failure to perform their duties” (Austria); (Unofficial Translation of The Austrian Cooperative Societies Act, paragraph 24e. paragraph 6.) “the president of the cooperative, members of the management and supervisory boards, as well as the inspector and the director, are liable for damage caused to the cooperative by their actions and omissions” (Slovenia); (Law on Cooperatives, Art. 32.) “the director of the cooperative bears material liability for decisions he has made as a result of which the cooperative suffers material damage” (Bosnia and Herzegovina, Republika Srpska). (General Law on Cooperatives of BiH, Art. 44, paragraph 3.) This means that, for a cooperative body to be liable for damage caused, it is necessary, *inter alia*, that there is a causal relationship between the damage incurred and its act. This relationship may arise from active conduct (an act), when damage is caused by an action that should not have been undertaken, or from passive conduct, when a required action has not been taken.

Culpability of the Injurer – In the specifically examined cooperative legislations, the culpability of the bodies or members of the bodies of a cooperative is generally regulated by a broad formulation, without a more precise conceptual definition, with possible specification of degrees of culpability for which liability arises and cases of exemption from liability. In such cases, general rules of civil law apply to the conceptual determination of culpability. In civil law theory, culpability is generally defined as blameworthy behavior, as the conduct of a responsible person from which damage has resulted, whether it is the result of a deliberate act or an unintentional one. The Law on Obligations does not define the concept of culpability, but only establishes its two degrees: when the damage results from an intentional act and when it results from negligence. (Law on Obligations, Art. 158.)

In the examined cooperative legislation, the culpability of the injurer is reflected in the following legal solutions: members of the management board are liable “if they caused damage to the cooperative by their culpability” (Bulgaria); (Cooperatives Art. 24, paragraph 1.) the director of the cooperative is materially liable for damage caused to the cooperative “if the damage was caused by gross negligence or with the intent to cause damage” (Montenegro). (Cooperatives Art. 49, paragraph 2.) “the president and members of the management board are liable for damage caused by their decision ‘if that decision was made with gross negligence or with the intent to cause damage’” (Bosnia and Herzegovina, Republika Srpska).

For the liability of a cooperative body or its members to exist, among other things, their culpability for the damage caused to the cooperative must also exist. Their culpability is reflected in the violation of duties imposed on them by law, the rules of the cooperative, or decisions of the general assembly of the cooperative. A breach of duty may be committed through active conduct or passive inaction and may be intentional or negligent. Intent (*dolus*) is the most severe degree of culpability in civil law, occurring when the damage results from a deliberate act of the injurer. In legal theory, an act is considered intentional if the perpetrator knew the consequences that would result from their conduct or consented to them. Intent is assessed according to concrete criteria. Negligence (*culpa*) is a milder degree of culpability. Unlike intent, negligence is assessed based on abstract criteria. Negligence is a complex concept and has two forms: gross negligence (*culpa lata*) and ordinary negligence (*culpa levis*). This is a quantitative distinction that does not allow precise definitions of these terms. They can only be framed in the most abstract formulations, which represent a minimal basis

for evaluation in each specific case. Ordinary negligence is understood as a mistake that could occur even to a careful person, whereas gross negligence refers to a mistake that a proper person would never make (carelessness, disregard). (General Law on Cooperatives of BiH, Art. 39.)

5. DISCLAIMER OF LIABILITY

The Rule on Exemption from Liability – The general rule is that all members of a cooperative body are liable, whether because they undertook actions that were prohibited to them, or because they failed to undertake actions they were obliged to perform. This implies that the scope of their statutory liability is extensive. Their liability can only be excluded in cases explicitly provided by law and under conditions established by law.

Some of the examined cooperative legislations found it necessary to specify the legal conditions for exemption from liability for damage caused by the bodies or members of the bodies of a cooperative to the cooperative. The fulfillment of these legal conditions excludes the liability of the body or its members. For example, the president of the cooperative, members of the management and supervisory boards, as well as the inspector and director, are liable for damage caused to the cooperative by their acts or omissions, “unless they prove that they acted entirely in accordance with their duty and cannot be blamed for negligence in preventing the damage.” The assembly is authorized to decide whether to file a lawsuit against these persons or to release them from liability (Slovenia). (Cooperatives Law, Art. 32.) Alternatively, members of the management and supervisory boards are jointly liable for damage caused by their decision if that decision was made with gross negligence or with the intent to cause damage. For these persons and bodies, liability for damage is excluded under legally determined conditions: “if they were opposed to the decision and recorded their opinion in the minutes” (Bosnia and Herzegovina, Republika Srpska). (General Law on Cooperatives of BiH, Articles 39 and 42.) In German cooperative law, members of the management (executive board) and the supervisory council can be exempted from liability for damage to the cooperative “only if they prove that they exercised the necessary care in performing their duties.” Furthermore, they are not liable for damage “if the assembly adopted their report, except where it is based on inaccurate or incomplete data that misled the membership.” (Cooperative Law in the Federal Republic of Germany: 100 Years of Cooperative Law, Regulations on Cooperatives in Some European Countries, p. 131.)

As observed in the literature, exemption from liability can only apply to damage caused by decisions of the cooperative bodies; it cannot be invoked for tasks involving the actual performance of activities. For damage caused to the cooperative in the course of performing its activities, only the direct executors or persons under whose immediate influence the acts were performed are liable. (Marković, 1938. p. 99)

6. JOINT LIABILITY

As a rule, members of a cooperative body act collectively toward the cooperative and decide on their competencies in sessions by adopting decisions. In the process of decision-making, their mutual cooperation is present, which means they may jointly breach their duties. In practice, a situation may arise where, in making the same decision, some members commit a breach of duty through active conduct, while others do so by omission; the former by adopting an unlawful decision, the latter by failing to protest against such a decision.

In civil law, the general rule is that for any damage caused by multiple persons, all those responsible for its occurrence are jointly liable. In the cooperative legislations examined, joint liability of members of the cooperative bodies is also regulated (Austria, Bulgaria, BiH, Republika Srpska) with formulations such as: “jointly liable to the cooperative for any damage caused”; “jointly liable if they caused damage to the cooperative through their fault”; “jointly liable for damage caused by their decision.”

In other cooperative law systems, joint liability for cooperative bodies is similarly established: members of the management board and supervisory council are jointly liable for damage if they have breached their duties (Germany); (Cooperative Law in the Federal Republic of Germany: 100 Years of Cooperative Law, Cooperative Regulations in Some European Countries, p. 131.) members of the supervisory board are obliged to conscientiously perform their duties “and are jointly liable with the members of the management board” for compensation for omissions in case of insufficient care (Italy); (Cooperatives in Italian Law (General Issues), Regulations on Cooperatives in Some European Countries, p. 77.) “members of the management council are jointly liable for damage intentionally caused, through abuse of authority or gross negligence, to the cooperative or to individual members, participants, or creditors” (Spain); (Cooperatives in Spain, Regulations on Cooperatives in Some European Countries, p. 111.) “members of the management, executives, and other authorized persons are jointly liable to the cooperative and to third parties for damage caused by violating laws, cooperative rules, or assembly resolutions, or if they perform their duties negligently” (Portugal). (Portuguese Cooperative Law, Cooperative Regulations in Some European Countries, p. 95.)

All members of a cooperative body are liable for damage caused to the cooperative. The cooperative may sue all members, provided that the members whose actions directly caused the damage are liable to the other members if the latter have compensated the cooperative for the damage. Other members of the cooperative, whose actions did not contribute to the damage, acquire the right to sue the members who caused the damage. It is necessary for them to prove that the damage resulted from the actions of the defendant, that the plaintiff was held liable for its compensation, and that the compensation was indeed paid.

7. PROCEDURE IMPLEMENTATION

In the implementation of proceedings for compensation for damage caused by cooperative bodies to the cooperative, several significant procedural issues arise in practice: at what point a lawsuit for damages can be filed, whether a specific decision of the cooperative assembly is required before filing a lawsuit, whether cooperative members are authorized to bring such a lawsuit and at what moment, the consequences of malicious or reckless filing, interference of cooperative members in litigation, etc. Answers to these questions are primarily sought in the provisions of cooperative laws and laws on commercial (business) companies, and subsidiarily in general procedural law regulations and case law.

Some of the cooperative legislations examined found it necessary to specify more precisely the persons who may initiate legal proceedings, determine the conditions under which the proceedings may be initiated, and identify the authorized persons entitled to do so in cases of damage caused by the actions of cooperative bodies or members of such bodies toward the cooperative. For illustration, under the Portuguese Cooperative Law, the cooperative has the

right to file a lawsuit against members of the management board, executives, other authorized persons, and members of the supervisory council, exclusively based on a prior decision of the cooperative assembly. The decision may also be made at an assembly where the annual financial statement and the business report are on the agenda, not only when the proposed decision was explicitly highlighted in the meeting notice. In the initiated court proceedings, the cooperative is represented by the management or by cooperative members authorized by the assembly. (Portuguese Cooperative Law, Cooperative Regulations in Some European Countries, p. 95.) Similarly, under the Slovenian Cooperative Law, the cooperative assembly is authorized to decide whether to file a lawsuit against the cooperative president, members of the management and supervisory boards, or the inspector and director, or to release them from liability for damage caused to the cooperative by their actions or omissions, unless they prove that they acted in full compliance with their duties and cannot be accused of negligence in preventing the damage. (Cooperatives Law, Art. 32.)

8. INSTEAD OF A CONCLUSION

As a rule, the cooperative legislations examined contain only general (principled) rules on the legal liability of cooperative members toward the cooperative, with minor exceptions. Some legislations refer to the application of relevant provisions from other special laws, e.g., laws regulating commercial (business) companies. Due to the lack of more specific rules for this legal form of liability, in practice, in proceedings to determine the liability of cooperative bodies toward the cooperative, the general rules of civil law will be applied.

At both the national and international level, certain trends in changing the legal status of cooperatives are present, reflected in their increasing “commercialization,” primarily in some of their external elements—relations of the cooperative with third parties. Redefining certain elements of the cooperative in line with the latest trends in comparative and cooperative law of the European Union (EU), driven by the development of the modern market economy, is manifested in the need to modernize and amend the traditional cooperative concept. At the national level, we can take as examples the legal status of cooperatives in the Czech Republic and Slovakia. At the end of the 20th century (1991), in these legal systems, they were regulated by the Commercial Code and were regarded as subjects of commercial law. Their legal status predominantly features elements of a limited liability company. They differ from a commercial company only in terms of specific regulation of internal relations between the cooperative and its members, as well as among the members themselves, where cooperative members participate in joint business activity and share its results analogously to members of a commercial company. (Vitez, 1998, p. 23) At the EU level, the European Cooperative Society represents the continuation of creating a special legal form designed to enable cross-border establishment, merger, or reorganization of cooperatives from different EU member states. To that end, at the beginning of the 21st century, Regulation 1435/2003 on the Statute of the European Cooperative Society (Council Regulation 1435/2003 of 22 July 2003 on the Statute for European Cooperative Society (SCE), OJ, L 207, od 18. 08. 2003, str. 1-24.) and Directive 2003/72/EC on the position of employees in European cooperative societies were adopted. (Council Directive 2003/72/EC of 22 July 2003 supplementing the Statute for a European Cooperative Society with regard to the involvement of employees, OJ, L 207, od 18. 08.2003, str. 25-36.) To facilitate overcoming obstacles in these processes, the European Cooperative Society is organized “in the legal form of an atypical capital company with an internal cooperative structure and a supranational character.” (Vitez, 2009. p. 286) To facilitate overcoming obstacles in these processes, the European Cooperative Society is

organized “in the legal form of an atypical capital company with an internal cooperative structure and a supranational character.” (Vitez, 2009. p. 304)

Are there contemporary trends in cooperative legislation and legal theory regarding the liability of cooperative bodies toward the cooperative, and if so, what do they consist of? The brief answer is that such trends exist but are minor. On the normative level, this is the expansion and strengthening of the rules on the “application,” i.e., “corresponding application” of relevant provisions of laws regulating commercial (business) companies, prior to the subsidiary application of the general rules of civil law on causation and compensation of damages. In the vast majority of cases, special cooperative legislation has remained based on the general rules of civil law, on general formulations regarding the prerequisites of liability for damage caused by cooperative bodies toward the cooperative. For certain legal institutions, some legislators have made minor advances in specifying particularities and special conditions for liability for such damage. An example of this is the legal institution of exclusion from liability, where, besides a general rule, the legislator created specific statutory conditions for exemption from liability—requiring a cooperative body member to express opposition to a decision at the meeting itself and to demand that their position be entered in the minutes of the session where the decision was made. Another example is the need to more precisely define the persons who may initiate legal proceedings, the conditions under which it may be initiated, the timeframe, and by which authorized persons, in cases of damage caused by the actions of cooperative bodies or members of such bodies toward the cooperative. On the theoretical level, for example, requirements have been highlighted for elaborating and expanding the liability of the president and members of the management board and the director of the cooperative for other forms of their conduct, not only for the decisions they have made. (Vitez, 2000. p. 239)

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EDUCATION AND YOUTH SUPPORT IN AGRIBUSINESS: STRATEGIES FOR SUSTAINABLE RURAL DEVELOPMENT

ОБРАЗОВАЊЕ И ПОДРШКА МЛАДИМА У АГРО-БИЗНИСУ: СТРАТЕГИЈЕ ЗА ОДРЖИВИ РАЗВОЈ СЕЛА

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Abstract: This paper explores the issue of youth capacity building in agribusiness as a key factor for the sustainable development of rural areas (FAO, 2020; OECD, 2016). In the context of contemporary socio-economic challenges, including rural depopulation and insufficient competitiveness of agricultural production (Shucksmith, 2018), the study analyzes opportunities to enhance the role of young people through education, innovation, and development policies (European Commission, 2015). The methodological approach includes an analysis of secondary sources, comparative analysis, and a case study. Special focus is placed on Montenegro and the implementation of the IPARD program as one of the most significant instruments supporting agribusiness (European Commission, 2020; Ministry of Agriculture and Rural Development of Montenegro, 2019). The research results indicate that a combination of education, access to financial resources, and institutional support significantly influences the development of entrepreneurial activities among young people in rural areas (OECD, 2016; World Bank, 2018). The paper concludes that further improvement of educational and development policies is necessary to ensure the long-term sustainable development of agribusiness and to reduce youth migration from rural areas (Carr & Kefalas, 2009).

Keywords: agribusiness, rural development, youth, education, IPARD program

Апстракт: Рад истражује проблематику усавршавања младих у агро-бизнису као кључног фактора одрживог развоја руралних подручја (ФАО, 2020; ОЕЦД, 2016). У контексту савремених социо-економских изазова, укључујући депопулацију села и недовољну конкурентност пољопривредне производње (Shucksmith, 2018), анализирају се могућности унапређења улоге младих кроз образовање, иновације и развојне политике (European Commission, 2015). Методолошки приступ обухвата анализу секундарних извора, компаративну анализу и студију случаја. Посебан фокус стављен је на Црну Гору и имплементацију ИПАРД програма, као једног од најзначајнијих инструмената подршке агро-бизнису (European Commission, 2020; Ministry of Agriculture and Rural Development of Montenegro, 2019). Резултати истраживања указују да комбинација едукације, приступа финансијским средствима и

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институционалне подршке значајно утиче на развој предузетничких активности младих у руралним подручјима (OECD, 2016; World Bank, 2018). Рад закључује да је неопходно даље унапређење образовних и развојних политика како би се обезбедио дугорочно одржив развој агро-бизниса и смањиле миграције младих из руралних средина (Carr, Kefalas, 2009).

Кључне речи: агро-бизнис, рурални развој, млади, образовање, ИПАРД програм

1. INTRODUCTION

Rural areas represent an important segment of the economic, social, and cultural system of any country (OECD, 2016). They are sites of significant agricultural production, as well as the preservation of traditions, natural resources, and local identity. However, contemporary development trends have led to notable changes in the structure of rural communities, which face numerous challenges, particularly depopulation, population aging, and a lack of economic opportunities.

One of the key problems in rural areas is the continuous decline in the number of young people (Shucksmith, 2018). Migration from villages to urban centers, as well as abroad, reduces the available labor force and limits development potential. Young people often leave rural areas in search of better educational and career opportunities, further deepening regional inequalities. In this context, agribusiness emerges as one of the most important sectors capable of contributing to the revitalization of rural areas (Ellis & Biggs, 2001). Modern agribusiness involves the integration of agricultural production with processing, distribution, and market placement of products, alongside the application of innovations and new technologies (FAO, 2017). This approach enables increased competitiveness and the creation of added value, which is particularly important for small and medium-sized farms.

Young people play a special role in this process (OECD, 2016), as they represent a key factor in modernization and development. Their ability to acquire new knowledge, utilize digital technologies, and apply entrepreneurial models positions them as agents of change in agribusiness. However, their involvement in this sector is often hindered by a lack of financial resources, limited access to land, and underdeveloped support and educational systems.

Education and continuous capacity building are fundamental for the successful engagement of youth in agribusiness (Carr & Kefalas, 2009). Formal education through secondary schools and higher education institutions, as well as non-formal forms of learning such as training programs, workshops, and mentoring, play a crucial role in developing the necessary competencies. Additionally, digital skills are becoming increasingly important due to the growing use of information technologies in agriculture.

To promote agribusiness development and retain young people in rural areas, governments and international organizations implement various support programs. European Union programs, such as IPARD, are particularly significant (European Commission, 2020), providing financial assistance for agricultural modernization and rural development. These programs enable young people to start or improve their businesses, although their effectiveness also depends on the level of awareness, accessibility, and users' ability to meet administrative requirements.

This paper places particular emphasis on analyzing the role of youth capacity building in agribusiness development, as well as identifying key factors influencing their engagement in

rural areas. Through both theoretical and empirical approaches, the study aims to provide a comprehensive insight into this issue, with a special focus on the case study of Montenegro and the implementation of the IPARD program.

2. AIM OF THE STUDY AND RESEARCH OBJECTIVES

2.1 Aim of the Study

The primary aim of this study is to analyze the significance of youth capacity building for the development of agribusiness in rural areas, with a particular focus on the factors influencing their active engagement in this sector. The paper seeks to examine how education, professional training, financial and institutional support, as well as European Union development programs, contribute to motivating young people to engage in agribusiness, while also identifying the obstacles that limit their full potential.

The specific objectives of the study are multi-layered and include the following aspects:
Examine the role of education and professional development – This analysis includes how formal education and additional training influence the knowledge, skills, and readiness of young people to start and improve agribusiness activities. Special emphasis is placed on practical and innovative aspects of professional development that can directly increase the productivity and competitiveness of rural farms.

Analyze the impact of institutional and financial support – The study investigates how access to subsidies, loans, grants, and advisory services affects youth participation in agribusiness. The objective is to identify which types of support are most effective and how barriers to accessing these resources can be overcome.

Assess the effects of development programs (IPARD) – Particular attention is given to the European IPARD program as one of the key instruments for financial support in agriculture and rural development. The study examines the level of awareness among young people about this program, as well as its potential effects on increasing their activity and innovation in agribusiness.

Identify obstacles and opportunities for improving the position of youth – The study aims to identify both internal factors (knowledge, motivation, experience) and external factors (finance, administration, market, institutional support) that limit or support youth engagement in agribusiness.

By expanding the objectives, the study allows for a comprehensive understanding of the issue and the development of strategies to enhance youth participation in agribusiness, thereby contributing to the sustainable development of rural areas, strengthening the local economy, and reducing migration pressures from rural to urban areas.

2.2 Research Tasks

In accordance with the defined aim of the study, the research tasks are designed to cover all key aspects influencing the development of agribusiness among young people in rural areas.

They represent practical steps toward achieving the study's objective and enable a systematic analysis of the sector's problems and potential.

- Analyze the theoretical foundations of agribusiness and rural development – This task involves a review of relevant literature, studies, and research related to the definition of agribusiness, its economic and social functions, and the role of youth in rural development. Special emphasis is placed on identifying principles of sustainability, innovation, and competitiveness within the agricultural sector.
- Identify key challenges faced by young people – The objective is to systematically identify obstacles in education, finance, market access, administration, and institutional support that hinder youth from actively participating in agribusiness. This analysis enables the formulation of strategic recommendations to improve the position of young people in the sector.
- Examine forms of education and capacity building – The study investigates the availability of formal and non-formal educational programs, practical training, and mentoring initiatives that enable young people to acquire the knowledge and skills necessary for successful engagement in agribusiness. Particular attention is given to identifying educational models that are best suited to the rural context and the needs of young farmers.
- Analyze development programs and support measures – This task involves reviewing institutional and financial support mechanisms, including national and international programs such as IPARD, with the aim of assessing their impact on youth motivation and success in agribusiness. The analysis also includes identifying barriers to accessing these programs and proposing ways to improve them.
- Conduct a case study (Montenegro) – Through a specific case study, the experiences of young people in agribusiness, the characteristics of the regional and institutional framework, and applied support measures are explored. This task allows for the comparison of theoretical and practical aspects and provides additional insights into models that can be applied in other rural contexts.
- Draw conclusions and provide recommendations – The final task involves synthesizing all collected data and research results to formulate concrete recommendations for improving education, financial support, institutional policies, and programmatic initiatives that encourage youth engagement in agribusiness and contribute to the sustainable development of rural areas. By completing these tasks, the study enables a comprehensive analysis of challenges and opportunities, contributing to both practical and theoretical understanding of the role of young people in agribusiness and the formulation of strategies to enhance their participation in rural development.

3. RESEARCH QUESTIONS

The following research questions are posed in this study:

1. What are the key factors influencing youth engagement in agribusiness?
2. To what extent do education and capacity building affect the success of young people in this sector?
3. What are the main obstacles faced by young people in rural areas?
4. How significant is institutional and financial support for the development of agribusiness?
5. In what ways does the IPARD program contribute to the development of young farmers in Montenegro?
6. How can the position of young people in rural areas be improved?

4. RESEARCH HYPOTHESES

Based on the study objectives and research questions, the following hypotheses have been formulated:

Main hypothesis (H₀):

Youth capacity building has a significant positive impact on the development of agribusiness in rural areas.

Supporting hypotheses:

- H₁: A higher level of education and professional development among young people increases their success in agribusiness.
- H₂: Financial and institutional support significantly influences young people's decision to remain in rural areas.
- H₃: Lack of education and access to resources represents a key barrier to agribusiness development among youth.
- H₄: The IPARD program has a positive impact on agricultural modernization and the development of young farmers in Montenegro.

5. THEORETICAL FRAMEWORK

5.1 Concept and Significance of Agribusiness

Agribusiness represents a complex and multi-layered system of economic activities encompassing all stages of the agricultural value chain, including production, processing, distribution, and marketing of agricultural products (Ellis & Biggs, 2001). Unlike traditional agriculture, which focuses exclusively on primary production, agribusiness integrates various sectors, combining production, financial, logistical, and market functions. This approach enables the creation of added value and increases product competitiveness, thereby strengthening the economic position of farms and rural communities.

According to contemporary theoretical approaches, agribusiness can be viewed as a value chain comprising the following key stages:

- Input procurement: Involves selecting and acquiring high-quality raw materials, seeds, fertilizers, protective agents, machinery, and other resources necessary for optimal production. Efficient input procurement directly affects productivity and profitability.
- Production: Encompasses primary agricultural production, applying modern technologies, agronomic practices, and innovative approaches to increase yields and reduce costs. Emphasis is also placed on sustainable practices that minimize environmental impact.
- Processing and packaging: This stage adds significant economic value through processing, refining, and packaging. Processing allows for longer shelf-life and higher market value, while adequate packaging enhances market competitiveness and improves brand image.
- Distribution: Includes logistics, transport, and storage, which are crucial for maintaining product quality and timely delivery to end consumers. Efficient distribution contributes to reduced losses and increased profitability.
- Marketing and sales: Marketing and sales strategies enable product positioning, customer attraction, and competitive advantage. This includes promotion, branding, digital sales channels, and direct interaction with consumers.

Such an integrated approach enhances competitiveness and efficiency, especially in the context of globalization and increasingly demanding markets, where innovation and adaptability are key to success (FAO, 2017).

The significance of agribusiness in contemporary society is multifaceted:

- Food security: Agribusiness ensures stable food production and reduces dependence on imports.
- Income generation: Contributes to economic development, job creation, and increased income for rural populations.
- Rural development: Encourages youth retention in villages, infrastructure development, and improved quality of life in rural communities.
- Poverty reduction: Through increased productivity and additional economic activities, agribusiness reduces social inequalities and creates opportunities for self-employment.

Current trends in agribusiness include:

- Digital agriculture: Use of software solutions, farm management applications, precision agriculture, and data analytics (FAO, 2017).
- Sustainable production: Application of ecological practices, recycling, reduction of chemical inputs, and conservation of natural resources (Pretty, 2008).
- Development of short supply chains: Direct sales to consumers, farmers' markets, and online platforms, increasing profitability and reducing losses (OECD, 2016).
- Innovation and value addition: Development of new products, processing, branding, and diversification, enabling differentiation and competitiveness (Zander et al., 2016).

Overall, agribusiness is not only an economic activity but also a strategy for sustainable development, integrating knowledge, technology, and market mechanisms with the clear aim of increasing competitiveness, profitability, and sustainability in rural areas.

5.2 Rural Development – Concept and Dimensions

Rural development is a multidimensional process aimed at improving economic, social, and environmental living conditions in rural areas, going beyond the traditional agricultural-focused understanding of development (OECD, 2016; Pretty, 2008). Modern approaches integrate various aspects that enable sustainable growth of rural communities and encourage local population participation in development strategy formulation.

Rural development is based on the following key dimensions:

1. Diversification of economic activities: Beyond agricultural production, it is important to develop additional economic activities, such as processing industries, rural tourism, crafts, and services. Diversification contributes to more stable incomes, reduces dependence on primary agriculture, and increases the resilience of rural communities to economic shocks.
2. Infrastructure development: Investments in transport, energy, digital, and communal infrastructure facilitate market access, improve logistics, and enhance quality of life. Efficient infrastructure is crucial for connecting rural areas with urban centers and supporting local entrepreneurship.

3. Improvement of quality of life: Rural development involves not only economic growth but also improvements in education, healthcare, housing, and social services. These factors contribute to retaining young people in villages, reducing migration, and strengthening social cohesion.
4. Environmental conservation: Rural development must be based on sustainability principles, including the preservation of natural resources, biodiversity, and ecosystems. Sustainable agricultural and industrial practices contribute to long-term development and increase product competitiveness through eco-friendly standards.
5. Social inclusion: Rural development involves including all social groups, especially youth, women, and marginalized communities, in decision-making and economic activity. An inclusive approach increases community participation and ensures fair distribution of development benefits.

Rural development is closely linked to regional and sustainable development policies, which define strategic goals and support tools. Within European policies, rural development is based on principles of:

- Competitiveness: Improving productivity and market position of rural farms and entrepreneurs.
- Sustainable production and consumption: Integrating economic development with environmental protection and resource conservation.
- Innovation and technological development: Applying modern technologies and innovative approaches in agriculture, processing, and service sectors.
- Inclusiveness: Ensuring all community members have access to resources, education, and opportunities for active participation in development.

The concept of sustainable development is particularly important, implying a balance between economic growth, environmental protection, and social equity (Pretty, 2008). In rural areas, sustainability is reflected in rational land and resource use, application of eco-friendly production methods, and creation of conditions for economically stable and socially just livelihoods.

All dimensions of rural development are interconnected and require an integrated approach, combining education, financial support, infrastructure, environmental protection, and social inclusion policies. Only through coordinated and comprehensive strategies is it possible to create conditions for long-term sustainable and competitive agribusiness, in which youth play an active and significant role.

5.3 Role of Youth in Rural Development

Young people represent a key resource for rural development (FAO, 2020; OECD, 2016), as their energy, innovativeness, and willingness to apply new knowledge and technologies directly contribute to the modernization and competitiveness of agribusiness. Their involvement in agricultural and processing activities enables innovation, increased productivity, and diversification of economic activities, which are essential for sustainable village development and reducing migration pressures.

The role of youth in agribusiness can be observed through several key aspects:

1. Introduction of new technologies: Young people are generally more open to applying modern technologies, digital tools, and precision agriculture. Use of information systems, farm management software, automated equipment, and

modern crop protection methods contributes to increased efficiency and reduced production costs.

2. Improvement of production processes: Young entrepreneurs often implement innovative production methods, optimize workflows, and apply quality and food safety standards. These practices increase competitiveness and allow farms to access broader markets, including international ones.
3. Entrepreneurship development: Youth contribute to rural entrepreneurship by starting new businesses, diversifying products, and developing additional services. They identify market niches and leverage creativity and innovation to create new business models in agribusiness.
4. Diversification of activities: Beyond conventional farming, young people support the development of agritourism, organic production, processing capacities, and craft activities. This diversification enables more stable incomes, reduces dependence on a single revenue source, and contributes to sustainable economic development of rural areas.

However, theoretical and empirical research highlights several obstacles that limit active youth engagement in agribusiness (World Bank, 2018):

- Limited access to capital: Lack of financial resources and difficulties accessing loans or subsidies hinder business initiation and sustainability.
- Land scarcity: Young people often face problems acquiring agricultural land or encounter unfavorable conditions, directly limiting production expansion or modernization.
- Insufficient institutional support: Incomplete or poorly promoted support policies, including training, advisory services, and grants, reduce youth motivation to enter the sector.
- Negative perception of agriculture: Agriculture is still perceived in many areas as less attractive compared to urban occupations, decreasing youth interest in professional agribusiness.

In response to these challenges, targeted policies and programs are necessary to:

- Encourage youth to remain in rural areas,
- Facilitate access to capital and land,
- Improve education and professional training,
- Promote a positive perception of agribusiness and entrepreneurship among young people.

Studies and experiences from countries that successfully integrate youth into agribusiness demonstrate that a combination of education, financial support, and innovative policies significantly increases productivity, competitiveness, and sustainability of rural communities while simultaneously reducing social and economic marginalization of youth in villages.

5.4 Education and Capacity Building in Agribusiness

Education represents a key factor in developing human capital and forms the foundation for successful engagement in agribusiness (Carr & Kefalas, 2009). In contemporary conditions, knowledge is one of the most important resources, as it enables young people to apply innovations, manage resources more efficiently, and increase the competitiveness of their farms. Education in agribusiness encompasses formal, non-formal, and lifelong learning,

which complement each other to provide youth with necessary competencies and practical skills.

5.4.1 Formal Education

Formal education provides the basis for acquiring theoretical knowledge and professional competencies. It includes:

- Secondary vocational schools, which offer basic training in agriculture, animal husbandry, horticulture, agronomy, and related disciplines. These schools enable youth to gain practical skills and prepare for further training or independent farm management.
- Higher education, including faculties of agriculture, economics, and management, which provide in-depth theoretical knowledge, analytical, and managerial skills. Studies at this level allow exploration of modern technologies, financial planning, and marketing in agribusiness.

Formal education is important as it provides a structured knowledge framework, but it often requires supplementation with practical and market-oriented skills for successful participation in agribusiness.

5.4.2 Non-formal Education

Non-formal education includes flexible learning approaches tailored to market needs and specific competencies required in agribusiness. It encompasses:

- Professional training focusing on modern production techniques, farm management, financial planning, and innovative agricultural methods.
- Seminars and workshops, which facilitate experience exchange, practical demonstrations, and awareness of sector trends.
- Mentorship, where experienced farmers and entrepreneurs provide individual support to youth, helping them develop business strategies and overcome practical challenges.
- Practical training on farms or in processing facilities, allowing experience acquisition in real conditions and increasing readiness for independent agribusiness management.

Non-formal education is adaptable and practical, enabling young people to respond quickly to changes in market demands and technological trends. It also facilitates innovation adoption and enhances their ability to apply new knowledge directly to production or entrepreneurial activities.

5.4.3 Lifelong Learning

The concept of lifelong learning involves the continuous acquisition and improvement of knowledge and skills throughout one's career (OECD, 2016). This is particularly important in agribusiness due to:

- Rapid technological changes in production, processing, and food distribution.
- Changes in regulatory frameworks, quality standards, and market requirements.
- The need for constant adaptation to new economic and environmental challenges, including sustainable production and digitalization.

Lifelong learning allows young people to:

- Maintain the competitiveness of their farms,

- Apply innovative technologies and methods,
- Develop additional competencies in management, marketing, and finance.

Integration of formal, non-formal education and lifelong learning forms the foundation for preparing youth for successful engagement in agribusiness, increasing productivity, contributing to activity diversification, and strengthening the resilience of rural communities to economic and market challenges.

5.5 Entrepreneurship in Agribusiness

Entrepreneurship is a key factor in agribusiness development, as it enables:

- Launching new business activities,
- Increasing competitiveness,
- Promoting innovation.

Young entrepreneurs play a crucial role in rural development by:

- Creating new jobs,
- Developing the local economy,
- Introducing new products and services. Agro-entrepreneurship often relies on small and medium-sized enterprises, which offer flexibility and growth potential.

5.6 Digitalization and Innovation in Agribusiness

Digitalization is one of the most important trends in modern agriculture, encompassing: (FAO, 2017)

- Information systems,
- Precision agriculture,
- Smart devices (IoT),
- Digital sales platforms.

The advantages of digitalization include:

- Increased efficiency,
- Reduced costs,
- Better production control,
- Improved market access.

Young people play a key role in this process due to their higher digital literacy.

5.7 Institutional Support and Development Policies

The development of agribusiness and youth engagement in the sector largely depends on institutional support and development policies that provide the framework, resources, and incentives needed for successful operations (European Commission, 2015). Institutional support encompasses a range of mechanisms and instruments enabling youth to overcome financial, organizational, and market barriers.

Key elements of institutional support include:

- Agricultural policies, which define rules, standards, and development strategies for agriculture and rural areas. These policies provide the legal framework for subsidies, loans, investment programs, and innovative initiatives.

- Subsidies and grants, providing direct financial assistance to farms and entrepreneurs. These mechanisms enable initial investments, production modernization, and reduce financial risk for young entrepreneurs.
- Credit lines and favorable loans, offering financial support for investments, equipment purchase, land acquisition, or new product development. Access depends on information availability and youth capacity to meet administrative and financial requirements.
- Advisory services, providing technical, organizational, and market support. These include experts in agronomy, management, marketing, and finance, enhancing youth capacity to manage their operations effectively.

International support programs, particularly the IPARD program (Instrument for Pre-Accession Assistance in Rural Development), are of special importance (European Commission, 2020). IPARD facilitates:

- Investment financing, including modern machinery acquisition, construction or reconstruction of facilities, and development of processing and distribution,
- Production modernization through the introduction of modern technologies, ecological standards, and sustainable resource management practices,
- Alignment with European standards, enabling young farmers to access broader markets and increase the competitiveness of their products.

The effectiveness of these programs depends on several key factors: (European Court of Auditors, 2017)

1. Information availability, as lack of awareness about programs and procedures significantly reduces usage and support effectiveness,
2. Administrative procedures, which often involve complex requirements and bureaucratic barriers that can discourage young farmers,
3. User education and expertise, since youth capacity to prepare quality projects and efficiently use available resources directly affects program success.

Therefore, it is necessary to develop integrated policies combining financial support, education, and advisory services, with simplified administrative procedures. Only such an approach enables young people to actively engage in agribusiness, implement innovations, and contribute to the sustainable development of rural areas.

5.8 Sustainable Development and Agribusiness

Sustainable development is a concept that integrates economic, social, and environmental goals, emphasizing the long-term preservation of resources and quality of life. (Pretty, 2008) In the context of agribusiness, sustainability implies a balance between production and environmental protection, while achieving economic profitability and social inclusion of rural communities.

Key principles of sustainable agribusiness include:

- Rational use of resources: Optimal use of land, water, energy, and inputs reduces costs, increases efficiency, and contributes to the long-term sustainability of production. The application of precision agriculture, integrated pest management, and waste-reduction techniques enables maximum productivity with minimal negative environmental impact.

- Environmental protection: Sustainable agribusiness involves reducing the use of chemical inputs, conserving soil and water, lowering greenhouse gas emissions, and recycling by-products. These practices not only preserve ecosystems but also enhance product competitiveness through ecological standards and certifications.
- Long-term production sustainability: Focusing on continuous improvement in technology and management ensures stable food production and economically sustainable operations. Long-term sustainability also involves planning and adapting to climate change, market trends, and regulatory shifts.

The contribution of sustainable agribusiness includes:

- Biodiversity conservation: Implementing eco-friendly methods and preserving natural habitats helps maintain plant and animal species, protecting ecosystems essential for agriculture.
- Pollution reduction: Utilizing renewable energy sources, minimizing pesticides and chemical fertilizers, and applying sustainable processing techniques reduce negative environmental impacts.
- Improvement of rural quality of life: Sustainable agribusiness contributes to healthier living environments, stable incomes, and the preservation of local communities. It also enables young people and entrepreneurs to develop innovative and competitive activities that are sustainable in the long term.

Contemporary trends in sustainable agribusiness include the integration of digital technologies, ecological standards, and local supply chains, resulting in greater transparency, reduced losses, and increased profitability, while simultaneously preserving natural resources. (Zander et al., 2016)

Overall, sustainable agribusiness represents a synergy of economic development and environmental conservation, providing young people with the opportunity to develop competitive, innovative, and socially responsible farms in rural areas.

5.9 Theoretical Research Model

Based on the previous analysis of the theoretical framework and literature, a theoretical research model can be defined that describes the dynamics of agribusiness development in rural areas through the engagement of youth. The model is structured around three main components: input factors, process activities, and expected outcomes.

Input Factors

Input factors represent the fundamental resources and prerequisites for agribusiness development and include:

- Education – formal and non-formal education of young people, professional training, and capacity-building programs that enable the acquisition of necessary knowledge and competencies.
- Finance – availability of capital, subsidies, grants, and credit lines that enable the initiation and modernization of production.
- Institutional Support – agricultural policies, advisory services, and development programs (e.g., IPARD) that provide technical, administrative, and financial assistance.

Process

The process represents the activities through which input factors become effective in creating value:

- Youth capacity building – continuous education, mentorship, and practical training that enable the application of acquired knowledge.
- Knowledge application – implementation of innovations, new technologies, and modern management practices in agribusiness.
- Entrepreneurial activities – establishment and development of farms, production diversification, development of processing capacities, and marketing strategies.

Outcomes

Outcomes reflect the effect of the synergy between input factors and processes on agribusiness development:

- Agribusiness development – increased productivity, competitiveness, and innovativeness within the sector.
- Income growth – greater economic stability and sustainability of rural households.
- Youth retention in rural areas – creation of conditions for long-term professional engagement of young people in villages, reduction of migration, and promotion of social cohesion.

The theoretical framework indicates that agribusiness development in rural areas is a complex and multidimensional process that depends on the interconnection of multiple factors. The role of youth as drivers of innovation and development is emphasized, alongside the need for their continuous education and support. Integration of knowledge, financial resources, and institutional measures represents the key to successful agribusiness development and sustainability of rural communities.

This model also provides a foundation for empirical research, as it allows for the identification of specific indicators that can be measured and analyzed through case studies, surveys, or other research methods.

6. RESEARCH METHODOLOGY

6.1 Subject and Aim of the Research

The subject of this study is the analysis of the role of youth training and professional development in the development of agribusiness in rural areas, with a particular focus on factors influencing their participation in this sector. The research focuses on the interaction between education, financial resources, and institutional support, as well as on identifying obstacles and opportunities for improving the position of young people in agribusiness.

The aim of the research is to:

- Determine the extent to which education, professional training, and mentoring influence the ability of young people to successfully manage agribusiness;
- Analyze the effects of institutional and financial support, including programs such as IPARD;
- Identify key barriers and challenges limiting youth engagement;
- Provide recommendations for improving support policies and educational programs in rural communities.

This aim allows for a comprehensive assessment of the factors of success and challenges in the process of developing agribusiness among young people.

6.2 Research Methods

The study employs a combination of qualitative and quantitative methods, enabling a holistic understanding of the research problem.

Qualitative methods include:

- Literature analysis, which systematizes existing knowledge in the fields of agribusiness, rural development, and youth education;
- Descriptive method, allowing for detailed description of phenomena, sample characteristics, and the research context;
- Comparative analysis, which compares different policies, programs, and support models in regional countries;
- Case study of Montenegro, providing practical insights into local conditions, development policies, and the role of youth in agribusiness.

Quantitative methods include:

- Survey research, conducted among young people in rural areas to collect data on knowledge, education, experience, and attitudes;
- Statistical data analysis, including percentage distribution of responses, correlation analysis, and trend identification;
- Result analysis, which allows for testing hypotheses and drawing empirically based conclusions.

This combined approach allows for a precise assessment of the impact of education, financial support, and institutional policies on the development of agribusiness among youth, with parallel interpretation of qualitative and quantitative data.

6.3 Research Hypotheses

The research hypotheses are derived directly from the theoretical framework and the proposed model:

- H0: Youth training has a positive effect on agribusiness development.
- H1: Education and professional training increase the success of young people in agribusiness.
- H2: Financial support and subsidies influence the retention of young people in rural areas and their long-term engagement.
- H3: Lack of resources, including land, capital, and infrastructure, represents a key barrier to youth participation in agribusiness.
- H4: The IPARD program and similar development instruments positively affect the modernization and development of agribusiness among youth.

6.4 Research Sample

The research was conducted on a sample of 100 respondents, aged 18 to 40, living in rural areas with varying levels of involvement in agribusiness. The sample includes:

- Farmers and farm owners who are already actively involved in agribusiness;

- Young people interested in agribusiness, planning to start or expand their activities;
- Young people with different levels of education, including secondary schools, university studies, and non-formal training.

The sample was selected using **purposeful sampling**, to focus the research on the population of youth with potential or experience in agribusiness. This approach ensures the collection of high-quality and relevant data, while statistical processing of results allows for the identification of trends, barriers, and opportunities to enhance youth participation in agribusiness.

7. RESEARCH RESULTS AND ANALYSIS

7.1 Sample Description

The research was conducted on a sample of 100 respondents living in rural areas, with the aim of examining the attitudes and involvement of young people in agribusiness. The sample was carefully selected to include young people aged 18 to 40, covering the key working segment of the population with the potential to actively participate in the development of rural entrepreneurship and innovative agricultural activities.

The respondents represented diverse educational levels, including secondary, post-secondary, and higher education. Most participants have completed secondary or higher education, allowing for an assessment of how formal education influences knowledge, motivation, and readiness to engage in agribusiness. The sample also included respondents with varying degrees of involvement in the sector: some are already active in agribusiness, others are not yet involved, and some are considering potential participation.

This diversity allows for a comprehensive analysis of the factors influencing youth interest and capacity for agribusiness development, including education, access to information, financial support, and participation in training programs. Furthermore, the sample is representative of young residents in rural areas where agriculture and agribusiness are key segments of the local economy. Analyzing such a sample provides insights into the actual field situation, identifies existing barriers, and highlights potential opportunities for improvement, enabling the formulation of concrete recommendations for rural development policies and youth training programs.

7.2 Youth Interest in Agribusiness

Youth involvement in agribusiness is one of the key factors for rural development and the improvement of economic performance in the agricultural sector. Young people, with their innovative approaches and willingness to adopt new technologies, represent significant potential for modernizing and increasing the competitiveness of agribusiness. (FAO, 2020) Research on their interest enables the identification of motivational factors, barriers, and the need for additional education and support.

Monitoring the level of youth interest provides insights into how effective current programs and support policies are and where there is room for improvement. It is particularly important to understand the differences between those already involved in agribusiness, those not yet engaged, and those considering entering the sector, as this directly impacts the planning of educational, financial, and institutional interventions.

The results show the following:

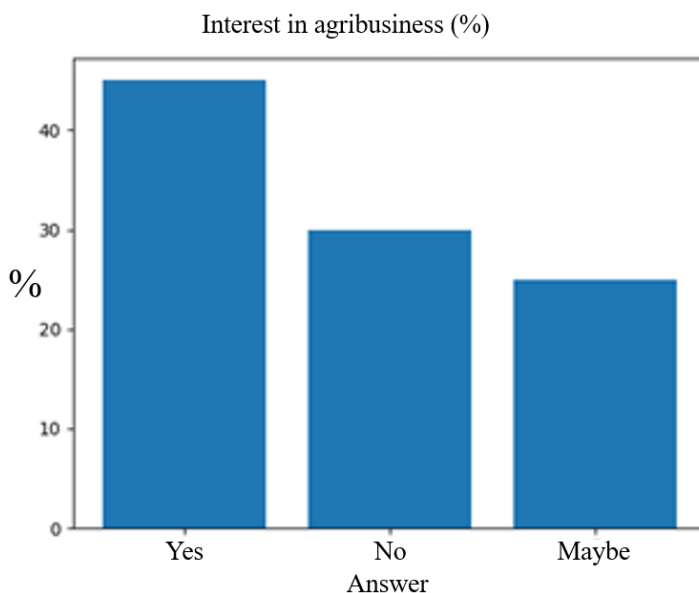
- 45% of respondents are already involved in agribusiness
- 30% are not engaged in agribusiness
- 25% are considering participation

The results indicate that 45% of respondents are already actively participating in agribusiness, clearly highlighting the presence of a stable segment of young people willing to invest their time and resources in developing this sector. This group represents a driving force in rural entrepreneurship and has potential for applying modern technologies, innovations, and entrepreneurial strategies.

Conversely, 30% of respondents are currently not engaged in agribusiness, which may be due to a variety of factors, including lack of financial resources, knowledge, or motivation, as well as limited access to support programs. This group presents a challenge for development policies, as without adequate support, there is a risk that young people may leave rural areas or fail to participate in the sector.

A third segment (25%) is considering entering agribusiness. This group represents strategic potential for sector growth, as, with proper education, mentorship, and financial incentives, these young people could become active participants in agribusiness. Their interest indicates latent motivation, which can be guided through targeted training, access to funds, and better awareness of the market and support programs.

Chart 1. Youth Interest in Agribusiness



Overall, these data suggest significant potential for agribusiness development among young people, while also indicating room for additional motivation and institutional support. Effective implementation of training programs, subsidies, and educational initiatives can significantly increase youth participation, enhance productivity, and contribute to the sustainable development of rural areas.

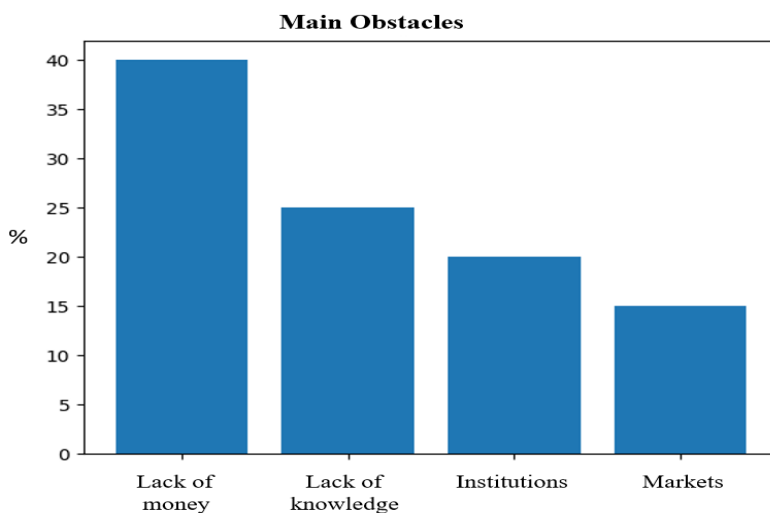
7.3 Main Barriers to Agribusiness Development

The research revealed that young people in rural areas face multiple barriers when trying to engage in agribusiness. The most significant challenges identified among respondents are:

- Lack of financial resources (40%) – the majority of respondents indicated that insufficient capital is the primary obstacle to starting or expanding a business. (World Bank, 2018) This finding underscores the importance of access to subsidies, credit lines, and programs such as IPARD, which can significantly facilitate access to necessary resources.
- Lack of knowledge and professional competencies (25%) – a high percentage of respondents highlighted that they do not possess sufficient education and practical skills for effectively managing agribusiness. (OECD, 2016) This emphasizes the need for vocational training, mentorship, and continuous education for young farmers.
- Administrative barriers (20%) – complex procedures and bureaucratic requirements hinder access to financial and development-investment programs. Simplifying administrative processes and improving user awareness could substantially increase the efficiency of support programs.
- Lack of market access (15%) – limited access to buyers and markets reduces the motivation of young people to invest and innovate. Developing local and regional supply chains, marketing strategies, and product certification can help overcome this challenge.

The data clearly show that financial factors remain the dominant barrier, but insufficient professional preparation of young people also plays a significant role. These obstacles are interrelated: lack of finances limits access to education, while insufficient knowledge complicates the preparation of high-quality project proposals for funding. Administrative barriers further complicate access to existing programs, indicating the need for an integrated approach—combining education, financial support, and simplified institutional procedures.

Chart 2. Main Barriers to Agribusiness Development



These results are consistent with the theoretical research model, which indicates that youth training, access to resources, and institutional support collectively determine success in agribusiness development.

The chart clearly illustrates the relative importance of individual barriers. The dominant financial factor highlights the need for support through subsidies and grants, while the other obstacles suggest that education and administrative simplification are key for the success of young people in agribusiness.

7.4 Awareness of the IPARD Program

The research results show that only 35% of respondents are aware of the IPARD program, while 65% of young people in rural areas are not familiar with this type of financial support. These data indicate a significant problem regarding the availability of information on agricultural and rural development programs. The IPARD program (European Commission, 2020), as one of the key instruments of the European Union, provides young people with the opportunity to receive grants for farm modernization, equipment purchase, development of processing capacities, and the introduction of innovations in agribusiness.

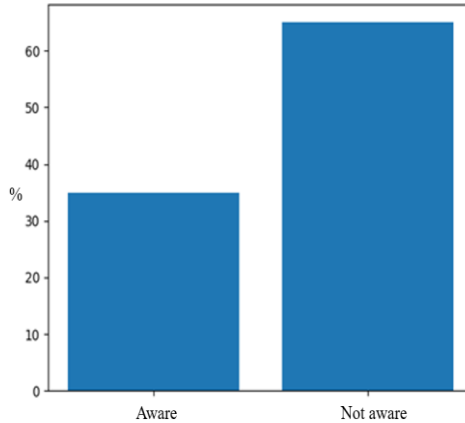
Lack of awareness among young people can have multiple consequences:

1. Unused financial resources – a large portion of potential beneficiaries does not utilize the available funds, reducing the program's impact on the modernization and competitiveness of rural farms.
2. Limited development of entrepreneurial initiatives – young people who are not familiar with the program do not have access to the tools and mentorship needed to start or improve their businesses.
3. Increased social inequality – those who are informed and have access to funds gain an advantage, while others remain marginalized, potentially widening the gap between successful and less successful rural farms.
4. Lower adoption of innovations and technologies – the lack of financial and educational resources directly affects the implementation of new technologies and sustainable production practices, which may limit long-term sector development.

These findings also suggest the need for targeted education and promotion of the program among young people. Information campaigns, workshops, collaboration with schools, and local advisory services could significantly increase awareness and thereby improve the effectiveness of the IPARD program. It is also important to adapt the content and format of information for young people, using digital platforms and social media, which is particularly important given the high level of digital literacy among rural youth.

In conclusion, the low level of awareness is not merely an administrative issue but directly affects the efficiency of rural development and the retention of young people in agribusiness, which is a key goal of both national policies and European development programs.

Graph 3. Awareness of IPARD



7.5 Respondents' Attitudes (Analysis)

The analysis of respondents' answers using a Likert scale highlights several key observations:

- Education as a key to success (Carr & Kefalas, 2009): The majority of respondents agree that professional education and continuous training are essential for successful engagement in agribusiness. This emphasizes that mere interest in agriculture is not sufficient; practical skills, knowledge of modern technologies, and management competencies are crucial.
- Perspective on agribusiness (FAO, 2017): Respondents show a positive attitude toward agribusiness, recognizing its potential for income generation, innovation, and economic growth in rural areas. This suggests that young people are motivated and willing to engage in the sector, provided that adequate resources and support are available.
- Insufficient institutional support: Respondents point out shortcomings in the availability of financial resources, subsidies, advisory services, and administrative support. This indicates that current policies and programs are not fully effective in enabling young people to realize their potential.

The research results indicate a generally positive attitude of young people toward agribusiness, but also a pronounced need for improvements in the support system. Successful development of the sector requires not only motivating young people but also:

1. Increasing the availability and quality of educational and professional programs to equip young people with the competencies required for modern agribusiness.
2. Enhancing institutional support, simplifying administrative procedures, and ensuring easier access to financial instruments and funding programs.
3. Promoting innovation and entrepreneurial initiatives through mentorship, practical training, and access to local and international markets.

Overall, the conclusion shows that young people recognize the potential of agribusiness and want to participate, but their success depends on a combination of education, institutional support, and financial resources. This aligns with the theoretical research model, which emphasizes that only the integration of input factors and active training processes can lead to real agribusiness development and retention of young people in rural areas.

7.6 Tabular Presentation of Results

Table 1. presents integrated data on young people’s involvement in agribusiness, their self-assessed knowledge, and participation in educational programs. This overview allows for a clear understanding of the key factors that influence young people’s ability to actively participate in rural entrepreneurship.

Analysis of this data helps identify potential barriers and opportunities for improving professional training and support for young people in agribusiness, which is crucial for rural development.

Table 1: Youth Involvement, Knowledge Level, and Participation in Educational Programs

Question / Answer	Number of respondents Percentage (%)	Number of respondents Percentage (%)
Engaged in agribusiness		
Yes	45	45%
No	30	30%
Maybe	25	25%
Level of knowledge for agribusiness		
Yes	30	30%
No	40	40%
Partially	30	30%
Participation in training		
Yes	35	35%
No	65	65%

The table presents integrated data on youth involvement in agribusiness, their self-assessed knowledge, and participation in educational and professional programs. The results show that 45% of respondents are already actively engaged in agribusiness, representing a significant indicator of initiative and interest among young people in this sector. On the other hand, 30% of respondents are currently not involved in agribusiness, while 25% are considering participation, indicating a substantial potential for further sector expansion.

The analysis of knowledge levels shows that 40% of respondents feel they do not have sufficient knowledge to successfully engage in agribusiness. Only 30% consider themselves to possess adequate competencies, while another 30% assess their knowledge as partially sufficient. These results clearly indicate the existence of a significant gap between interest and actual ability to manage agribusiness successfully. This emphasizes the need for continuous education and practical training, enabling young people to apply modern production methods, financial management, and marketing practices.

Furthermore, data on participation in educational programs show that 65% of respondents have not participated in any professional or non-formal training programs, while only 35% had the opportunity for further education. This finding is particularly significant, as it demonstrates a substantial deficit in practical knowledge and skills necessary for competitive engagement in agribusiness under contemporary market conditions. The combination of

insufficient knowledge and limited participation in training can lead to reduced business efficiency and constraints in the adoption of new technologies.

Overall, the table indicates a strong interest and motivation among young people to engage in agribusiness, but barriers—primarily the lack of knowledge and limited education—are key factors slowing sector development. These results clearly highlight the need for an integrated approach that includes educational programs, mentorship, and financial incentives, which would enable young people to participate more actively in agribusiness, increase their productivity, and contribute to the sustainable development of rural areas.

Additionally, the results emphasize the strategic importance of investment in human capital, as well-educated and trained young people have a greater chance to innovate, adopt modern technologies, and develop competitive business models. This aligns with European and national rural development policies, which particularly stress the need to support youth through education and professional training as a key factor for retaining population in rural areas and fostering agribusiness growth.

Table 2 presents the main obstacles faced by young people in agribusiness, their level of awareness about available support programs, and respondents' opinions on opportunities and support in rural areas. These data provide a comprehensive view of factors affecting youth participation in the sector and help identify key challenges that require additional interventions through education, financial support, and institutional programs.

Table 2: Obstacles, Awareness, and Respondents' Attitudes

Question / Answer	Number of respondents	Percentage (%) / Average score
Main obstacles		
Lack of money	40	40%
Lack of knowledge	25	25%
Administration	20	20%
Lack of market	15	15%
Awareness of the IPARD program		
Aware	35	35%
Not aware	65	65%
Attitudes (Likert scale 1–5)		
Education is key to success	—	4.5
Agribusiness has a perspective	—	4.2
Young people have good opportunities in rural areas	—	3.1
The state supports young people sufficiently	—	2.8

The analysis of combined data presents a multi-layered picture of the obstacles and challenges young people face in rural areas when engaging in agribusiness.

1. Financial and educational challenges: The largest number of respondents identified the lack of financial resources (40%) as the primary barrier. This confirms previous research findings that financial resources are a key factor for success in rural entrepreneurship. Additionally, the lack of knowledge (25%) further complicates

the initiation and development of business activities, highlighting the importance of formal and non-formal education, professional training, and mentorship.

2. Administrative and market factors: Administrative barriers (20%) and lack of market access (15%) indicate additional structural challenges. Complex administrative procedures and the absence of adequate market channels often demotivate young people from developing their businesses. These factors together can limit innovation and competitiveness in rural areas.
3. Awareness of support programs: Data on awareness of the IPARD program shows that 65% of young people are uninformed, which represents a serious issue. A low level of awareness means that a large number of youth do not utilize available funding opportunities, directly affecting the development of entrepreneurial activities and reducing the effectiveness of rural development programs.
4. Attitudes and perceptions of youth: Likert scale results indicate that respondents recognize the importance of education (average score 4.5) and the potential of agribusiness (4.2), showing high motivational potential. However, a low score for government support (2.8) and a moderate score for opportunities in rural areas (3.1) suggest that young people feel the existing institutional and political framework does not provide sufficient support.

The overall analysis suggests that a combination of personal and structural factors influences youth engagement in agribusiness. Key recommendations include:

- Increasing financial support and facilitating access to funding,
- Enhancing educational programs and training for young people,
- Improving promotion and access to information on programs such as IPARD,
- Simplifying administrative procedures and supporting market development for products from young farmers.

This analysis confirms the study's hypotheses: lack of resources and knowledge are the main barriers, while education and institutional support play a crucial role in the successful development of youth-led agribusiness in rural areas.

7.7 Discussion of Results

The obtained results confirm the proposed hypotheses:

- H1 confirmed – education influences success
- H2 confirmed – financial support is crucial
- H3 confirmed – lack of resources is a main barrier
- H4 partially confirmed – IPARD has potential but is underutilized

The main hypothesis (H0) is confirmed, as the results clearly indicate that the training and development of young people have a significant impact on the development of agribusiness. (OECD, 2016; World Bank, 2018)

Conclusion of the Empirical Section

The analysis of the research results shows that young people have significant potential for agribusiness development, but they face serious obstacles, particularly regarding finance and education. The low level of awareness about support programs further limits the growth of this sector.

8. CONCLUSION

The aim of this study was to analyze the role of youth development and training in the growth of agribusiness in rural areas, with a particular focus on factors influencing their engagement in this sector. Through the theoretical framework, empirical research, and a case study of Montenegro, the study demonstrated that young people represent a key resource for the modernization and sustainable development of rural areas (FAO, 2020; OECD, 2016), yet their potential is not fully utilized due to various barriers.

The main research findings are as follows:

1. Education and youth training (Carr & Kefalas, 2009) have a significant impact on success and productivity in agribusiness. Formal education provides foundational theoretical knowledge, while non-formal education, practical training, and mentorship enable the application of modern technologies and business practices. Lifelong learning is crucial due to rapid changes in the sector and the need for continuous adaptation.
2. Financial support and institutional mechanisms play a key role in motivating youth to engage in agribusiness. Subsidies, loans, and development programs, particularly IPARD (European Commission, 2020), facilitate production modernization, increased competitiveness, and access to broader markets. However, low awareness and administrative barriers reduce the effectiveness of these instruments.
3. Integration of input factors (education, finances, institutional support) through the process of training and entrepreneurial activities leads to tangible outcomes: agribusiness development, increased income, and retention of youth in rural areas. Empirical data show significant potential among youth already participating in agribusiness or considering entry, but additional empowerment through education and support is necessary.
4. Sustainable development and the adoption of innovative practices in agribusiness contribute to the preservation of natural resources, pollution reduction, and improved quality of life in rural areas (Pretty, 2008). Young people, as drivers of innovation, play a key role in implementing digitalization, ecological standards, and local supply chains.
5. The Montenegro case study indicates that a combination of education, institutional support, and financial instruments significantly enhances young people's chances of successfully developing agribusiness (Ministry of Agriculture and Rural Development of Montenegro, 2019). Nevertheless, challenges such as lack of land, capital, administrative barriers, and insufficient promotion of development programs remain significant and require strategic interventions.

Recommendations:

- Increase the availability and promotion of educational programs and professional training tailored to the needs of young farmers;
- Simplify administrative procedures and enhance the transparency of financial and development programs;
- Promote innovation and digitalization in agribusiness through practical training and mentorship;
- Develop policies that integrate economic, social, and environmental objectives to retain youth in rural areas and enhance sector sustainability.

Overall, the study confirms that young people are a key factor for a sustainable and competitive agribusiness, but their potential can only be fully realized through coordinated application of education, financial support, and institutional measures. Integrating these elements enables the creation of innovative, profitable, and socially responsible farms, which directly contribute to rural community development and the overall strengthening of the agro-economic sector.

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BUILDING, FARMING, DWELLING Integrated Approaches to Sustainable Rural Development in the Era of Climate Change

ГРАДЕЖНИШТВО, ЗЕМЈОДЕЛСТВО, СТАНУВАЊЕ Интегрирани пристапи кон одржлив рурален развој во ерата на климатските промени

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Abstract: *This essay undertakes a phenomenological and existentialist investigation of sustainable rural development in the Balkans under conditions of accelerating climate change. Drawing primarily on the philosophical frameworks of Martin Heidegger, Edmund Husserl, Maurice Merleau-Ponty, and Hannah Arendt, and engaging critically with contemporary agrarian studies, political ecology, and the geopolitics of EU integration, I argue that the prevailing technocratic paradigm of “development” operates as a mode of Gestell (enframing) that reduces rural lifeworlds to calculable resources, thereby foreclosing precisely those forms of embedded knowledge, communal practice, and ecological attunement on which genuine sustainability depends. The Balkan rural landscape, marked by the accumulated traumas of Ottoman dissolution, socialist collectivization, post-socialist dispossession, and the ongoing pressures of EU harmonization, constitutes a privileged site for this analysis. I propose that authentic sustainable development requires not the imposition of external technological solutions but a Heideggerian Wiederholung (retrieval) of inherited agrarian practices, reappropriated for contemporary conditions through what I term “phronetic integration”: a mode of practical wisdom that holds together traditional ecological knowledge, appropriate technology, and collective political action.*

Key words: *phenomenology, Heidegger, sustainable development, rural Balkans, climate change, Gestell, authenticity, traditional ecological knowledge, EU integration, food sovereignty*

Резюме: *Това есе предприема феноменологично и екзистенциалистично изследване на устойчивото развитие на селските райони на Балканите при условјата на ускорени климатични промени. Основавајќи се предимно на философските рамки на Мартин Хайдегер, Едмунд Хусерл, Морис Мерло-Понти и Хана Аренд, и ангажирајќи се критично със съвременните аграрни изследвания, политическата екологија и геополитиката на интеграцијата в ЕС, аз тврдя, че преобладаващата технократична парадигма на „развитие“ функционира като режим на Gestell (опреждане), който редуцира селските житейски светове до изчислими ресурси, като по този начин блокира точно онези форми на вградени знания, общностна практика и еколошко настрояване, от които зависи истинската устойчивост. Балканският селски пейзаж, белязан от натрупаните травми на османското разпадане, социалистическата колективизация, постсоциалистическото отчуждаване и текущите натиски на хармонизация с ЕС, представлява привилегировано място за този анализ.*

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Предлагам, че автентичното устойчиво развитие изисква не налагане на външни технологични решения, а Heideggerian Wiederholung (възстановяване) на наследените аграрни практики, преосмислени за съвременните условия чрез това, което наричам „фронетична интеграция“: режим на практическа мъдрост, който обединява традиционните екологични знания, подходящите технологии и колективното политическо действие.

Ключови думи: феноменология, Хайдегер, устойчиво развитие, селски Балкани, климатични промени, Gestell, автентичност, традиционни екологични знания, интеграция в ЕС, продоволствен суверенитет

1. INTRODUCTION: The Mood of the Land

There is a mood that pervades the rural Balkans today, and it is not one that lends itself to the optimistic vocabularies of development policy. It is a mood of quiet depletion, of watching something drain away without being able to name precisely what is being lost. Our villages are not merely losing population, though they are losing population at alarming rates. They are losing something more fundamental: a coherent way of being in the world, a form of life in which human activity, ecological rhythm, and communal obligation were woven into a fabric of meaning that no policy document can reconstruct from the outside. To speak of *sustainable rural development* in this context requires, first of all, an account of what it is that is unsustainable about the present condition, and this account cannot remain at the level of economic indicators or climate projections, however indispensable these may be. It must reach the existential and phenomenological dimensions of the crisis.

I address this essay primarily to colleagues in the agrarian sciences, and I do so with full awareness that the philosophical vocabulary I deploy may appear remote from the practical concerns of agricultural research, rural policy, and climate adaptation. I ask for patience and good faith. The argument I develop is not intended to replace empirical investigation but to disclose the *conditions of possibility* within which empirical findings acquire their meaning. When we measure soil degradation, model climate impacts, or design irrigation systems, we are already operating within a pre-theoretical understanding of what land, climate, and water *are* — an understanding that is historically constituted, culturally specific, and by no means self-evident. Phenomenology, as Edmund Husserl conceived it, is the rigorous investigation of precisely this pre-theoretical stratum: the *Lebenswelt*, the lifeworld, the taken-for-granted horizon of meaning against which all scientific activity is projected. (Husserl, 1970)⁷⁰

The Balkans occupy a peculiar position in the European imaginary and in the geopolitical architecture of the continent. Neither fully *inside* the structures of Western European modernity nor simply *outside* them, the region has been subjected to a series of violent modernization projects, Ottoman administrative extraction, nineteenth-century nation-building, socialist collectivization, post-1989 “transition,” and now the disciplinary apparatus of EU accession, each of which has reshaped the relation between human communities and the land they inhabit. (Spoor, 2009; Burawoy, Verdery, 1999)⁷¹ What persists through these

⁷⁰ Husserl’s concept of the *Lebenswelt* is developed in Part III A as the pre-theoretical horizon of all scientific activity.

⁷¹ For the political economy of post-socialist agrarian transformation, see Max Spoor, ed., *The Political Economy of Rural Livelihoods in Transition Economies: Land, Peasants, and Rural Poverty in Transition* (London: Routledge, 2009); and Michael Burawoy and Katherine Verdery, eds., *Uncertain*

transformations, often damaged but never entirely destroyed, is a stratum of agrarian practice and ecological knowledge that predates and exceeds the categories of modern agricultural science. It is this stratum that I propose to retrieve, not as nostalgia or as romantic primitivism, but as a resource for thinking and acting otherwise in the face of climate catastrophe.

2. BEING-IN-THE-LAND: TOWARD A PHENOMENOLOGY OF RURAL EXISTENCE

Heidegger's fundamental ontology in *Being and Time* begins from the insight that human existence — *Dasein* — is always already situated in a world, not as a subject confronting an external environment but as a being whose very constitution is *In-der-Welt-sein*, Being-in-the-world. (Heidegger, 1927/2008; Heidegger, 1977)⁷² This seemingly abstract formulation has concrete and far-reaching implications for how we understand the relation between rural communities and their environments. The farmer does not first exist as a detached subject who then enters into a relation with soil, water, and season. The farmer *is* this relation. The soil is not first an object of neutral perception that is subsequently put to agricultural use. It is encountered from the outset as *zuhanden* (ready-to-hand), as that which sustains, resists, demands care, yields or withholds.⁷³

This point is not merely philosophical decoration. It names a structural feature of agricultural existence that modern development discourse systematically obscures. When the World Bank or the European Commission or the FAO speaks of “land” as a “productive asset” or a “natural resource,” it has already performed an ontological reduction: it has transformed the lived, meaningful, historically saturated relation between a community and its territory into a calculable quantum available for optimization. This reduction is not innocent. It is, in Heidegger's terms, the operation of *Gestell*, the technological enframing that constitutes the deepest essence of modern technology — not any particular machine or technique, but the mode of disclosure in which everything that is shows up as standing-reserve, as resource awaiting extraction and deployment. (Heidegger, 1977, 3-35)

The concept of *Gestell* requires careful handling. Heidegger's analysis of technology is neither a rejection of technological devices nor a nostalgic call for pre-modern simplicity. It is an ontological diagnosis: modern technology, unlike the *techne* of the ancient Greeks, does not merely employ natural forces but *challenges* (*herausfordert*) nature to deliver its energies for human stockpiling and distribution.⁷⁴ The river becomes a hydroelectric resource; the forest becomes a timber reserve; the field becomes an input-output function in an agricultural production model. What is lost in this transformation is not the *utility* of these entities but

Transition: Ethnographies of Change in the Postsocialist World (Lanham, MD: Rowman and Littlefield, 1999).

⁷² The concept of *In-der-Welt-sein* (Being-in-the-world) is the fundamental constitution of *Dasein*, denoting the structural unity of *Dasein*'s engagement with its environment, not a spatial containment relation.

⁷³ *Zuhandenheit* (readiness-to-hand) names the primary mode of encountering entities as equipment within a referential totality of practical involvement, as distinct from *Vorhandenheit* (presence-at-hand), the derivative mode of theoretical observation.

⁷⁴ The concept of *Gestell* (enframing) designates the mode of revealing characteristic of modern technology, in which beings are disclosed as *Bestand* (standing-reserve), that is, as resources available for ordering and optimization.

their capacity to show themselves in their own terms, to be encountered as phenomena rather than as variables.

In the Balkan context, this technological enframing has taken historically specific forms. The Ottoman millet system, for all its extractive character, preserved a degree of communal agricultural autonomy that was disrupted by the centralizing ambitions of the post-Ottoman nation-states. The socialist period, particularly the forced collectivization of agriculture in Bulgaria, Albania, and Yugoslavia (with the partial exception of Yugoslavia's self-management system), represented a massive imposition of industrial-productivist logic onto agrarian landscapes that had developed over centuries of organic adaptation.⁷⁵ The post-1989 period, far from restoring the pre-socialist relation between communities and land, introduced a new form of enframing: the market rationality of privatization, structural adjustment, and eventually EU harmonization, in which "modernization" became synonymous with conformity to Western European agricultural standards designed for entirely different ecological and social conditions.

What was displaced in each of these transformations was not merely a set of agricultural techniques but an entire mode of *dwelling* — a way of inhabiting the land that integrated productive activity with ecological awareness, seasonal rhythm, communal ritual, and practical wisdom transmitted across generations. Karl Polanyi's concept of the economy as *embedded* in social relations is relevant here, but phenomenology presses the point further: the embeddedness is not merely social but ontological. The traditional Balkan peasant economy was not an economy *within* a society that was itself *within* a natural environment. It was a unified form of life in which these distinctions had not yet been operationalized as separate domains. (Lampe & Jackson, 1982)⁷⁶

3. CLIMATE CHANGE AS ONTOLOGICAL DISRUPTION

Climate change, as it is typically framed in policy discourse, is a problem of environmental management: rising temperatures, altered precipitation patterns, increased frequency of extreme weather events, all requiring technical solutions in the form of adaptation strategies, mitigation technologies, and resilience frameworks. This framing is not wrong, but it is radically incomplete. It treats climate change as an external perturbation to which human systems must adjust, rather than as a transformation in the very conditions of human dwelling on the earth. The phenomenological perspective discloses climate change as an *ontological disruption* — a rupture in the lived relation between human communities and the ecological systems that constitute their lifeworld. (Polanyi, 2001 [1944])⁷⁷

For the rural Balkans, this disruption is already underway and accelerating. The Mediterranean climate zone, to which much of the southern and central Balkans belongs, is identified by the IPCC as a climate change hotspot, with projected temperature increases

⁷⁵ For a comprehensive treatment of Balkan agricultural systems in historical perspective, see John R. Lampe and Marvin R. Jackson, *Balkan Economic History, 1550–1950: From Imperial Borderlands to Developing Nations* (Bloomington: Indiana University Press, 1982), especially chapters 8–12 on the agrarian question.

⁷⁶ Polanyi's concept of "embeddedness" denotes the integration of economic activity within broader social, cultural, and ecological relations, prior to the disembedding effects of market society.

⁷⁷ Maria Kaika, "'Don't Call Me Resilient Again!': The New Urban Agenda as Immunology ... or ... What Happens When Communities Refuse to Be Vaccinated with 'Smart Cities' and Indicators," *Environment and Urbanization* 29, no. 1 (2017): 89–102.

significantly exceeding the global mean and precipitation declines that threaten the viability of rain-fed agriculture across vast areas.⁷⁸ The specific projections are sobering: summer temperatures in Southeast Europe are projected to increase by 3–5°C by the end of the century under high-emission scenarios, while summer precipitation may decline by 10–30 percent, with some models projecting even more severe drying in the southern regions.⁷⁹ These are not abstract statistical projections. They name a transformation in the basic conditions of agricultural life that has no precedent in the historical memory of Balkan rural communities.

What does it mean, phenomenologically, when the seasons no longer behave as they have behaved within living and inherited memory? When the rhythms of planting and harvest, of drought and rain, that have structured agricultural practice for generations become unreliable? Husserl's analysis of the *Lebenswelt* is instructive here. The lifeworld is not a collection of facts but a horizon of familiarity, a background of taken-for-granted regularities against which practical engagement with the world becomes possible.⁸⁰ When climate change disrupts these regularities, it does not merely present new technical problems to be solved. It undermines the perceptual and practical ground on which agricultural knowledge has been built. The farmer who can no longer trust the timing of the first frost or the reliability of spring rains is not simply confronting a management challenge. She is experiencing the dissolution of a world.

This dissolution is compounded by the way in which dominant responses to climate change reproduce the very logic of technological enframing that contributed to the crisis. The standard prescription, more efficient irrigation, drought-resistant crop varieties developed through biotechnology, precision agriculture driven by satellite data and algorithmic optimization — represents the intensification of *Gestell*, not its overcoming. The land is further reduced to a technical substrate to be managed through increasingly sophisticated forms of calculation.⁸¹ What is never questioned is the ontological framework within which these solutions are conceived: the assumption that the relation between humans and the earth is fundamentally one of resource management, that the appropriate response to a crisis of dwelling is more effective engineering.

4. TRADITIONAL ECOLOGICAL KNOWLEDGE AND THE QUESTION OF RETRIEVAL

The Balkans, precisely because they have been imperfectly modernized, retain significant reservoirs of traditional ecological knowledge (TEK) that offer alternatives to the

⁷⁸ For climate projections specific to Southeast Europe, see Filippou Trentacoste et al., “Climate Change Impacts on Agriculture in Southeast Europe,” in *Regional Assessment of Climate Change in the Mediterranean*, ed. Antonio Navarra and Laurence Tubiana (Dordrecht: Springer, 2013), 2:155–78.

⁷⁹ Intergovernmental Panel on Climate Change, *Climate Change 2023: Synthesis Report*, ed. Hoesung Lee and José Romero (Geneva: IPCC, 2023), 42–56. The IPCC Sixth Assessment Report identifies the Mediterranean basin, including the Balkans, as a climate change hotspot with projected temperature increases of 2–4°C above the global mean by 2100 under high-emission scenarios.

⁸⁰ Husserl, *Crisis of European Sciences*, 121–48. The mathematization of nature, for Husserl, substitutes the idealized constructions of mathematical physics for the intuitive givenness of the lifeworld, producing a “garment of ideas” that conceals the experiential ground from which all scientific meaning ultimately derives.

⁸¹ Heidegger, “Question Concerning Technology,” 14–17. The Rhine as hydroelectric power plant is Heidegger's paradigmatic example of the way in which modern technology transforms a natural entity from a self-showing phenomenon into a calculable resource.

technocratic paradigm.⁸² This knowledge is not a closed system of fixed practices but a living tradition of ecological attunement, constantly adapted to local conditions and transmitted through practice, narrative, and communal institutions. It includes knowledge of local seed varieties adapted to micro-climatic conditions, water management techniques developed over centuries of interaction with specific watersheds, soil conservation practices suited to the particular topographies of mountain and valley agriculture, and grazing strategies that maintain rather than degrade grassland ecosystems.⁸³

The epistemological status of this knowledge is a matter of considerable debate in the agrarian sciences, and the phenomenological perspective can contribute to clarifying it. TEK is not proto-scientific knowledge awaiting formalization in the categories of modern agronomy. Nor is it a mere repository of empirical observations that might be extracted and integrated into technical databases. It is a form of *practical wisdom* — what Aristotle called *phronesis* — that is inseparable from the concrete contexts of its exercise. It is knowledge embodied in practices, embedded in places, and transmitted through forms of life. To “extract” it from these contexts and “integrate” it into a technocratic framework is to destroy precisely what makes it valuable: its situatedness, its responsiveness to local conditions, its integration within a holistic understanding of the relation between human activity and ecological process.

This does not mean that TEK is incommensurable with scientific knowledge or that any attempt at dialogue between them is doomed to violence. It means that the dialogue must be conducted on terms that respect the integrity of both knowledge systems. Hans-Georg Gadamer’s hermeneutical concept of *wirkungsgeschichtliches Bewusstsein* (historically effected consciousness) is helpful here.⁸⁴ For Gadamer, understanding is never a neutral operation performed by a detached observer upon an inert object. It is always a *Horizontverschmelzung*, a fusion of horizons, in which the interpreter’s own situatedness is brought into productive tension with the object of interpretation. Applied to the encounter between modern agrarian science and traditional ecological knowledge, this means that the scientist must approach TEK not as raw material to be processed but as a horizon of meaning that challenges and potentially transforms the scientist’s own pre-understandings.

In practical terms, this hermeneutical approach has significant implications for research methodology. It suggests that the participatory research frameworks increasingly advocated in development studies are not merely ethically desirable (as a matter of “giving voice” to marginalized communities) but epistemologically necessary. The knowledge that Balkan rural communities possess about their local ecosystems cannot be accessed through extractive research methods — questionnaires, structured interviews, remote sensing — alone. It must

⁸² Vandana Shiva, *Monocultures of the Mind: Perspectives on Biodiversity and Biotechnology* (London: Zed Books, 1993), 5–32. Shiva’s analysis of the displacement of indigenous agricultural knowledge systems by industrial monoculture provides a useful, if somewhat polemical, complement to the phenomenological critique developed here.

⁸³ For the concept of traditional ecological knowledge and its relation to scientific knowledge systems, see Fikret Berkes, *Sacred Ecology: Traditional Ecological Knowledge and Resource Management*, 4th ed. (New York: Routledge, 2018), particularly chapters 1–4 on the epistemological status of TEK.

⁸⁴ Hans-Georg Gadamer, *Truth and Method*, trans. Joel Weinsheimer and Donald G. Marshall, 2nd rev. ed. (London: Continuum, 2004), 268–306. Gadamer’s concept of *wirkungsgeschichtliches Bewusstsein* (historically effected consciousness) names the condition in which tradition is not an object of knowledge but the medium through which understanding occurs.

be encountered in the medium of its own practice, through sustained engagement with the communities that embody it. This is not a counsel of methodological purity but a pragmatic recognition that certain forms of knowledge are destroyed by the very operations designed to capture them.

5. THE POLITICAL ECONOMY OF INAUTHENTICITY

The phenomenological analysis of rural existence and the epistemological defense of traditional ecological knowledge are necessary but insufficient. They must be supplemented by a political-economic analysis of the structures that actively suppress the forms of life and knowledge described above. The Balkans do not suffer merely from a deficit of authentic dwelling. They are subjected to a systematic political-economic machinery that produces and reproduces inauthenticity — that is, in Heidegger's technical sense, a mode of existence in which Dasein's own possibilities are determined not by its own appropriation of its situation but by the anonymous dictates of *das Man*, the They.⁸⁵

The most immediate mechanism of this inauthenticity in the Balkan rural context is the EU accession process and its associated conditionality regimes. The Common Agricultural Policy (CAP), designed for the intensive, large-scale agriculture of Western Europe, is progressively extended to the Western Balkans through Stabilisation and Association Agreements and the Instrument for Pre-Accession Assistance (IPA). The effect is to impose a normative framework of agricultural "modernization" that systematically disadvantages small-scale, diversified, ecologically adapted farming practices in favor of specialization, mechanization, and market integration.⁸⁶ Compliance with EU phytosanitary standards, food safety regulations, and quality certification requirements imposes costs that are prohibitive for smallholders, effectively functioning as a barrier to market access that drives consolidation and abandonment.

This process is not merely an economic restructuring. It is, in David Harvey's terms, a form of *accumulation by dispossession*: the appropriation of communal and small-scale assets by larger economic interests, facilitated by state policy and legitimated by the discourse of "modernization" and "European integration."⁸⁷ The phenomenological vocabulary allows us to identify what is at stake in this process at a level that political economy alone cannot reach. What is being dispossessed is not merely land or market share but a *mode of being*: a way of inhabiting the world that carries within it accumulated ecological wisdom, communal solidarity, and existential meaning. The young person who leaves the village for the city or for Western Europe is not simply making a rational economic calculation. It is being expelled

⁸⁵ Heidegger, *Being and Time*, §25–27. *Das Man* (the They or the One) names the anonymous, publicly constituted self of average everydayness, in which Dasein's own possibilities are levelled down to the conventional and the familiar.

⁸⁶ For the broader context of EU accession and agricultural policy reform in the Western Balkans, see Sophia Davidova, Luca Freddi, and Andrew Gorton, "Farm Productivity and the Structure of Agriculture in the Western Balkans," in *Western Balkan Agriculture and European Integration*, ed. Sophia Davidova et al. (London: Routledge, 2013), 67–95.

⁸⁷ David Harvey, "The 'New' Imperialism: Accumulation by Dispossession," *Socialist Register* 40 (2004): 63–87. Harvey's concept of accumulation by dispossession extends Marx's analysis of primitive accumulation to describe the ongoing appropriation of public and communal assets under neoliberal governance.

from a form of life that has been rendered materially unviable by structural forces operating at continental and global scales.

The geopolitical dimension of this analysis deserves emphasis. The Balkans occupy a strategic position at the intersection of European, Russian, Turkish, and Chinese spheres of influence, and agricultural policy is by no means exempt from these geopolitical dynamics. Chinese investment in Serbian and North Macedonian agriculture and infrastructure, Russian energy leverage over the region, and Turkish cultural and economic influence in the former Ottoman territories all shape the conditions within which rural development is conceived and implemented. The EU's insistence on regulatory harmonization as a condition of accession is not merely a technical requirement but a geopolitical strategy aimed at securing the Balkans within the European economic and normative space, against the gravitational pull of these competing powers. Rural communities in this context are caught between multiple forms of external determination, none of which is primarily concerned with the sustainability or authenticity of local forms of life.

6. AUTHENTICITY AS POLITICAL PROJECT: TOWARD PHRONETIC INTEGRATION

If the foregoing analysis is even approximately correct, then the question of sustainable rural development in the Balkans cannot be addressed by technical means alone. It requires what Heidegger calls *Eigentlichkeit* — authenticity — understood not as a private moral virtue but as a collective ontological reorientation: a taking-over of one's own thrown situation in a way that opens genuine possibilities rather than merely reproducing the anonymous prescriptions of the dominant order.⁸⁸ What would such an authenticity look like in concrete terms?

I propose the concept of *phronetic integration* to name the mode of practical engagement that I believe authentic sustainable development requires. *Phronesis*, Aristotelian practical wisdom, names a form of knowledge that is irreducible to both theoretical science (*episteme*) and technical skill (*techne*). It is the capacity to discern what the situation requires and to act appropriately within it, drawing on experience, judgment, and an understanding of particular circumstances that cannot be formalized into universal rules. Phronetic integration, as I conceive it, involves three interrelated dimensions.

First, the retrieval of traditional ecological knowledge. Heidegger's concept of *Wiederholung* (retrieval or repetition) is essential here.⁸⁹ Retrieval is not a backward-looking nostalgia that seeks to restore the past as it was. It is a creative reappropriation of inherited possibilities that frees them for future projection. In the agricultural context, this means taking the accumulated ecological knowledge of Balkan rural communities — knowledge of local varieties, water management, soil conservation, seasonal rhythms, grazing patterns and subjecting it to critical evaluation, experimental verification, and creative adaptation to changed climatic and economic conditions. The goal is not to freeze traditional practices in

⁸⁸ Heidegger, *Being and Time*, §54. *Eigentlichkeit* (authenticity) is not a moral category but an ontological one: it names Dasein's capacity to own its being by taking over the possibilities thrown to it, rather than dispersing itself in the anonymous dictates of *das Man*.

⁸⁹ Heidegger, *Being and Time*, §65. *Wiederholung* (retrieval or repetition) names Dasein's authentic relation to its heritage: not a passive reception of the past but an active appropriation that frees inherited possibilities for future projection.

place but to mobilize the practical intelligence they embody in response to contemporary challenges.

Second, the critical appropriation of technology. The argument against *Gestell* is not an argument against technology as such. Heidegger himself insisted on this point. The question is whether technology is deployed within a framework that treats the land and its inhabitants as standing-reserve, or within one that preserves what Heidegger calls a “free relation” to technological means — a relation in which technology serves dwelling rather than replacing it. In practical terms, this means favoring technological interventions that enhance rather than supplant local knowledge and capacity: low-cost sensor networks that complement farmers’ observational expertise, open-source agricultural databases that are governed by the communities they serve, renewable energy systems scaled to village-level needs, and agroecological methods that work with rather than against local ecological dynamics.

Third, the reconstitution of political agency. Authentic dwelling is not a solitary achievement. Heidegger’s concept of *Mitsein* (Being-with) reminds us that *Dasein* is always already constituted by its relations with others.⁹⁰ But Heidegger’s own political imagination was notoriously deficient, and here we must supplement his ontology with the explicitly political thinking of Hannah Arendt.⁹¹ Arendt’s concept of *action*, the capacity to initiate something new in a space of appearance among equals provides the political supplement that Heidegger’s ontology requires. Sustainable rural development cannot be achieved by individuals or households acting in isolation. It requires the reconstitution of collective political agency at the local, regional, and transregional levels: cooperatives, farmers’ associations, community land trusts, food sovereignty networks, and other institutional forms that enable rural communities to act as political subjects rather than passive recipients of external development prescriptions.

7. THE BODY, THE SOIL, AND EMBODIED KNOWLEDGE

The phenomenological account of agricultural existence would be incomplete without attention to the bodily dimension of rural practice. Merleau-Ponty’s phenomenology of perception provides the essential conceptual resources here.⁹² Against the Cartesian tradition that treats the body as a machine inhabited by a mind, Merleau-Ponty demonstrates that the body is the primary locus of our engagement with the world: we perceive, act, and understand through our bodily being, not despite it. This insight has profound implications for how we understand agricultural knowledge.

The experienced farmer’s knowledge is, to a significant degree, bodily knowledge. The capacity to read the soil by its texture, color, and smell; to assess a crop’s health by the

⁹⁰ Heidegger, *Being and Time*, §26. *Mitsein* (Being-with) names the ontological structure by which *Dasein* is always already related to others, not through an additive combination of subjects but as a constitutive dimension of its own being.

⁹¹ Hannah Arendt, *The Human Condition*, 2nd ed. (Chicago: University of Chicago Press, 1998), 175–247. Arendt’s concept of action as the political capacity to begin something new, exercised in a space of appearance among equals, provides the political supplement to Heidegger’s ontology that his own work conspicuously lacks.

⁹² Maurice Merleau-Ponty, *Phenomenology of Perception*, trans. Donald A. Landers (London: Routledge, 2012), 137–70. Merleau-Ponty’s account of the body as the primary locus of perceptual engagement with the world provides an essential phenomenological complement to Heidegger’s more ontologically oriented analysis.

subtlest variations in leaf color and posture; to predict weather from the behavior of animals, the movement of clouds, the feel of the air on the skin: these are not cognitive operations that happen to be mediated by the body. They are forms of understanding that are constituted by bodily engagement with the agricultural environment over years and decades of practice. This knowledge cannot be transmitted through textbooks or training programs alone. It is acquired through apprenticeship, through the patient formation of perceptual habits that attune the body to the specific affordances and demands of a particular landscape.

The implications for agricultural education and extension are significant. The dominant model of knowledge transfer in development contexts assumes a unidirectional flow from scientific expertise to local practice: the agricultural extension officer brings the latest research findings to the farmer, who is expected to adopt them. This model is not merely condescending; it is epistemologically naive. It fails to recognize that the farmer's embodied knowledge of her specific environment may contain information and practical intelligence that the scientist's generalized models cannot capture. A genuinely phenomenological approach to agricultural extension would reverse the direction of learning, or more precisely, would establish a dialogical relation in which scientific and embodied knowledge are brought into productive interaction.

8. COMMONS, COMMUNITY, AND THE ZADRUGA LEGACY

The moral economy of the peasant, as James C. Scott and E. P. Thompson have analyzed it, rests on a set of normative expectations *about reciprocity, mutual aid, and collective responsibility that are not reducible to economic self-interest*.⁹³ In the Balkan context, these expectations were historically institutionalized in communal forms of land management and social organization, most notably the *zadruga*, the extended family cooperative that structured rural life across much of the South Slavic world.⁹⁴ The *zadruga*, which persisted in various forms from the medieval period into the twentieth century, was not merely an economic unit but a mode of social being: a way of organizing production, consumption, care, ritual, and political decision-making within a framework of mutual obligation and shared responsibility.

The *zadruga* was progressively dismantled by the combined forces of nation-state formation, market integration, and socialist collectivization, and it would be naive to propose its restoration in anything like its historical form. But the principle it embodied, that the management of land and natural resources is a communal responsibility that cannot be adequately discharged by either individual ownership or state control, retains its force. Elinor Ostrom's Nobel Prize-winning work on common-pool resource management has demonstrated empirically what Balkan rural communities knew practically for centuries: that

⁹³ For the concept of "peasant moral economy" and its political implications, see James C. Scott, *The Moral Economy of the Peasant: Rebellion and Subsistence in Southeast Asia* (New Haven, CT: Yale University Press, 1976); and for its application to European contexts, E. P. Thompson, "The Moral Economy of the English Crowd in the Eighteenth Century," *Past and Present* 50 (1971): 76–136.

⁹⁴ For a detailed account of *zadruga* (extended family cooperative) structures and their historical significance in Balkan rural life, see Philip E. Mosely, "The Peasant Family: The *Zadruga*, or Communal Joint-Family in the Balkans, and Its Recent Evolution," in *The Cultural Approach to History*, ed. Caroline Ware (New York: Columbia University Press, 1940), 95–108.

commons can be managed sustainably through locally devised institutional arrangements, provided that certain design principles are respected.⁹⁵

The revival of commons-based institutional forms in the Balkan countryside is not merely an economic strategy but an existential and political project. It is a way of reconstituting the communal dimensions of rural dwelling that have been eroded by decades of privatization and individualization. Contemporary experiments in community-supported agriculture, cooperative food processing, communal watershed management, and shared renewable energy infrastructure represent, in however embryonic a form, an attempt to rebuild the institutional basis for authentic collective dwelling on the land. These experiments deserve support not because they are economically optimal in narrow terms, they frequently are not, but because they represent the kind of institutional innovation through which rural communities can reclaim agency over the conditions of their own existence.

9. TECHNOLOGY, SOVEREIGNTY, AND THE GEOPOLITICS OF FOOD

The question of technology in agriculture cannot be separated from the question of sovereignty. The dominant model of agricultural modernization, promoted by international development institutions and increasingly by the technology industry, involves a progressive integration of farming into global supply chains, proprietary seed systems, and data-driven management platforms controlled by multinational corporations. This model raises profound questions of political economy and geopolitical power that are directly relevant to the Balkan context. Bruno Latour's provocation that we need a "parliament of things" in which nonhuman entities participate in political deliberation resonates here, though it must be grounded in the material conditions of actually existing rural politics.⁹⁶

Food sovereignty, the right of peoples to define their own food systems, as articulated by La Via Campesina and elaborated by scholars such as Philip McMichael and Raj Patel⁹⁷ provides a crucial political framework for thinking about technology in the Balkan rural context. Food sovereignty does not reject trade or technology. It insists that the terms of engagement with global markets and technological systems must be determined by the communities affected, not imposed by external institutions. In the Balkans, where agricultural policy is increasingly shaped by EU conditionality, Chinese infrastructure investment, and the imperatives of global commodity markets, the assertion of food sovereignty is simultaneously an assertion of political autonomy.

⁹⁵ Elinor Ostrom, *Governing the Commons: The Evolution of Institutions for Collective Action* (Cambridge: Cambridge University Press, 1990). Ostrom's empirical demonstration that communities can and do manage common-pool resources sustainably without privatization or state control is directly relevant to the Balkan context of communal land management.

⁹⁶ Bruno Latour, *Politics of Nature: How to Bring the Sciences into Democracy*, trans. Catherine Porter (Cambridge, MA: Harvard University Press, 2004), 1–52. Latour's proposal for a "parliament of things" resonates with the phenomenological dissolution of the nature/culture binary, though from a distinct epistemological trajectory.

⁹⁷ For the geopolitics of food sovereignty and its implications for small states, see Philip McMichael, "A Food Regime Genealogy," *Journal of Peasant Studies* 36, no. 1 (2009): 139–69; and Raj Patel, "Food Sovereignty," *Journal of Peasant Studies* 36, no. 3 (2009): 663–73.

Arturo Escobar's concept of "*pluriversal design*" is suggestive here.⁹⁸ Against the universalism of Western development discourse, which assumes a single trajectory of modernization toward which all societies are converging, Escobar proposes a plurality of design practices rooted in the specific territorial, cultural, and ecological conditions of diverse communities. Applied to the Balkans, this means resisting the assumption that sustainable rural development looks the same in the Peloponnese as in the Rhône Valley, or that what works for Dutch greenhouse agriculture is appropriate for the mountain terraces of North Macedonia. It means insisting on the legitimacy of locally specific development paths that draw on local knowledge, respond to local conditions, and serve local needs, even when these paths do not conform to the standardized metrics of "development" as defined by international institutions.

The technological dimension of this sovereignty is increasingly critical. The global trend toward "smart agriculture", a satellite-guided precision farming, AI-driven crop management, blockchain-based supply chain tracking promises efficiency gains but also deepens the dependence of farmers on proprietary technological systems they do not own, understand, or control. For Balkan smallholders, this dependence is particularly dangerous because it compounds an already precarious economic position with technological vulnerability. The alternative is not technological rejection but technological sovereignty: the development and deployment of open-source, community-governed technological tools that enhance rather than supplant local knowledge and capacity. This is not an impossible aspiration. The open-source agricultural technology movement is growing globally, and the relatively low entry costs of many digital agricultural tools make community-level adoption feasible.

10. DWELLING, BUILDING, THINKING: TOWARD AN AUTHENTIC SUSTAINABILITY

In his later essay "Building Dwelling Thinking," Heidegger proposes that the *essence of building is dwelling*, and the essence of dwelling is the way mortals are on the earth.⁹⁹ Dwelling, in this sense, is not a mere function of housing or habitation but a fundamental mode of being: a way of relating to the earth and sky, to other mortals and to the dimension of the sacred, that lets beings be in their own essential character rather than forcing them into the mold of human projects. This vision of dwelling is utopian in the best sense: it names a possibility that is not yet realized but that exercises a claim on us from the future.

Applied to the question of sustainable rural development, the concept of dwelling as letting-be offers a radical alternative to the productivist logic that dominates development discourse. Sustainability, from this perspective, is not a matter of optimizing resource use to ensure the indefinite continuation of economic output. It is a matter of learning to inhabit the earth in a

⁹⁸ Arturo Escobar, *Designs for the Pluriverse: Radical Interdependence, Autonomy, and the Making of Worlds* (Durham, NC: Duke University Press, 2018), 1–45. Escobar's concept of "pluriversal design" challenges the universalism of Western development discourse and proposes a relational ontology grounded in territorial practice.

⁹⁹ Heidegger, "Building Dwelling Thinking," in *Poetry, Language, Thought*, trans. Albert Hofstadter (New York: Harper and Row, 1971), 143–59. Heidegger's fourfold (*das Geviert*) — earth and sky, mortals and divinities — names the gathering structure of dwelling as a mode of being that lets beings be in their own essential character.

way that respects its own rhythms and limits, that preserves the conditions of life for future generations not as a resource stock to be managed but as a world to be dwelt in. Heidegger's concept of *Geschichtlichkeit* (historicality) is relevant here: Dasein's temporality is not the abstract time of the clock or the calendar but the lived time of heritage and projection, of having-been and coming-toward.¹⁰⁰ Authentic sustainability is a mode of historical existence in which a community takes over its inherited past and projects it toward a future that is genuinely its own.

The violence of climate change, precisely because it disrupts the taken-for-granted regularities of the lifeworld, can serve, in a paradoxical way, as a catalyst for the kind of existential reorientation I have described. Rob Nixon's concept of "slow violence" names the gradual, often invisible destructiveness of environmental degradation, which precisely because of its slowness fails to register as violence within the temporal horizons of political attention.¹⁰¹ But when climate change accelerates to the point where its effects become unmistakably present in the lived experience of rural communities, as is increasingly the case in the Balkans, it can break open the taken-for-granted character of the existing order and create space for alternative possibilities.

10.1 The Anxiety of Transition: Existential Dimensions of Post-Socialist Rural Life

The post-socialist transition in the Balkans has been analyzed primarily in economic and institutional terms: privatization of state assets, liberalization of markets, establishment of property rights regimes, reform of administrative structures. These analyses, however indispensable, fail to capture what is perhaps the most significant dimension of the transition: its existential character. The dissolution of the socialist order was not merely a change of economic system. It was the collapse of an entire horizon of meaning within which rural life had been organized for two or more generations. Whatever the failures and violences of the socialist period, and they were many and severe, the socialist state provided a framework of social legibility: roles were defined, futures were projected, the relation between individual effort and collective welfare was at least nominally articulated. The post-socialist transition destroyed this framework without providing a coherent alternative.¹⁰²

Heidegger's analysis of *Angst* (anxiety) in *Being and Time* illuminates this condition.¹⁰³ Anxiety, for Heidegger, is not fear directed at a specific threatening entity. It is a fundamental mood in which the familiar world loses its significance, in which the network of references

¹⁰⁰ Heidegger, *Being and Time*, §74. *Geschichtlichkeit* (historicality) names the ontological structure of Dasein's temporal being as constitutively stretched between birth and death, and thereby as essentially related to its heritage and its fate.

¹⁰¹ For the concept of "slow violence" as it pertains to environmental degradation in peripheral regions, see Rob Nixon, *Slow Violence and the Environmentalism of the Poor* (Cambridge, MA: Harvard University Press, 2011), 1–44.

¹⁰² For the existential dimensions of post-socialist transition, see Michael Burawoy, "The State and Economic Involution: Russia Through a China Lens," *World Development* 24, no. 6 (1996): 1105–17; and for the specific Balkan context, Deema Kaneff, *Who Owns the Past? The Politics of Time in a "Model" Bulgarian Village* (New York: Berghahn Books, 2004), 1–30.

¹⁰³ Heidegger, *Being and Time*, §40. *Angst* differs from fear (*Furcht*) in that its object is not a specific intraworldly entity but the worldhood of the world as such. In anxiety, Dasein is brought before its own thrownness and the uncanniness (*Unheimlichkeit*) of its being-in-the-world.

and meanings that ordinarily sustains Dasein's practical engagement with things collapses into uncanniness. The post-socialist rural subject experiences something structurally analogous: the land is still there, the tools are still there, the neighbors are still there, but the web of meanings that connected these into a coherent form of life has dissolved. The cooperative is gone. The guaranteed purchase price is gone. The social services provided through the collective farm are gone. What remains is the bare givenness of a situation stripped of its former intelligibility.

This existential anxiety is compounded by the temporal structure of the transition. The rural subject is caught between a past that is irrecoverable and a future that is radically uncertain. The socialist past, however ambivalently remembered, cannot be restored. The European future, however earnestly promised, remains perpetually deferred, contingent on reforms and harmonizations that seem designed to benefit everyone except the rural poor. The result is a peculiar temporal paralysis: a being-in-the-present that is neither rooted in a living tradition nor oriented toward a credible future. It is this temporal paralysis, more than any specific economic deprivation, that drives the depopulation of Balkan villages. The young leave not because there is no land to work but because there is no *world* to inhabit.

The demographic data are stark and well known. Bulgaria has lost approximately 25 percent of its population since 1989, with rural areas experiencing even more dramatic declines. North Macedonia, Serbia, Bosnia-Herzegovina, and Albania all exhibit similar, if less extreme, patterns of rural-to-urban and international migration that have hollowed out village communities across the region.¹⁰⁴ But the demographic data, precisely because they are quantitative, cannot express what is qualitatively at stake: the loss of intergenerational continuity, the severing of the transmission chains through which agricultural knowledge, ecological awareness, and communal memory were passed from elders to youth. Each village that falls below a critical population threshold loses not merely labor power but a repository of situated knowledge that cannot be reconstructed from external sources.

11. EDUCATION, LANGUAGE, AND THE TRANSMISSION OF AGRICULTURAL KNOWLEDGE

The crisis of knowledge transmission in Balkan rural communities has a specifically linguistic dimension that deserves attention. Agricultural knowledge, like all forms of practical wisdom, is embedded in language: in the specific vocabularies, metaphors, proverbs, and narrative structures through which communities articulate their understanding of soil, water, weather, plants, and animals. These vocabularies are not merely ornamental. They encode distinctions that are operationally significant for agricultural practice: distinctions between soil types, microclimatic conditions, plant behaviors, and animal temperaments that may not be captured by the standardized terminology of modern agrarian science.¹⁰⁵

¹⁰⁴ For comprehensive demographic data on rural depopulation in the Balkans, see World Bank, "Western Balkans Regular Economic Report: Living Up to Potential," no. 21 (Washington, DC: World Bank Group, 2022); and Eurostat, "Agriculture, Forestry and Fishery Statistics: 2020 Edition" (Luxembourg: Publications Office of the European Union, 2020), 17–45.

¹⁰⁵ For the role of language in the constitution and transmission of ecological knowledge, see Keith Basso, *Wisdom Sits in Places: Landscape and Language Among the Western Apache* (Albuquerque:

The progressive displacement of local agricultural vocabularies by the technical language of scientific agronomy, development policy, and EU regulation represents an epistemological loss that is difficult to quantify but real. When a Macedonian farmer speaks of the land using terms inherited from generations of practical engagement with specific terrains and microclimates, she is not employing a quaint dialect that could be straightforwardly translated into the standardized categories of soil science. She is articulating a form of knowledge that is constitutively tied to its linguistic medium, a knowledge that exists in the space between the word and the thing it names. Ludwig Wittgenstein's later philosophy, with its insistence that meaning is a function of use within a form of life, provides a useful framework for understanding this point.¹⁰⁶ The meaning of an agricultural term is not its dictionary definition but its role in the practical activities of the community that employs it.

Agricultural education in the Balkans, as currently conceived, tends to reproduce the logic of technological enframing. University programs in agronomy and agricultural economics are modeled on Western European curricula, oriented toward industrial agriculture, and conducted in the conceptual idiom of modern science. There is nothing wrong with this in itself. The problem is the *exclusivity* of this orientation: the failure to integrate local and traditional knowledge systems as legitimate objects of study and sources of practical insight. A reformed agricultural education, one informed by the phenomenological and hermeneutical perspectives developed in this essay, would include systematic engagement with local agricultural vocabularies and practices, training in participatory research methods, and sustained fieldwork in rural communities as an integral component of the curriculum, not as an optional supplement.

The role of elder farmers as repositories of ecological knowledge deserves particular emphasis. In many Balkan village communities, the last generation with comprehensive knowledge of pre-industrial agricultural practices is now in its seventies and eighties. The urgency of documenting and, more importantly, of *learning from* this knowledge cannot be overstated. This is not an exercise in ethnographic preservation for its own sake. It is a practical necessity for climate adaptation. The agricultural practices that sustained Balkan communities through centuries of climatic variability, political upheaval, and economic hardship contain practical intelligence about resilience, diversification, and ecological management that is directly relevant to the challenges of the present. But this knowledge will die with its bearers if no institutional mechanisms exist for its transmission and creative reappropriation.¹⁰⁷

University of New Mexico Press, 1996), especially chapters 2–4 on the relationship between place-names and ecological knowledge.

¹⁰⁶ Ludwig Wittgenstein, *Philosophical Investigations*, trans. G. E. M. Anscombe, P. M. S. Hacker, and Joachim Schulte, 4th ed. (Oxford: Wiley-Blackwell, 2009), §§198–242. The concept of meaning as use within a “form of life” (*Lebensform*) is directly relevant to the understanding of agricultural vocabularies as constitutive rather than merely descriptive of practical knowledge.

¹⁰⁷ For methodologies of documenting and revitalizing traditional agricultural knowledge, see Alejandro Argumedo and Michel Pimbert, “Protecting Indigenous Knowledge Against Biopiracy in the Andes,” IIED Briefing Paper (London: International Institute for Environment and Development, 2006); and for the European context, Mauro Agnoletti, ed., *The Conservation of Cultural Landscapes* (Wallingford: CABI, 2006), 1–19.

12. REGIONAL SOLIDARITY AND THE POSSIBILITY OF A BALKAN AGRICULTURAL COMMONS

The Balkan nations, for all their historical antagonisms and political differences, share a remarkably similar set of agricultural challenges: small average farm sizes, fragmented landholding patterns, aging rural populations, limited access to credit and technology, vulnerability to climate change, and the pressures of EU regulatory harmonization. These shared challenges create the conditions for a form of regional cooperation that would be qualitatively different from the competitive integration into European markets that is currently promoted by the EU accession framework.¹⁰⁸

I want to propose, somewhat speculatively, the concept of a *Balkan Agricultural Commons*: a framework for regional cooperation in sustainable agriculture based on the principles of shared knowledge, mutual aid, and collective self-determination. Such a framework would include the systematic exchange of traditional ecological knowledge across national boundaries, recognizing that the agrarian heritage of the region transcends the political borders drawn in the nineteenth and twentieth centuries. Bulgarian, Serbian, North Macedonian, Albanian, Bosnian, and Greek smallholders have more in common with each other, in terms of the practical challenges they face and the knowledge resources they possess, than any of them has with the industrial farmers of Northern Europe whose production systems serve as the implicit norm of EU agricultural policy.

The institutional form of such a commons would need to be developed through a process of bottom-up negotiation and experimentation, not imposed from above. But its elements can be anticipated: networks for the exchange of locally adapted seed varieties and livestock breeds across the region; shared platforms for documenting and disseminating traditional agricultural practices; cooperative research programs that bring together scientific expertise and local knowledge in the investigation of climate adaptation strategies; regional food sovereignty initiatives that create alternative market channels for small-scale producers; and transnational advocacy coalitions that represent the interests of Balkan smallholders in EU policy deliberations.¹⁰⁹

Such a project would be politically ambitious, and its obstacles should not be underestimated. The legacy of national antagonisms in the Balkans is real and enduring, and the tendency of political elites to instrumentalize rural populations for nationalist purposes remains strong. But the existential and ecological pressures described in this essay may prove more powerful than the political divisions they must overcome. When the drought is the same on both sides of the border, when the young are leaving at equal rates from Bulgarian and Macedonian and Serbian villages, when the EU's regulatory demands fall with equal weight on smallholders across the region, the material basis for solidarity exists, even if the political will must still be cultivated. The phenomenological insight that dwelling is always already *Mitsein*, Being-

¹⁰⁸ For the common agricultural challenges of the Western Balkans and prospects for regional cooperation, see FAO, "Smallholders and Family Farms in Europe and Central Asia," FAO Regional Synthesis Report (Budapest: FAO Regional Office for Europe and Central Asia, 2020), 23–45.

¹⁰⁹ The concept of "seed sovereignty" as a component of food sovereignty is developed in La Via Campesina, "Our Seeds, Our Future," Notebook no. 6 (Harare: La Via Campesina, 2013). For its application to European contexts, see Guy Kastler et al., "Seed Laws That Criminalise Farmers: Resistance and Fightback," GRAIN Report (Barcelona: GRAIN, 2015).Isto

with, has a concrete political corollary: authentic sustainability cannot be achieved in isolation. It requires a community of practice that extends beyond the individual, beyond the village, beyond the nation, to encompass all those who share the common condition of inhabiting and cultivating this particular region of the earth.¹¹⁰

13. CONCLUSION: THE SAVING POWER

Heidegger's late meditation on technology concludes with the enigmatic citation from Hölderlin: "Where the danger is, there grows also the saving power."¹¹¹ The danger, as I have analyzed it in this essay, is multiple: the ontological danger of *Gestell*, which reduces the earth and its inhabitants to standing-reserve; the ecological danger of climate change, which disrupts the lifeworld conditions of agricultural existence; the political-economic danger of accumulation by dispossession, which dismantles the communal institutions through which rural communities exercise collective agency; and the epistemological danger of technocratic universalism, which erases the situated knowledge systems that constitute the most valuable resource for ecological adaptation.

The saving power, I have argued, lies not in more technology, more capital, more integration into global markets, or more compliance with externally imposed standards of modernity. It lies in what I have called phronetic integration: the creative, practically wise reappropriation of inherited ecological knowledge, the critical deployment of appropriate technology within a framework of communal self-determination, and the reconstitution of collective political agency through commons-based institutional forms. This is not a romantic or anti-modern proposal. It is, if anything, a more radical form of modernity than the one currently on offer: a modernity that takes seriously the finite, situated, embodied, and communal character of human existence on the earth, rather than fantasizing its transcendence through technological mastery.

I address these concluding remarks to my colleagues in the agrarian sciences with a plea and a provocation. The plea is to take the phenomenological dimension of rural existence seriously, to recognize that the crisis of Balkan agriculture is not merely a crisis of productivity or market access but a crisis of meaning, of dwelling, of the relation between human communities and the earth that sustains them. The provocation is to consider whether the categories within which agrarian science operates: yield, efficiency, productivity, and optimization are adequate to the reality they purport to describe, or whether they constitute part of the problem they are designed to solve. If the analysis developed here has any merit, it is that the most valuable resources for sustainable rural development in the Balkans are not the ones that appear in economic models or policy frameworks, but the ones that are carried in the bodies, practices, and memories of the communities that have inhabited this land for

¹¹⁰ For the political potential of transregional solidarity in the Balkans, see Jasmin Mujanović, *Hunger and Fury: The Crisis of Democracy in the Balkans* (New York: Oxford University Press, 2018), 145–72; and for a broader theoretical framework, Chantal Mouffe, *Agonistics: Thinking the World Politically* (London: Verso, 2013), 1–25

¹¹¹ Heidegger, "Question Concerning Technology," 33–35. The saving power that grows where the danger is does not name a dialectical overcoming but a transformation of the essence of technology through a free relation to it — a relation that Heidegger locates, provocatively, in the proximity of art and *techne*.

centuries communities that are still here, still working the soil, still watching the sky, still waiting for the rain.

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ARTIFICIAL INTELLIGENCE IN THE FUNCTION OF ECO- SECURITY AND TRANSPORTATION OF FOOD PRODUCTS ALONG CORRIDOR 10

VEŠTAČKA INTELIGENCIJA U FUNKCIJI EKO-BEZBEDNOSTI I TRANSPORTA PREHRAMBENIH PROIZVODA DUŽ KORIDORA 10

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Abstract: *Today's modern technological revolution is accompanied by a corresponding wave of new vocabulary, which we all have to learn, until it becomes so familiar that we forget we never knew it. The superintelligent program aims to ensure that artificial intelligence systems (much smarter than humans) follow human intentions. The key is that we all - from governments of various countries to citizens - get to grips with the risks and benefits that this new technology could bring represents. Transportation of food products is a complex logistical process that requires strict adherence to HACCP procedures and maintaining a cold chain to preserve freshness and quality, using refrigerated trucks and other temperature-controlled technologies. Key factors include precise planning and implementation of GMP standards for safe delivery. Eco-safety of transport includes measures to reduce the negative impact on the environment and increase safety, especially in the transport of dangerous goods and through the application of eco-driving. The key elements are reducing emissions, optimizing routes, using GPS tracking to analyze driving style and reducing the risk of accidents. Starting from the position that regardless of numerous peculiarities, modern wars are essentially nothing new. The authors single out the most important elements that are characteristic of every war, and, combining them, define war as a sufficiently long-term organized struggle regulated by international law, in which states or other subjects of international law participate on one or all sides, and which use some weapon to cause significant casualties and destruction to other subjects, for the purpose of achieving some important political, economic or other interest. Artificial intelligence means the capacity of an artificial. Some areas of today's information processing research are focused on scientific research programs, which seek to enable computers to understand written and verbal information, create summaries, give "answers" to certain questions or redistribute data to users interested in environmental safety in production and business in the following XXI century. With the progress of modern science, the research of this type of intelligence develops through two basic directions: psychological and physiological research into the nature of the human mind and the*

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technological development of increasingly complex information systems. The goal of our artificial intelligence research is to develop programs (software), which will enable computers to behave in a way that could be characterized as intelligent in searching for "answers" to eco-problems. The paper aims to contribute to the understanding of the potential of artificial intelligence in solving challenges in the field of traffic safety, but also to present the practical application of artificial intelligence in the field of creating models for improving traffic safety. The goal of this co-authored paper was to improve the efficiency, safety and sustainability of the transportation of food products along Corridor 10 by applying artificial intelligence and mathematical optimization. With the support of a central data management system, we are developing methods for network optimization and planning the loading of food products/goods, which should be displayed through a web-based interface for easier insight and practical application.

Key words: food products, packaging, transport, eco-risks, artificial intelligence, corridor 10, eco-safety

Апстракт: Савремену технолошку револуцију данас прати одговарајући талас новог речника, који сви морамо да научимо, све док нам не постане толико познат да заборавимо да га некад нисмо знали. Суперинтелигентни програм има за циљ да осигура да системи вештачке интелигенције (много паметнији од људи да следе људске намере. Кључно је, да сви од влада разних земаља до грађана - будемо хватали у "коштац" са ризицима и предностима које би ова нова технологија могла да представља. Транспорт прехранбених производа је комплексан логистички процес који захтева строго поштовање НАССР процедура и одржавање хладног ланца ради очувања свежине и квалитета, користећи камионе хладњаче и друге технологије за контролисану температуру. Кључни фактори укључују прецизно планирање и примену ГМП стандарда за безбедну доставу. Еко-безбедност транспорта обухвата мере за смањење негативног утицаја на животну средину и повећање сигурности, посебно код транспорта опасних материја и кроз примену еко-вожње. Кључни елементи су смањење емисије штетних гасова, оптимизација рута, употреба ГПС праћења за анализу стила вожње и смањење ризика од акцидента. Вештачка интелигенција означава капацитет једне вештачке творевине за реализовање функција које су карактеристика људског размишљања. Напретком савремене науке, истраживање ове врсте интелигенције развија се преко два основна смера: психолошка и физиолошка истраживања природе људског ума и технолошки развој све слојенијих информатичких система. Неке области данашњих истраживања процесовања информација се концентришу на научно-истраживачке програме, који настоје оспособити рачунар за разумевање писане и вербалне информације, стварање резимеа, давање "одговора" на одређена питања или редистрибуцију података корисницима заинтересованим за еколошку безбедност у производњи и пословању у наставку XXI века. Циљ нашег истраживања вештачке интелигенције је развијање програма (софтвери), који ће омогућити рачунарима да се понашају на начин који би се могао окарактерисати интелигентним у тражењу "одговора" на еко-проблеме. Рад има за циљ да допринесе разумевању потенцијала АИ у решавању изазова у области безбедности саобраћаја, али и да представи практичну примену вештачке интелигенције у области креирања модела за унапређење безбедности транспортног саобраћаја. Циљ израде овог коауторског рада био је да се применом вештачке интелигенције и математичке оптимизације унапреди ефикасност, безбедност и одрживост транспорт прехранбених производа дуж Коридора 10. Уз подршку централног система за управљање подацима, развијамо методе за оптимизацију мреже и планирање утовара прехранбених производа/робе, које треба приказати путем веб-базираног интерфејса ради лакшег увида и практичне примене.

Кључне речи: прехранбени производи, амбалажа, транспорт, еко-ризичи, вештачка интелигенција, коридор 10, еко-безбедност

1. INTRODUCTION

A product is the result of a set of interrelated or interacting activities that transform inputs into outputs. Food products encompass a wide range of items of plant and animal origin (meat, milk, eggs, nuts, vegetables), classified according to quality, type, and storage conditions of food and other food products. They satisfy the basic nutritional needs of humans, and their understanding includes knowledge of the causes of spoilage, as well as packaging and labeling of goods, particularly in transport.

The need for food is one of the fundamental life necessities of human beings. Food enables normal growth, development, and functioning of the body. Food includes everything used for eating and drinking, in processed or unprocessed form, for nourishment and enjoyment, as well as drinking water. Prepared meals are made from foodstuffs such as meat, fish, flour, vegetables, fruit, etc. No single food item can meet all the needs of the body. Therefore, we consume a variety of foods of plant and animal origin. Food is necessary for building the body, generating energy for work and life processes, and protecting against disease.

Food is composed of a large number of components, i.e., nutrients. The nutrients essential in our diet can be divided into six main groups: water, carbohydrates, proteins, fats, vitamins, and minerals. The nutrients required in large quantities are water, carbohydrates, proteins, and fats, while vitamins and minerals are needed in smaller amounts. The nutrients that provide energy are called energy-yielding nutrients, namely carbohydrates, fats, and proteins.

Water is essential for life on Earth, and the human body contains approximately 66% water. Nutrients are dissolved in water, and vital life processes take place in it. Most of our water requirements are met through food and beverages. Foods such as milk, vegetables, and fruits contain large amounts of water. Water should be consumed throughout the day, and thirst is best quenched with drinking water. It is recommended to drink about eight glasses of water daily (1.5 to 2 liters), replenishing the water the body loses depending on psycho-physical activity.

A proper diet that meets an individual's nutritional needs can be summarized in the following recommendations: Eat a variety of foods! Consume cereals, rice, and potatoes several times a day! Eat vegetables and fruit daily—more than five servings. Meat, poultry, fish, eggs, and legumes are rich sources of high-quality protein. Consume milk and dairy products daily! Reduce fats and oils to recommended amounts! Use sugar in moderation! Water is a vital fluid. Be moderate in alcohol consumption! Maintain a healthy body weight and be physically active!

Food spoilage is most often caused by microorganisms, resulting in changes in appearance, smell, and taste. Spoilage reduces the nutritional value of food and renders it hygienically unsafe. The spoilage process can be slowed or prevented by the application of heat, cold, dehydration, the addition of acids, chemical preservatives, etc.

In the market, there are at least three interested parties (stakeholders) that communicate with one another:

Customer – an organization or person receiving a product, e.g., consumer, client, end user, retailer, aid recipient, buyer; for an organization, the customer may be internal or external.
Organization – a group of people, facilities, and associated equipment with established

responsibilities, authorities, and relationships, e.g., company, corporation, enterprise, institution, humanitarian organization, trade organization, association, or parts/combinations thereof. Environment – the context in which the customer, organization, and product operate, e.g., interest groups, trade unions, workforce, competitors, suppliers, financial institutions.

Today's technological revolution is accompanied by a corresponding wave of new terminology that we must all learn until it becomes so familiar that we forget we once did not know it. A superintelligent program aims to ensure that artificial intelligence systems function responsibly and effectively. It is essential that everyone—from governments to citizens—grapples with the risks and benefits that this new technology may present. Artificial intelligence refers to the capacity of an artificial entity to perform functions characteristic of human reasoning. With the advancement of modern science, research in this field develops along two main directions: psychological and physiological studies of the human mind, and technological development of increasingly complex information systems.

Some areas of contemporary information processing research focus on scientific programs that aim to enable computers to understand written and spoken information, generate summaries, provide answers to specific questions, or redistribute data to users interested in environmental safety in production, the transport of food products, and business operations in the 21st century.

Through this paper, we have demonstrated how artificial intelligence can make freight transport more efficient. The developed prototypes help maximize vehicle capacity, use resources more rationally, and make combined transport more attractive. This represents an important step toward shifting freight from road transport along Corridor 10 and thereby contributing to environmental protection.

Based on many years of experience in the inspection of food products in domestic trade, export, and import, as well as on professional literature in this field, the authors have prepared this paper with the aim of making food trade operations more successful, ensuring that export and import procedures are carried out more professionally and with higher quality, and minimizing misunderstandings in the production–trade–inspection relationship. Furthermore, the paper aims to contribute to creating conditions in which producers and consumers can be more confident that they are purchasing food products of appropriate quality and are not being misled. Particular emphasis is placed on the environmental requirements of product/goods transport along Corridor 10.

The combination of artificial intelligence and optimization opens entirely new possibilities for combined freight transport. Forecasts of reservation numbers can be directly integrated into optimization processes, enabling more efficient train loading and more stable network management. In this way, a practical approach is created that directly supports operational systems and enhances the performance of road and rail transport.

2. FOOD PRODUCTS / GOODS

Products are what organizations offer to potential customers. Each product represents a package composed of a combination of goods and services (tangible and intangible components).

Developed models for planning the loading of food products enable trucks and trains to be utilized to their maximum capacity in terms of weight and length, while simultaneously reducing crane movements and transshipment processes. Numerous parameters are automatically and simultaneously taken into account during optimization. The network planning component combines AI-based freight volume forecasts with mathematical optimization in order to allocate cargo units in a way that enables optimal train utilization and faster transport with a minimal number of transshipments.

The total quantity of a particular product is generally not of uniform quality and is therefore classified into quality grades: Extra class – high quality, First class – good quality, Second class – medium quality, Third class – lower quality

Methods for testing the quality and properties of goods are divided into the following groups:

- **Sensory testing** – conducted using the senses, assessing the appearance, smell, and taste of food;
- **Mechanical and physical testing** – usually carried out using special tools or devices (e.g., testing flour purity by sifting through sieves);
- **Chemical testing** – determines the composition of goods and the presence of harmful substances in food;
- **Microbiological testing** – determines the presence of microorganisms in food that may cause disease.

Foodstuffs, i.e., food products, are stored separately from other goods, in special rooms or warehouses. Two types of storage facilities are distinguished:

- **Warehouses for dry food products** (flour, sugar, rice, pasta, salt, oil, vinegar, canned foods, etc.). These facilities must be dry, well-ventilated, and protected from direct sunlight;
- **Warehouses for perishable food products** (meat and meat products, milk and dairy products, eggs, fish, fruits, and vegetables). These facilities are equipped with refrigeration systems.

Technology is the science concerned with the processes of converting raw materials into semi-finished and finished products. Raw materials are substances found in nature, mostly in an unprocessed state, and are used for further processing. In culinary practice, raw materials include fruit, vegetables, meat, fish, and similar items. Semi-finished products result from partial processing of raw materials. An example is frozen vegetables used in the preparation of various dishes.

Finished products are final goods that are not subject to further processing but are ready for use, for example: bread, prepared meals, and confectionery. The production of such goods is referred to as the technological production process.

Food products are the most important and most widely consumed goods of mass consumption. The scale of production, trade, and consumption of these products is reflected in the fact that over 60% of the household budget is spent on purchasing food, i.e., on nutrition.

Food products are products of the food industry obtained by processing raw materials of plant and animal origin. Products of plant origin include flour, bakery products, pasta and related

products, biscuits and similar goods, starch, dextrin and related products, sugar, coffee and coffee substitutes, cocoa products, confectionery and cream products, vegetable fats, vegetables and vegetable products, fruits and fruit products, alcoholic and non-alcoholic beverages. Products of animal origin include meat and meat products, fish and fish products, milk and dairy products, eggs, and animal fats.

Table 1. Categories of basic products for the market

Categories of basic (generic products)	Basic product characteristics	Example
Hardware	- Products of a material nature that have a clear form - Countability - Tangibility	Food products, furniture, cars, shoes, clothing
Software	- Products that are essentially an intellectual creation composed of information recorded on a suitable carrier (written information, concepts, instructions or procedures)	Computer program, dictionary, film, picture
Process materials	- Products obtained on the basis of primary materials	Fuel, lubricant, sheet metal
Services	- Products obtained as a result of the activities of the organization, which take place partially or completely in contact with the user	Transport, education, treatment

Food products also include spices, as well as semi-prepared and ready-made meals. All food products are manufactured according to appropriate technological procedures, packaged, and placed on the market in accordance with applicable legal regulations. Products must comply with the quality standards prescribed by relevant regulations, and manufacturers are obliged to continuously monitor and ensure this quality.

Given their significant economic importance, the specific characteristics of food products, and the need for a thorough understanding of these goods—along with the requirements arising from new knowledge, experience, and numerous international and national regulations governing production, domestic trade, export–import, transport, storage, and other activities related to food products—the involvement of many professionals of various profiles is essential. Consequently, there has been a need in our country for a comprehensive manual that can provide interested parties with the necessary information at any time to ensure successful operations in the food sector, as working with these goods is highly responsible and requires substantial expertise.

According to their material nature, products may be:

- Tangible: hardware, processed materials (goods);
- Intangible: software;
- Combined: services.

Knowledge of goods encompasses practical expertise regarding products. It covers: origin, characteristics and quality, types of goods, packaging, transport and storage, and usage. Goods are products of human labor intended for exchange on the market.

- Commodity turnover – the total volume of all sales and purchases of goods and services within a specific period in a particular market.
- Commodity fund – the total quantity of produced goods that will be offered for sale within a specific period in a particular market.
- Commodity stocks (inventories) – quantities of unsold goods stored in warehouses awaiting sale.
- Standards (Norms) – technical quality specifications for products that must be harmonized with international standards and the technical regulations of EU countries.
- Law on Market Inspection – Market Inspection supervises the implementation of laws and regulations determining the prices and quality of products and services, as well as the conditions for conducting trade and services.
- Law on Sanitary Inspection – Sanitary Inspection conducts sanitary supervision over facilities, activities, plants, equipment, and individuals who may in any way adversely affect human health.¹¹⁶
- Declaration (Labeling) – found on the packaging of food products and must contain the date of production, expiration date, name and registered office of the manufacturer, main ingredients, and any additives.

2.1. Classification of Goods: by Origin, Stage of Production, and Economic Purpose

The essential properties of goods are those characteristics that enable a product to fulfill the purpose for which it was produced (e.g., the essential property of sugar is its sweetness and nutritional value). Non-essential properties are those that do not affect the usability of the product (e.g., sugar may be white or yellowish in color, and may appear in the form of powder, crystals, or cubes).

According to their properties, goods are distinguished as genuine or non-genuine. Genuine goods possess all essential characteristics, whereas non-genuine goods include products that lack the characteristic properties of genuine goods and are referred to as substitutes or surrogates (e.g., margarine as a substitute for butter).

- Quality of goods – a set of all properties of goods.
- Packaging – everything that is used to package goods.
- Division of goods: transport, returnable, non-returnable.

Research conducted in the Eastern European market has shown that many products are of lower quality than those offered under the same brand and in the same packaging in the “old” EU Member States. According to the European Commission’s assessment, the right of traders to adapt products for so-called legitimate reasons—such as the availability of raw materials and consumer preferences—should remain. All dilemmas that could cause consumer dissatisfaction must be resolved. If manufacturers wish to modify the ingredients of a product, this must be made perfectly clear to consumers.

¹¹⁶ The European Commission has announced that it will ban the sale of food products under the same brand and packaging but of lower quality to consumers in Central and Eastern Europe. The move follows pressure from EU member states in Central and Eastern Europe who have complained about food waste. Brussels also said it was working on a methodology for testing food quality, and that other products, such as household chemicals, could be targeted later.

The provisions of the applicable regulations concerning quality, hygienic safety, packaging, labeling, and related matters are printed in bold in the text of the manual, making them easily noticeable.¹¹⁷

Table 2. Basic differences between services and goods

Services	Hardware, Software, Process materials
Cannot be stored	Can be stored
Production and use are simultaneous	Time gap between production and use
Equipment and device are located close to the consumer	Factories are centralized and far from the consumer
Typically more labor-intensive	Production can be more easily automated
Quality is difficult to measure	Quality is more easily measured
Quality depends heavily on the entity providing the service	Quality does not depend on the individual
Output is difficult to count	Output is usually countable

Unfortunately, in our practice, cases of returned export goods and the payment of allowances or penalties are still not uncommon due to products that were poorly sorted, of lower or inconsistent quality, contaminated, or affected by other defects. There are also instances of problems arising during the import of certain goods (wheat, soybeans, rice, coffee, cocoa beans, peanuts, etc.), whether due to the conclusion of unfavorable contracts or due to shortcomings in inspection and acceptance procedures for such highly valuable goods.

The existing Manual is intended for agricultural experts, technologists, and commercial specialists in agricultural enterprises, cooperatives, and cooperative associations; technologists and quality control personnel in the food industry, including the production of alcoholic and non-alcoholic beverages, as well as organizations engaged in the processing and packaging of goods; staff in trading companies and foreign trade organizations; personnel working in warehouses, ports, freight forwarding agencies, and inspection services (agricultural, market, sanitary); organizations responsible for contractual quality control; institutes for food testing and analysis; consumer protection services; students of agriculture and food technology; vocational school students; and all those who work directly or indirectly with food products.

3. CORRIDOR 10 – ROLE AND IMPORTANCE IN GOODS TRANSPORT

Corridor 10 is a key Pan-European transport route passing through Serbia, connecting Western and Central Europe (Austria, Hungary, Slovenia, Croatia) with Bulgaria, Greece, and North Macedonia. This main transport axis, which includes the E-75 and E-70 highways, is of exceptional economic and strategic importance for Serbia and the wider region, linking major cities and ports.

¹¹⁷ In many countries, such as the USA, Canada, the USSR, France, the Federal Republic of Germany and others, there are professional manuals and a wealth of professional literature dedicated to food production, internal trade and consumer protection, as well as international and overseas trade in these goods and raw materials. They place special emphasis on the preparation of food products for export, in order to avoid complaints, returns of goods from importing countries and payment of rebates.

Corridor X is one of the Pan-European transport corridors. It stretches from Austria to Greece and runs largely through the territories of the former Yugoslav republics. It was officially added to the network after the end of the conflicts in the former Yugoslavia, at the Helsinki Conference in 1997. The corridor includes both railway and road infrastructure.

Key information about Corridor 10:

a) Routes through Serbia:

- Branch A (E-70): Border with Croatia (Batrovci) – Belgrade;
- Branch B (E-75): Border with Hungary (Horgoš) – Subotica – Novi Sad – Belgrade;
- Branch C (E-75): Belgrade – Niš – Vranje – Border with North Macedonia (Preševo);
- Branch D (E-80): Niš – Pirot – Border with Bulgaria (Gradina).

b) Significance: It improves infrastructure, accelerates the transport of goods and passengers, and fosters economic development and regional connectivity.

c) Connectivity: It connects eight countries: Austria, Hungary, Slovenia, Croatia, Serbia, Bulgaria, North Macedonia, and Greece.

Figure 1. Corridor 10, four projects through Serbia



Corridor 10 has been completed, including the demanding sections through the Grdelica Gorge, thereby providing a modern, full-profile motorway across the entire territory of Serbia.

Corridor 10 is one of the most important Pan-European transport corridors passing through Serbia, connecting Austria, Hungary, Slovenia, Croatia, Serbia, Bulgaria, North Macedonia, and Greece.¹¹⁸

¹¹⁸ Even after 40 years, since Corridor 10 was first declared a "priority of priorities", the works show no signs of ending. The constant delays in the completion of sections have also managed to annoy the head of the EU delegation in Serbia, Vincent Degert, who recently requested a plan of priorities and deadlines for the completion of the works from the Ministry of Transport and the "Corridor of Serbia". Degert recently said that this road route is extremely important for Europe, and that he is concerned about the delays and non-withdrawal of funds for the sections. Therefore, he says, three sections are at risk – near Vladičin Han, the Bancarevo tunnel on the eastern branch from Niš to the Bulgarian border, and the Čiflik-Pirot section. The EU has allocated around 4.8 billion euros to finance these sections.

Construction of the Pojate–Čačak branch is currently underway. The project is costly and progressing slowly; works have reached Vrnjačka Banja, and the route will connect to the “Miloš Veliki” motorway, which runs from Belgrade to Čačak. The rehabilitated tunnels are equipped with modern traffic monitoring and management systems. Supervision is carried out 24 hours a day from a central control center. The tunnels are fitted with video cameras that provide real-time monitoring, enabling the detection of traffic congestion, identification of the number and type of vehicles in motion, and the provision of all necessary data aimed at preventing disruptions. Through a variable message light signaling system, drivers are informed via warnings or speed restrictions. Users also have access to an SOS communication system, allowing them, in the event of a breakdown or accident, to notify and request assistance from the operator in the control center. In addition, several tunnels are equipped with ventilation and air quality control systems, as well as automatic fire detection and alarm systems installed along the entire length of the tunnels.

Figure 2. Modern road infrastructure along Corridor 10



According to the Ministry of Finance, more than a billion euros of loans approved by the EBRD, EIB and the World Bank have not yet been withdrawn. This can sometimes have objective reasons, explains Goran Rodić, a construction expert, and cites as an example the unfinished expropriation of land, which makes work more difficult. But, he says, in order for this to not happen, it is necessary to separate capital investments from political marketing.

4. ARTIFICIAL INTELLIGENCE IN THE TRANSPORT OF FOOD PRODUCTS

We live in an era of rapid technological advancement, in which the impact of modern technology is evident in almost all areas of life, including food production. Over the past decade, agriculture has undergone a remarkable transformation through the integration of cutting-edge technologies—from the use of drones in fields to various tools that facilitate food production. In this way, efficiency, production sustainability, and product quality have all been improved.

While artificial intelligence dominates global technological and political discourse, the European Union is building its ambition to become a global leader more quietly, yet systematically. The concept of the so-called “AI Continent,” increasingly present in Brussels policy documents, is not merely a response to a passing technological trend, but rather an attempt to address a much deeper and long-term issue of European competitiveness.

- How does artificial intelligence enhance the efficiency of combined transport?
- How can artificial intelligence improve the quality and safety of food during transport, storage, and use for human consumption?
- To what extent can artificial intelligence assist in risk management, increase resilience to natural disasters, and contribute to building more sustainable and resilient critical infrastructure systems?
- European artificial intelligence: between ambition and reality?

At the heart of the issue lies a concerning low rate of AI adoption within the European Union. According to available data, only 13.5% of enterprises currently use AI technologies, while the percentage among small and medium-sized enterprises is even lower, at just 12.6%. This gap between European ambitions and actual implementation forms the starting point of the European Commission’s new strategy—Apply AI.

This analysis examines the key elements of the Apply AI strategy, focusing on its broader political and economic significance: its potential to strengthen Europe’s technological sovereignty, reduce dependence on the United States and China, and shape a distinctive “European approach” to artificial intelligence. At the same time, the text highlights structural challenges that could limit the scope of this strategy—from financial constraints to internal differences among Member States.

The Apply AI strategy is not based solely on financial incentives; it also introduces a new governance model for AI policy. This model rests on three complementary pillars: an alliance bringing together industry, academia, and the public sector; an observatory that monitors trends, analyzes impacts, and guides investments; and a coordination body that connects Member States.

The Apply AI strategy represents a serious attempt to translate European ambition in the field of artificial intelligence into systemic policy. With an initial investment of one billion euros, intended to catalyze up to 20 billion euros in annual investments, the EU clearly signals that it views artificial intelligence as a key pillar of its future competitiveness and sovereignty.

Such a structure reflects the intention to manage AI policy as a dynamic, adaptive process rather than a one-time strategy with fixed objectives.

Energy, transport, water supply, telecommunications, security, healthcare, and finance constitute the system of critical infrastructure of every state. High-risk artificial intelligence is used, among other purposes, in the management and operation of critical infrastructure.

It is evident that data history, data collection from various sources, the use of big data (large and complex datasets), supercomputers, and digitalization in information processing can significantly increase the speed of information exchange—not only in terms of predictive maintenance of assets potentially exposed to threats, but also in enabling competent authorities and emergency services to respond quickly and bring specific events or incidents under control.

A major step forward is also the application of AI not only in food production but in reducing waste. Scientists and innovators worldwide are increasingly focusing on the use of artificial intelligence for food quality and safety control. Although this field is still in its early stages, it is already clear that AI has the potential to revolutionize quality control by enabling faster and more precise inspections, detecting contaminated products, and thereby ensuring higher safety and quality of products that reach consumers.

AI optimizes production processes by analyzing data, increasing efficiency and reducing waste. Although the results so far are impressive, it is believed that future advances in AI will further improve the food production industry, especially in the field of product safety and quality.

As explained for the website *New Food* by Anok van de Vol, a food safety expert, in order to better understand the importance of artificial intelligence in this field, we must first understand the entire chain—from production and harvesting to packaging, transport, storage, and final placement before the consumer in retail stores. If any stakeholder fails at any point in this chain, product safety may be compromised. Therefore, food safety monitoring systems are crucial for risk management and for maintaining the prescribed quality standards.

Food industries worldwide spend thousands of hours each year ensuring that food is produced according to the highest standards and that its quality is preserved on its way to consumers. Finding more efficient and reliable ways to monitor food safety is at the top of every manufacturer's priority list. New technologies provide opportunities to detect and resolve quality or safety issues more quickly. The time required for data analysis, collection, and processing can be drastically reduced.

In one experiment, cocoa ingredients were tested and the data were manually entered into a computer. This process takes between 35 and 45 minutes. However, when cocoa is analyzed using equipment based on infrared technology for data collection and processing, the entire procedure is completed in just 5 minutes. This means that more measurements can be performed and more reliable data obtained. The increase in data volume throughout the supply chain opens exciting opportunities for artificial intelligence.

As we collect more data, we must also be able to process more information in real time. AI systems will eventually be capable of doing exactly that, helping us build even more precise and powerful food safety systems. Artificial intelligence will not only serve as a tool for measuring food quality and safety, but as an innovative technology that revolutionizes this field in the following ways:

- **Supply chain visibility** – AI closely monitors products throughout the supply chain, ensuring they move safely within controlled environments;
- **Detailed product tracking** – It monitors and analyzes quality parameters, ensuring the highest standards are maintained from farm to table;
- **Efficiency and transparency** – AI streamlines operations, increases efficiency, ensures quality, and enhances transparency;
- **Speed and accuracy** – AI-powered tools help food companies—including production, transport, and retail—improve automation, efficiency, precision, and safety, saving valuable time and resources;
- **Predictive analytics** – AI technology analyzes vast datasets to proactively identify quality issues before they manifest, minimizing potential damage;
- **Risk mitigation** – AI acts as a vigilant guardian, warning of equipment failures, reducing risks, and ensuring uninterrupted processes;
- **Product inspection** – The perceptive “eye” of AI detects product defects and deviations with unparalleled precision compared to human inspection.

The main trends today for the development of AI systems are: the development of expert systems and the development of neural networks. Expert systems try to reproduce human thinking through symbols. Neural networks do this more from a biological perspective (they recreate the structure of the human brain with the help of genetic algorithms). Despite the complexity of both systems, the results are very far from truly intelligent thinking.

Many scientists remain skeptical about the possibility of developing genuine AI. Human thinking is still not fully understood, which means that for a long time to come, the design of intelligent computer systems will be inherently limited in representing these unknown and complex processes. Research in AI focuses on the following components of intelligence: **learning, reasoning, problem-solving, perception, and the use of programming languages.**

Modern AI research concentrates on computational solutions aimed at constructing intelligent machines with capabilities similar to those of humans. Current trends focus on the development of neural networks and the enhancement of expert systems.¹¹⁹ The role of expert systems in this context is to reproduce human reasoning through specific symbols encoded into artificial intelligence. Neural networks are studied from a biological perspective, but their results are still far from true intelligent reasoning. Overall, the current state of AI is still far from genuine intelligence. Contemporary research continues to focus on **learning, reasoning, problem-solving, perception, and natural language understanding.**

¹¹⁹ The definition of artificial intelligence, or rather the term, was first introduced in 1956 in Hanover, USA, at a symposium of researchers who presented theories related to intelligence, neural networks and automata (robots). This symposium was organized by John McCarthy and his associates and laid the foundations of artificial intelligence, and paved the way for its further development and improvement.

An **expert** (synonyms: specialist, authority) is a person with extensive experience, knowledge, and skill in their field. When advice is needed for a business decision or professional task, the opinion of an expert is highly valued. Experts usually gain their experience over a lifetime by encountering various situations requiring rational decision-making, which gives them a strong foundation in making critical judgments.

5. THE PATH TO CREATING ARTIFICIAL INTELLIGENCE

Artificial intelligence (AI) is a collection of techniques and methods that enable computers to perform tasks considered complex for ordinary humans. Applying these techniques in transportation allows the creation of intelligent systems for monitoring and control, as well as for predicting and responding to potential risks. Traffic safety indicators are measurable variables that determine the level of safety in a transportation system. Accurately defining and monitoring these indicators is essential for the effective and efficient management of traffic safety. AI applications include activities such as computer vision and object detection algorithms, which can recognize potential hazards on the road, such as pedestrians, vehicles, obstacles, and more.

Enhancing traffic safety through AI involves implementing automated traffic management systems, monitoring driving behavior, predicting risky situations, and developing intelligent transportation systems. This includes the use of technologies such as autonomous vehicles, hazard detection, and real-time adaptation of goods transport.

In an era of rapid technological advancement, AI is revolutionizing the transport sector, transforming it into an intelligent and predictable ecosystem. From autonomous vehicles that improve safety to traffic management systems that optimize the flow of vehicles, AI is shaping the future of mobility.

Artificial intelligence is software that accesses vast databases and uses that information to make decisions independently. Its ability to make decisions sets it apart from other software. AI has a wide range of applications, but its primary purpose is to make life easier for humans—for example, self-driving cars.¹²⁰ Research and development in AI are already well underway and will continue to improve technologies we already know and use. AI enables process automation, enhances operational efficiency, and increases the accuracy and precision of decisions.

Today, there are five remarkable applications of artificial intelligence. For example, according to chip manufacturer NVIDIA, the company INSILICO used generative AI in every step of its drug discovery process.

The technological revolution at the end of the 20th century and the beginning of the 21st century has networked all of humanity, and “membership” in this network is no longer a matter of choice. A society in which information takes the place of capital and becomes a defining element of its functioning is called the information society.

¹²⁰ To dream of a car moving without a driver may indicate that you are having problems mastering your actions or that you are not in control of your life.

Ignoring or distancing a community from this global network results in isolation and a permanent loss of progress. These facts, confirmed by research, are captured in the term “digital divide”, which highlights that poor countries and regions, due to underdeveloped information and communication infrastructure, become poorer, while rich countries, thanks to the exponential development and application of new technologies, become increasingly wealthier. The sought solution is not limited to technological or infrastructural measures. Priority is given to the application of ICT across diverse social domains—from business to philosophy.

Figure 3. Components in an artificial intelligence system



Thus, the creativity, success, and readiness of a society to find ways to use ICT to improve its own functioning critically determine its position on the digital divide map. Studies have also shown that investment in ICT is directly correlated with an increase in a country's GDP.

Intelligence, usually measured by IQ and other standardized tests, is commonly used in educational, business, military, and law enforcement organizations because it serves as a reliable indicator of an individual's behavior and problem-solving potential.

Although there are various concepts of intelligence, the most influential approach to understanding it is psychometrics, i.e., intelligence testing. Intelligence can be measured using IQ tests, which are believed to assess *g*, the general factor of intelligence. *g* is often divided into fluid intelligence (GF) and crystallized intelligence (GC).

Depending on IQ scores, levels of intelligence can be categorized as follows:

- Genius: IQ above 140
- Very high intelligence: IQ 120–140
- High intelligence: IQ 111–120
- Average intelligence: IQ 90–110
- Borderline intelligence: IQ 70–89
- Intellectual disability (IQ below 70, either from birth or due to developmental issues), further classified as:
 - Mild intellectual disability: IQ 50–69

- Moderate intellectual disability: IQ 35–49
- Severe intellectual disability: IQ 20–34
- Profound intellectual disability: IQ below 20

Some definitions suggest that intelligence is determined by the speed of learning and/or the ultimate complexity of what is learned, particularly when studying animal intelligence. Learning drives the development of intelligence, and intelligence facilitates learning—a dynamic process of mutual reinforcement rather than a simple cause-and-effect relationship. According to some theories, the IQ coefficient is not a measure of immediate learning ability but a mathematical estimate of how learning capacity will change over time; other theories view IQ as a measure of current learning capability.

Historically, decision-making based on reason has been a human prerogative. Since the Enlightenment, rational thought has been a defining attribute of humanity. The emergence of machines capable of approximating human reasoning will transform both humans and machines. Machines may enlighten humans, expanding our reality in unexpected ways—or, conversely, machines that consume human knowledge could be used to diminish us. Simultaneously, humans will create machines capable of remarkable discoveries and conclusions—machines that can learn and evaluate the significance of their findings. The result will be a new epoch.

The waves of change brought by the Industrial Revolution continue to resonate across the economy, politics, intellectual life, and international relations. Without fully recognizing many of the modern advantages already provided by AI, we have gradually—and almost passively—begun to rely on technology, often without noticing our dependence or its implications. In daily life, AI acts as our partner, helping us decide what to eat, what to wear, what to believe, where to go, and how to get there.

Although AI can draw conclusions, predict outcomes, and make decisions, it lacks self-awareness—the ability to reflect on its role in the world. It has no intent, motivation, morality, or emotion; yet, even without these attributes, it will likely develop diverse and unintended methods for achieving its assigned goals. Inevitably, it will also change humans and the environments in which they live. When individuals grow up or train alongside AI, they may—even subconsciously—treat it as an anthropomorphic entity or as another “being.”

While technology may seem incomprehensible and mysterious to most of the human population, an increasing number of individuals in universities, corporations, and governments have learned to build, operate, and apply AI in everyday consumer products, often consciously or unconsciously. However, as more people gain the ability to create AI, those who contemplate the social, legal, philosophical, spiritual, and ethical implications of AI remain strikingly few.

Supported by the increasing use of AI, the human mind now has access to new horizons, approaching previously unattainable goals. This includes predictive models for mitigating natural disasters, deeper understanding of mathematics, and a more complete comprehension of the universe and our reality. Yet, these possibilities come at a cost—mainly altering human relationships with reason and reality. This is a revolution for which existing philosophical concepts and social institutions are largely unprepared.

Intelligent technological systems are focused on: technological recognition of machine components, visual inspection and object recognition, autonomous mobile robots, etc. AI programs that achieve expert-level competence in operational domains rely on applying knowledge of specific artificial tasks based on expertise or understanding of human behavior.

The term intelligence encompasses many cognitive abilities, including problem-solving, learning, and understanding computational languages. The greatest progress to date in AI has been in problem-solving, where the concepts and methods for constructing humanoid Expert Systems (ES) are based on knowledge bases and reasoning engines.

AI also helps guide food choices: the myth of the traditional food pyramid is being replaced (with the U.S. introducing new nutrition guidelines through 2030). Grains are no longer the dietary foundation; proteins and healthy fats now play a central role—reintroducing eggs, bacon, and cheese in place of toast and cereal.

Through new projects worldwide, leading experts have demonstrated how AI can make road, maritime, air, and rail freight transport more efficient. Developed prototypes help maximize vehicle capacity, optimize resource use, and make multimodal transport more attractive. This is an important step toward shifting cargo from roads to rail, thereby contributing to environmental protection.

Figure 5. Artificial intelligence improves the efficiency of combined transport



By creating indicators for monitoring traffic safety and using advanced artificial intelligence techniques, new opportunities can be identified for warning about traffic accidents and improving the safety of all participants in traffic. Developed models for train load planning allow for maximizing their utilization in terms of capacity and length, while simultaneously reducing crane movements and transshipment processes. Numerous parameters are automatically and simultaneously taken into account during optimization. The network planning component combines AI-based cargo volume predictions with mathematical optimization to allocate cargo units in a way that enables optimal use of trains and trucks, as well as faster transport with a minimal number of transshipments.

The combination of AI and optimization opens entirely new possibilities for intermodal transport. Forecasts of reservation numbers can be directly integrated into optimization processes, enabling more efficient loading of trains and trucks and more stable network management. In this way, a practical approach is created that directly supports operational systems and enhances the performance of road, maritime, and rail freight transport.

Which fruits and vegetables are most imported?

According to data and analyses from the Association for Plant Production and the Food Industry of the Serbian Chamber of Commerce, in 2022, 305,990.5 tons of fruit were imported. The highest import value in 2022 was for bananas, amounting to €61.2 million, followed by lemons and oranges, which is logical since these crops are not typical for our climate. In 2022, most bananas were imported from Ecuador, Costa Rica, and Colombia. Next were citrus fruits: oranges from Greece, Turkey, and Spain; clementines from Greece and Turkey; mandarins from Greece and Turkey; lemons from Turkey, Argentina, Spain, and Greece; and grapefruits from Turkey.

Apples were mainly imported from North Macedonia, while strawberries were mostly imported from Greece, Albania, and Turkey; pears from Italy and Poland; and nectarines and peaches from Greece, Italy, and Spain. By quantity, the largest imports were of new potatoes, tomatoes, and beans, with smaller amounts of onions, frozen vegetables, and cucumbers. The highest import value in 2022 was for tomatoes, while beans reached a total import value of €20.6 million, or 13.3% of the total import value.

In 2022, potatoes were mainly imported from the Netherlands and France, beans from Kyrgyzstan, tomatoes from Albania and North Macedonia, onions from the Netherlands and North Macedonia, while garlic came mostly from China. Cabbage was imported from North Macedonia, fresh peppers from North Macedonia and Albania, cucumbers from Albania, and frozen peas, spinach, and other frozen mixed vegetables in smaller quantities. Watermelons were imported mostly from Greece, and to a lesser extent from Albania and North Macedonia, while melons came mostly from Spain and Albania, but in significantly smaller quantities than watermelons.

Agriculture is a key sector of the Serbian economy, with about one million hectares of agricultural land (over 70% of the territory), most of which is arable. The main sectors are crop production (Vojvodina), fruit and vegetable farming (central Serbia), with significant potential for livestock farming. The sector is characterized by a moderate-continental climate and over 1.3 million farmers. Land resources: Of the total area of 8.84 million hectares, agricultural land covers 5,734,000 hectares, of which 4,867,000 hectares are arable.

There is a misconception in Serbia that there are about five million hectares of agricultural land, with arable land covering around 4.1 million hectares. According to the latest data from the Statistical Office of the Republic of Serbia, only about 3.488 million hectares are actually cultivated. Supposedly, the average per capita land in Serbia is 0.56 hectares, but in reality, we do not have more land than that. On the other hand, about 600,000 hectares remain uncultivated, which even much more developed countries cannot afford. The main problems in land use in Serbia are extensiveness, plot fragmentation, insufficient input of organic matter, low use of organic fertilizers, and degradation processes caused by natural and human factors.

In agriculture, some researchers, entrepreneurs, and politicians believe that the impact of AI and other advanced technologies is so significant that it is driving what is called the Fourth Agricultural Revolution.

One response to these challenges comes in the form of regenerative agriculture – an approach that not only ensures the production of healthy food but also restores the soil, reduces pollutant emissions, and strengthens rural areas, which is currently a major problem for us.

Artificial intelligence is increasingly changing the concept of security, becoming a key technology in company protection systems, critical infrastructure in cities, and rural areas.

The ability to automatically analyze data in real-time, recognize patterns, and identify threats are just some of the features through which AI enables faster and more accurate responses to security incidents. Although it offers many advantages, implementing AI for security purposes also raises new issues, including ethical challenges regarding privacy and data misuse.

One of the most important aspects of integrating AI into security systems is predictive analysis. Through real-time data analysis and pattern recognition, AI can predict and alert to potential threats. In large business centers, AI analyzes data from multiple modern IT sources (cameras, sensors, drones) to quickly identify risky situations and enable farmers and local authorities to respond before situations escalate and damage agricultural crops.

Artificial intelligence could accelerate data analysis of food products through automatic processing. It could handle vast amounts of data. Smart AI devices enable predictive analytics, allowing producers to proactively anticipate challenges, such as disease outbreaks and adverse weather events.

The transformative impact of AI on the transport and logistics industry is enormous, yet many misconceptions still need to be clarified. This is common for new technologies. Changes can be challenging, and while AI is an incredible “tool” that helps companies optimize operations, reduce production, transport, and storage costs, improve corporate social responsibility efficiency, and dispel misconceptions in a timely manner, its benefits are undeniable.

The largest European study on regenerative agriculture included 78 farms across 14 countries and compared their results with national and regional averages. The conclusions are revolutionary:

- 62% less synthetic nitrogen fertilizer,
- 76% fewer pesticides per hectare,
- 27% higher overall system productivity (Regenerating Full Productivity Index),
- Up to 84% of EU agricultural emissions could be reduced in the first years of transition.

These results confirm what many pioneers of regenerative agriculture already know: it is possible to produce sufficient food with fewer chemicals/pesticides while preserving soil and increasing farm resilience.

In the race for profit and investment in only “necessary inputs” over the last half-century, we have completely neglected the soil our ancestors left us. If we continue this way, there

will be nothing to leave for our children. It is high time to become aware and start returning to the soil what we have long taken from it.

Application of Green Manure: Green manure is a highly suitable agrotechnical measure for all types of organic production, yet it is still not widely used. For a crop to be suitable for this type of fertilization, it must rapidly form a large plant biomass and have a root system that grows deep into the soil to transfer nutrients from deeper layers to the organic layer of the soil.

Leguminous plants are the most favorable for green manure, as they can fix atmospheric nitrogen and transfer it into the soil. The most commonly used for this purpose are clover, lupine, pulses, and fodder peas. Among non-leguminous plants, the most frequently used are rapeseed, rye, barley, and mustard. Green manure enriches the soil with 35–40 t/ha of fresh organic mass and 100–200 kg/ha of fixed nitrogen.

Farmyard Manure: Applying farmyard manure to the soil is one way to improve its fertility. However, it should be noted that manure is not humus; rather, it is a material from which humus can form under favorable conditions and with the uninterrupted activity of beneficial microorganisms. Due to the reduced livestock stock, the use of this organic fertilizer has also decreased.

The chemical composition of farmyard manure mainly depends on the type of animal it comes from, and the average composition is considered as follows: water 75%, dry matter 25%, nitrogen 0.5%, phosphorus 0.2%, potassium 0.6%. From the amount of fresh manure, about 40% of composted manure is obtained. Such manure contains on average 0.5% N, 0.25% P₂O₅, and 0.60% K₂O, i.e., 20% organic matter.

Unlike conventional agriculture, which focuses on maximizing yields, regenerative agriculture has a broader goal: restoring ecosystems. This involves:

- increasing soil organic matter,
- reducing erosion and soil compaction,
- crop rotation and cover crops that feed the soil,
- agroforestry and syntropic systems that integrate agriculture with natural processes,
- reducing dependence on pesticides and mineral fertilizers,
- preserving biodiversity and natural resources.

The ultimate result is more resilient soils, healthier plants, and more stable yields, even under conditions of frequent climate changes. Simon Kraemer, one of the leaders of this initiative (regenerative agriculture), calls this eco-transformation the Fourth Agricultural Revolution. To recap, the first three revolutions were:

1. Mechanization – the transition from manual labor and animal power to tractors and machinery;
2. Green Revolution – introduction of high-yield varieties and mineral fertilizers;
3. Digital Agriculture – precision management using satellites, sensors, and algorithms.

The fourth revolution (regenerative agriculture) combines the best of the previous ones but emphasizes natural processes and sustainable development.

The institution **EIT Food** is a leading European initiative for innovation in the food sector, supported by the European Institute of Innovation and Technology (EIT). Its mission is to

build a new, innovative, sustainable, and reliable food system that produces healthier food and strengthens the European economy (EU).

Through a network of universities, research institutes, agencies, companies, and startups, EIT Food connects the entire value chain, from farmers and producers to traders, transporters, and ultimately consumers. One of their key initiatives is EARA – European Alliance for Regenerative Agriculture, an alliance of farmers, researchers, and innovators working to accelerate the adoption of regenerative practices across Europe.

The EARA network provides:

- research support and data collection,
- financial assistance to farmers transitioning to regenerative systems,
- education/training for producers of goods all the way to end consumers, especially food,
- networking and knowledge exchange among farmers from multiple Western Balkan countries and Europe as a whole.

Although most examples relate to Western European countries, the messages are universal and particularly relevant for our region:

1. Production costs can be reduced. Lower use of pesticides and fertilizers means less dependency on imports and lower costs per hectare;
2. Soil health = yield stability. Regenerative practices increase resilience to drought, hail, and floods, which is crucial under climate change conditions;
3. Consumers demand organic and local products. While organic products currently make up about 5% of the market in the region, demand is growing year by year;
4. Support from EU funds. Programs such as Horizon Europe, Interreg projects, and EIT Food grants already finance pilot farms and startups in the region.¹²¹

Regenerative agriculture already has evidence of success, but for it to become the dominant practice, the following are needed:

- more education for farmers,
- incentives from governments and EU programs,
- better market connectivity between producers and consumers,
- risk reduction through insurance and guarantee funds,
- organization of farmers into cooperatives and clusters for joint sales and marketing.

Europe has already embarked on the “fourth agricultural revolution.” Data from studies clearly show that regenerative agriculture does not mean producing less food, but smarter production. It brings lower costs, healthier soil, reduced emissions, and a more stable future for rural communities.

Companies in the transport and logistics sector are constantly under pressure to reduce costs, increase efficiency, and adapt to market changes. AI solutions are not just a passing

¹²¹ Startups are newly created, innovative companies focused on rapid growth, scalability, and the development of new products or services, often in the technology sector. They aim to quickly expand their user base and revenue. They differ from ordinary companies in terms of high risk, but also the potential for high profits. In Serbia, the Startup Portal offers information for development and financing.

trend – they are already proven and applied. Companies using them are already recording significant savings, simpler operations, and stronger partnerships.¹²²

Strategic Development Goals by 2030: These projects provide key tools, networks, and infrastructure that will enable the scientific community to contribute to EU priorities such as Destination Earth, the Green Deal, the Digital Strategy, and EU missions. Grants have been signed with the European Commission, and project activities began in January 2023. The projects support the creation of a network of reliable European digital repositories and promote the FAIR principles (Findability, Accessibility, Interoperability, Reuse) for data.

The European SMART ERA project, funded through the Horizon Europe program, launched its first public call for grants aimed at innovators, startups, and small businesses. The goal is clear – to find digital and technological solutions that can transform the face of European villages, enabling them to become centers of development, innovation, health, quality of life, and well-being.

Grants are intended for projects/programs that add value to rural communities and respond to their specific needs. They will finance:

- digital systems for agriculture and production monitoring,
- AI tools for tourism and micro-agriculture,
- platforms for rural businesses and agrotourism,
- mobile and health applications,
- solutions for promoting and networking local communities.

Instead of approaching AI with fear, companies should see it as a tool that complements human expertise, automates routine tasks, and allows teams to focus on growth and strategy.

Artificial intelligence in transport enables people to work smarter and achieve better results more efficiently. It has wide applications in passenger and cargo air transport, such as weather prediction, aircraft maintenance, and providing personalized advice to travelers after bookings.

The integration of technologies is being explored through examples such as the development of electrochemical sensors for detecting disease biomarkers in cow's milk, orange juice, and apple juice, and the use of integrated microsensors with 3D-printed smart devices for virus detection in tomatoes. However, these technologies also raise safety concerns regarding data collection through smart sensors; the cost of sensors, network infrastructure, and data management could be high, and connectivity issues may arise when smart devices are used in rural or remote areas where many farms are located.

¹²² The European research community had the opportunity to participate in the Horizon Implementation Day: Finding opportunities and submitting a proposal in Horizon Europe, which took place on 13.03.2025 from 09:30 to 12:30 CET (Brussels Time). This event provides a comprehensive overview of funding opportunities within the Horizon Europe program, offering practical guidance on searching for calls, finding partners and successfully submitting projects. This event was an opportunity for researchers, innovators and organizations that want to take advantage of the funding opportunities available through Horizon Europe. Participants received practical information and useful tips to increase their chances of successful application.

Biosensor expert Azahar Ali, a biological systems engineer at the Virginia Polytechnic Institute, is preparing for the Fourth Agricultural Revolution. This era is expected to harness the transformative potential of connected technologies emerging from the fourth industrial revolution. The new technology could attract younger, more tech-savvy farmers, while older farmers without the skills suitable for the new style of production may experience fear and stress.

Robots harvest only ripe fruit and then classify it by size and ripeness. Once a fruit is selected, the robot determines the best way to remove the ripe produce.

Drones collect data, and electric-powered tractors autonomously cultivate fields. Such smart robots could be used for planting and harvesting, weed removal, milking cows, while drones already help detect plant diseases, pests, and more. Other food production technologies include new types of gene editing to create disease-resistant varieties with higher yields. This production method requires higher financial investment but, on the other hand, reduces environmental pollution and greenhouse gas emissions.¹²³

Three technologies stand out for their potential to advance climate-resilient, precision agriculture: wearable agricultural sensors, connected or smart devices, and artificial intelligence. However, experts note that combining these cutting-edge technologies could lead to a paradigm shift in how the agricultural sector monitors food safety, quality, and productivity worldwide.

Rapid, accurate, and early monitoring will be a priority for sustainable and safe food production for the rapidly growing global population, which could reach nearly 10 billion by 2050 and will require 50% more food to maintain the global food supply chain.

Artificial intelligence could accelerate data analysis through automated processing, handling vast amounts of information. Smart devices and AI also enable predictive analytics, allowing producers to proactively anticipate challenges such as disease outbreaks and weather patterns.

The integration of these technologies is being explored in examples such as the development of electrochemical sensors for detecting disease biomarkers in cow's milk, orange juice, and apple juice, as well as the use of integrated microsensors with 3D-printed smart devices for virus detection in tomatoes.

6. CONCLUSION

Artificial intelligence, in a broad sense, refers to the capacity of an artificial creation to perform functions characteristic of human thinking. The term and concept of artificial intelligence were first introduced in 1956 in Hanover, USA, at a symposium of researchers presenting theories related to intelligence, neural networks, and automata (robots).

¹²³ See more: <https://www.agroklub.com/kolumna/dronovi-skupljaju-podatke-traktori-napajani-strujom-samostalno-obraduju-njive>

In the following years, the concept of AI rapidly evolved, and today its development is at its peak, with researchers worldwide competing to create the most intelligent machine, envisioning AI reaching the hypothetical threshold of producing robots with intelligence similar or equivalent to that of humans ("homo roboticus"). Many AI programs have been designed to solve practical problems regardless of their similarity to human mental architecture.

The application of AI holds significant potential to reduce traffic accidents and injuries, as well as to improve overall safety for all participants in traffic. From the proper monitoring and analysis of safety indicators to the implementation of intelligent systems for warning and responding to potential risks, AI enables enhanced management and control of traffic. Even expert systems, although heavily relying on the knowledge of specialists, do not attempt to simulate the internal human mental processes from a problem-solving perspective.

At the core of any virtual reality system is a powerful computer. It must be fast in rendering three-dimensional objects. Such a computer is called a reality machine. Headsets with screens and headphones, as well as hand controllers, are connected to the computer.

The emergence of the hikikomori culture reflects young people's reaction to the societal conditions they face. Youth experience a sense of incapacity to meet imposed expectations, withdrawing from social roles and isolating themselves from society.

Technological development is an inevitable fact, and the answers to the questions it raises will determine the scenario of the future in which coming generations will live. It remains to be hoped that future societies will be built around principles of elevated values, in the tradition of humanism and the cultivation of spirituality.

The evolution of the Internet is still ahead of us and will open up new possibilities, including for illegal activities. However, we should not blame technology or those who created the Internet, as it remains one of the greatest technological achievements of our civilization. The benefits and positive changes that the Internet has brought to the lives of many cannot be denied.

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RURAL TOURISM SERVICES AND THE ROLE OF COOPERATIVES IN THE REPUBLIC OF SERBIA

УСЛУГЕ СЕОСКОГ ТУРИЗМА И УЛОГА ЗАДРУГА У РЕПУБЛИЦИ СРБИЈИ

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Abstract: The authors of the paper point to the reaffirmation of cooperatives, both at the global and national levels, and their impact on the development of rural tourism in the Republic of Serbia. The main objective of the paper is to examine existing problems and find solutions, in the legislative field and in the institutional support of political office holders. The authors particularly emphasize the necessity of using the experiences of numerous European Union member states and applying the comparative method in the process of European integration. Providing services in rural tourism represents a great opportunity for the economic recovery of the Republic of Serbia.

Key words: cooperatives, rural tourism, services, Republic of Serbia, European Union

Анстракт: Аутори у раду указују на реафирмацију задруга, како на глобалном, тако и на националном нивоу и њихов утицај на развој сеоског туризма у Републици Србији. Основни циљ рада се састоји у сагледавању постојећих проблема и изналажењу решења, у законодавној области и у институционалној подршци носилаца политичких функција. Аутори посебно наглашавају неопходност коришћења искустава бројних држава чланица Европске уније и примењивање упоредног метода у процесу европских интеграција. Пружање услуга у сеоском туризму, представља велику шансу за привредни опоравак Републике Србије.

Кључне речи: задруге, сеоски туризам, услуге, Република Србија, Европска унија

1. INTRODUCTORY REMARKS

Tourism, in general, has significant social, economic, and political importance, as it primarily contributes to easier communication among people from different countries, better mutual understanding, and the exchange of customs, traditions, and lifestyles. The economic importance of tourism and its impact on a country's development are reflected in tourism expenditure, which has both direct and indirect effects on the economy. Tourism also has notable political implications, as it contributes to the preservation of peace and global stability; after spending time in a foreign country, tourists can gain a clearer understanding of its social relations and environment.

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Tourism gained importance in the 20th century, but at the beginning of the 21st century it experienced expansion and mass development through the emergence of specific forms of tourism. These include congress tourism, spa and wellness tourism, health tourism, religious tourism, ecological tourism, and more recently, rural tourism. Rapid urbanization in the modern era has increased the interest of urban populations—especially those living in large cities—in recreation within rural environments. At the same time, the transition processes at the end of the last century stimulated the development of small and medium-sized enterprises, as well as the production and food industries, both in the Republic of Serbia and neighboring countries.

Rural areas in the Republic of Serbia possess considerable potential for tourism development. Unique geomorphological features, numerous thermo-mineral springs and other hydrographic resources, mountains, a mild and pleasant climate, rich flora and fauna, along with cultural and historical monuments, traditions, and internationally recognized culinary specialties, make Serbia distinctive on the European tourism market. The authors of this paper aim to highlight the richness of Serbia's rural tourism resources and the wide range of services that can be offered. It is realistic to expect that the development of rural tourism will help reduce negative migration trends of young people moving to urban areas and contribute to the revitalization of rural regions. However, continuous education of the local population is essential, as it strengthens entrepreneurial spirit and fosters a business-oriented mindset in this field.

Tourism has numerous positive direct effects on gross domestic product and national income, as it stimulates the development of various sectors of material production that directly meet the needs of tourists. This primarily includes the hospitality industry, which provides services through various facilities such as hotels, motels, restaurants, cafés, bars, and others. Tourism also significantly influences the development of trade and transportation (road, air, rail, and water). In addition, craft services (such as the production of souvenirs, branded products, beverages, handicrafts, and traditional specialties) and communal services (water supply, waste management, and maintenance of infrastructure) play an important role. Furthermore, tourists require cultural and entertainment content during their stay, which can be provided through theaters, cinemas, festivals, carnivals, and various events.

To successfully implement all these activities and meet tourist needs, it is necessary to ensure the presence of numerous travel agencies, well-organized information systems, and continuous service provision. This has a strong impact on employment, as tourism requires a wide range of diverse and specific services delivered through direct human engagement. In addition to its direct effects, tourism also generates significant indirect impacts on the economy. It stimulates the development of construction through investments in accommodation facilities, transport infrastructure, and other supporting systems. Finally, tourism contributes to industrial development by encouraging increased production, particularly in agriculture.

An analysis of tourism in the Republic of Serbia and the utilization of its capacities indicates that these capacities are still insufficiently used, especially when compared to medium and highly developed European countries. Serbia has highly favorable conditions for the development of health and spa tourism, with over 1,000 mineral water springs. However, only slightly more than 30 spas are currently equipped for tourism services. Many other resources remain underutilized, including air spas, religious sites (numerous monasteries and

churches), mountains, rivers, quality hotels, and an increasing number of ethno-villages and rural households. These resources provide extensive opportunities for organizing various events, scientific conferences, round tables, congresses, cultural manifestations, hunting and fishing, and sports tourism.

The aim of this paper is to emphasize the growing importance of rural tourism, which has experienced a true renaissance in recent decades, particularly in recent years. The importance of rural areas became especially evident during the COVID-19 pandemic, when urban residents—restricted by limited mobility and confined living conditions—sought open and less crowded rural destinations, often regardless of cost. It is evident that the Republic of Serbia has exceptional potential for the development of this form of tourism, thanks to its natural beauty, cultural heritage, preserved environment, healthy traditional food, and well-known production of brandy, wine, and other specialties.

In the second part of the introductory remarks, attention is given to the importance of cooperatives in Serbia, a highly significant but historically neglected sector. Its gradual revitalization has been supported by the adoption of the Law on Cooperatives ("Official Gazette of the Republic of Serbia", No. 112/2015), which regulates the legal status, establishment, management, membership, property, operations, and governance of cooperatives. A cooperative is a legal entity representing a specific form of organization of individuals (members), who conduct their activities wholly or partially through the cooperative by using its services. Through cooperatives, members can market their products, procure inputs, access necessary services, and directly participate in business activities for which the cooperative was established. Cooperatives provide the greatest benefits to their members by enabling joint action through various organizational levels—local, regional, national, and international.

2. RURAL TOURISM SERVICES IN THE REPUBLIC OF SERBIA

The Republic of Serbia has highly favorable conditions for the development of rural tourism, owing to its diverse and suitable climate, which enables the provision of hospitality and tourism services throughout the year, depending on the preferences of potential users. Serbian rural areas are characterized by well-preserved natural environments, clean and unpolluted air, rivers and streams, rich flora and fauna, as well as a remarkable cultural and historical heritage, including numerous monuments of both material and spiritual significance. Additionally, the hospitality and friendliness of local hosts, along with the exceptional culinary skills of homemakers in preparing traditional Serbian dishes and specialties, represent a distinctive and attractive feature for both domestic and international tourists.

In order to stimulate the development of rural tourism and improve service provision in this sector, significantly greater investment in transport infrastructure is required. Improved accessibility would enhance the overall quality and comfort of tourists' stays in rural areas across Serbia. Furthermore, success in rural tourism—like in any other sector—depends on adequate education, professional training, and the competence of service providers, as well as appropriate administrative organization and institutional support.

This highlights the crucial importance of human resources in this field. Skilled and well-trained personnel play a key role in the development of rural tourism, as they must possess

relevant knowledge and competencies. Employees are expected to have a certain level of formal education, but continuous improvement through training programs and non-formal education is equally essential. This is particularly important in modern conditions, where meeting the specific needs and expectations¹²⁶ of consumers is considered a hallmark of high-quality service delivery (Tucović et al., 2017, p. 334).

A very important activity in the provision of rural tourism services is informing potential users through the preparation of appropriate promotional materials, as well as participation in domestic and international tourism fairs and other events. Such activities enable the establishment of necessary connections between supply and demand, that is, between service providers and users. It should be particularly emphasized that rural tourism is currently experiencing rapid growth, with rural areas being increasingly visited by tourists from large cities who seek unspoiled nature, peace, traditional food and beverages, and other experiences that enrich their stay.

Most of these tourists are not highly demanding in terms of accommodation standards and often prefer authentic settings, including facilities that are several hundred years old. However, it is essential to establish minimum standards for guest reception and accommodation, ensure proper hygiene conditions, maintain the quality and scope of services provided, and foster appropriate host behavior, in order to create a pleasant and satisfying stay for visitors in rural households.

To meet these minimum requirements, it is necessary to provide timely and adequate education for rural hosts, particularly in terms of applying service standardization and categorization. It is also important to emphasize that both the state and local authorities must ensure access to healthcare services. Without this, it is difficult to expect tourists from urban areas—where such services are readily available—to visit rural destinations. Many rural tourism visitors seek active holidays, which include participation in daily household activities (often engaging in certain agricultural tasks), excursions, exploration of the surrounding area, and recreational activities such as hiking, cycling, horseback riding, swimming, and various sports. Additionally, tourists are attracted to cultural events and manifestations, including folklore and music festivals, traditional gatherings, local celebrations, village fairs, seasonal games, and visits to cultural and historical heritage sites such as archaeological locations, medieval towns, monasteries, churches, and schools. Social gatherings centered on storytelling about rural life, traditions, customs, and folklore also contribute to the overall experience.

At this point, it is important to emphasize the need for authentic service provision in rural tourism, offering only what is characteristic of a particular area, as this is what visitors truly seek. Tourists come to rural environments expecting genuine experiences and must leave satisfied in order to share positive impressions and return in the future. Serbian hosts are widely recognized for their hospitality, especially in rural areas, where they create a welcoming atmosphere, offer high-quality traditional cuisine, and provide a relaxed environment enriched with humor and music. This is best achieved through homemade food prepared in traditional ways and local beverages such as wine, brandy, and liqueurs. To further enhance the quality of the stay, it is important to organize entertainment programs,

¹²⁶ This is where the famous saying comes into play: "The guest is always right", which actually enhances his personality.

recreational activities, sports, children's games, carriage rides, and various cultural events featuring traditional singing groups, folklore ensembles, musicians, and performers.

A key component for the development of rural tourism in the Republic of Serbia is the availability of appropriate resources. It can be said that Serbia has a strong comparative advantage, given its wide range of tourism resources that can be commercialized. These include restaurants, travel agencies, institutional and organizational structures, production capacities (especially in food production and accommodation services), as well as trained personnel. At the same time, it is necessary to follow developments in other countries—especially neighboring ones—and continuously improve both the quantity and quality of tourism resources.

An especially important aspect in this field is the consumption of agricultural products, which contributes to increased economic benefits for the population. Therefore, it is essential to ensure the parallel development of tourism and agriculture, which can support employment, particularly for young people, and reduce rural depopulation. In this context, the complementarity between tourism and agriculture should be given a central place in economic development planning, with organic agricultural production becoming a priority in recent decades. The concept of organic production dates back to the late 18th century, while formal definitions of organic production methods were established in the early 1970s, marking the beginnings of the International Federation of Organic Agriculture Movements.

This trend is further supported by the growing number of urban residents choosing to spend their leisure time in rural areas characterized by unpolluted environments, clean spring water, fresh air, healthy soil, and the absence of herbicides and pesticides—conditions necessary for the production of organic food. According to the definition provided by the Food and Agriculture Organization (FAO) of the United Nations and the World Health Organization (WHO), “organic agriculture is a production management system that promotes ecosystem health, including biodiversity and biological cycles, and emphasizes the use of methods that largely exclude off-farm inputs” (Jugović et al., 2020, p. 192).

The Republic of Serbia is still in the process of transition, and one of its main challenges is unemployment, which, according to official statistics, is below 10%. However, many researchers and experts from economic faculties and institutes in the country emphasize that such data should be interpreted with caution, as they are derived from different sources and based on varying criteria, making them not always fully comparable. In this context, rural tourism and the provision of related services represent a significant opportunity for young people to find employment within their own country and remain in their local communities. Unfortunately, there is a strong trend of migration toward more developed countries, which particularly affects Serbia, as many young and educated individuals leave in search of better employment opportunities and living conditions.

For this reason, opportunities for income generation and employment can be created through investment and the revitalization of abandoned rural properties. Today, returning to rural areas has become a growing trend, both in Europe and in Serbia, especially among younger generations. This is evident at numerous ethno-fairs and food festivals. Many young couples are purchasing rural properties, leaving urban areas, and engaging in organic production, tourism services, and related activities. Notably, a significant number of these individuals are highly educated. Life in rural areas—characterized by a clean and unpolluted environment,

fresh air, natural water sources, and healthy food—offers not only economic opportunities but also a healthier and less stressful lifestyle.

Although Serbia has around 4,800 registered villages, a major issue is that approximately one-quarter of them are completely abandoned, with a continuing trend of depopulation due to migration toward urban centers and abroad. Therefore, Serbia should adopt a comprehensive, well-designed, and legally grounded approach to the protection of numerous rural structures that represent important elements of cultural heritage but are currently neglected. These include religious and secular buildings such as monasteries, churches, and endowments, many of which were constructed from durable materials such as wood and stone and date back several centuries, some even to the 12th, 13th, or 14th century. In addition, Serbia possesses numerous archaeological sites dating back to the Neolithic period. The importance of preserving such assets can be observed in countries with highly developed tourism sectors, where both authorities and citizens demonstrate strong commitment to cultural heritage protection (Juul, 2015).

Despite existing shortcomings, progress in this field is evident, as awareness of the importance of rural tourism potential has increased. In December 2015, the Program for the Development of Sustainable Rural Tourism in Serbia was adopted, based on the Tourism Development Strategy of the Republic of Serbia for the period 2016–2025 and the 2011 Master Plan for Sustainable Rural Tourism Development (Vukojičić, 2013, p. 6). This program is fully aligned with the Law on Tourism of the Republic of Serbia (2009), and one of its main objectives is to contribute to the overall development of tourism by utilizing the significant potential of rural areas. Rural tourism and related services have the capacity to stimulate the entire national economy, given Serbia's rich diversity of natural, cultural, historical, and geographical resources.

The concept of providing tourism services in rural households originated in France in the mid-20th century, in a small village in Provence. Its primary goal was the preservation and development of rural areas, the creation of new jobs through tourism services, and the revitalization of agriculture, all aimed at preventing migration from rural to urban areas. Traditional residential buildings were adapted into accommodation facilities, and this model is now widely applied in Serbia as well. Rural tourism contributes to sustainable rural development and represents an important factor in stimulating agricultural and non-agricultural activities, as well as employment. It also creates opportunities for the development of small and medium-sized enterprises, as many entrepreneurs are directly involved in providing tourism services.

3. IMPACT OF RURAL TOURISM ON THE REVITALIZATION OF RURAL AREAS IN SERBIA

Rural tourism in the Republic of Serbia is still not sufficiently developed nor fully recognized as an important segment of the tourism offer. Existing research indicates its economic relevance, with estimates suggesting that it contributes over 10 billion dinars directly to the national economy (Đorđević-Milošević & Milovanović, 2012, p. 47). However, sustainable development in this field requires the coordinated involvement of multiple stakeholders, along with strong institutional and policy support. It is a complex and continuous process that depends on learning from international best practices, adopting innovations, and

implementing both corrective and preventive measures to improve the quality of services and meet the evolving needs of tourists.

Experiences from European Union countries, where rural tourism has reached a high level of development, provide valuable insights. These should not be copied directly, but rather adapted to local conditions through careful analysis of their strengths and weaknesses, contributing to the creation of a competitive and sustainable rural tourism model (Unković, 1995).

Rural tourism represents a significant opportunity for the revitalization of rural areas, including those that are depopulated or economically underdeveloped. It contributes not only to the recovery of agricultural activities but also to the broader utilization of rural tourism potentials. In addition, it stimulates the development of various complementary forms of tourism, such as cultural tourism (visiting heritage sites), sports tourism, health tourism, congress tourism, religious tourism, eco-tourism, and adventure tourism (Rogers, 2003).

Owing to its rich natural resources, preserved environment, thermal and mineral springs, and diverse cultural and historical heritage, Serbia has strong potential to position itself as a leading rural tourism destination in the Balkan region. The development of rural tourism can play a key role in revitalizing rural settlements, encouraging population retention and return, and supporting balanced regional development.

4. COOPERATIVES AND THEIR ROLE IN RURAL TOURISM DEVELOPMENT

Many experts analyzing contemporary global economic challenges emphasize the need to revive the cooperative movement, often described as a “movement for all times” (Zakić, 2013, p. 38). This perspective stems from the fact that cooperatives, throughout their long history, have repeatedly faced crises and structural challenges, yet have consistently demonstrated resilience and adaptability (Vujatović-Zakić, 2000). As such, cooperatives represent a distinct and enduring model of economic organization, not only at the national or regional level but also globally. The very notion of a “cooperative” implies collaboration and mutual benefit, which is why the term is frequently used interchangeably with “cooperative enterprise.” A widely accepted modern definition was established in 1995 in Manchester at the Congress of the International Co-operative Alliance (ICA), further confirming Europe as a historical center of cooperative development.

In the Republic of Serbia, particularly within the context of European integration processes, renewed attention is being given to strengthening the cooperative sector. Today, the country has more than 2,000 cooperatives organized into 16 unions, with approximately 123,000 members (Zakić, 2013, p. 38).

From a theoretical standpoint, rural development implies a modern, integrated approach to revitalizing underdeveloped rural areas. In this context, rural tourism, alongside agriculture, represents a key pillar of rural economies, following trends already well established in European Union countries. Serbia, therefore, faces the task of assessing its current level of rural development, identifying structural challenges, and defining strategic directions for future growth. The experience of European cooperative systems is particularly valuable in

this regard, as it demonstrates the important role cooperatives can play in supporting rural tourism and broader rural development.

All forms of cooperatives can contribute to this process, and their potential should not be underestimated, especially when considering the successful application of cooperative models in EU member states, including those that have undergone similar transition processes. As Serbia continues its path toward European integration, it becomes essential to better understand EU rural development strategies and to formulate a coherent national approach. In recent years, significant efforts have been made to revitalize the cooperative movement, which is increasingly supported within academic and professional circles.

Historically, cooperatives have proven their durability by overcoming numerous crises and continuously adapting to changing economic conditions. There is a strong expectation that Serbia may witness a renewed expansion of the cooperative sector, contributing to economic growth and improved living standards. Evidence from European countries clearly illustrates the impact of cooperatives on employment and economic performance. For example, France has over 20,000 cooperatives generating more than €180 billion annually, Italy counts over 70,000 cooperatives employing around one million people, while Germany's 8,000 cooperatives provide approximately 440,000 jobs. Significant contributions are also evident in countries such as Belgium, the United Kingdom, Finland—where cooperatives account for around 40% of GDP—as well as Slovenia,¹²⁷ Poland, Spain, and others.

It can be easily concluded that within the European Union the cooperative sector is highly developed, with cooperative organization reaching an advanced level. More than 100 million members participate in this system, while several million people are employed within the sector. This represents a significant opportunity for the Republic of Serbia, as well as for other former Yugoslav countries, especially considering that the cooperative movement throughout the 20th century went through various phases, ranging from periods of strong expansion to¹²⁸, following the development of this movement in Europe, all the way to its later decline. Particular reference is made to the experiments conducted within the Yugoslav system of self-management, when cooperatives were abolished and their assets expropriated. For this reason, there is now a clear need for a renewed and accelerated revitalization of the cooperative movement. Given its multifunctional nature, existing cooperative unions in Serbia and Vojvodina should expand their focus beyond agricultural cooperatives to include all forms of cooperative organization. This requires the establishment of a stronger institutional framework, more favorable conditions for cooperative development, greater public awareness of the potential contribution of cooperatives to national economic growth,

¹²⁷ Representatives from the city of Kragujevac and surrounding villages had the opportunity to witness this firsthand during their visit in October 2025 to cooperatives in several locations of this former Yugoslav republic, where cooperative activity—primarily in agriculture—has a long-standing tradition. For example, in one agricultural cooperative, over 70% of milk production is handled cooperatively, while around 80% of livestock is owned collectively through the cooperative. These experiences proved extremely valuable, leading to agreements for further mutual cooperation and visits to additional cooperatives in Italy and Austria, supported by the leadership of Kragujevac's local government. A reciprocal visit to our city has also been arranged, and it is expected that this collaboration will continue with our partners from North Macedonia..

¹²⁸ The first cooperative on the territory of present-day Serbia was established in 1846 in Bački Petrovac, in Vojvodina (then part of the Austrian Empire), while the first agricultural cooperative in central Serbia was founded in 1894 in the village of Vranovo near Smederevo.

and increased engagement of the academic community in researching and promoting this field.

When discussing the global re-emergence of the cooperative movement, it is important to note that its crisis was largely influenced by the global financial downturn, culminating in the early 21st century with the collapse of the liberal market economy model. In response, both in Serbia and worldwide, renewed efforts have been made to strengthen cooperatives, a process that has also been supported by the United Nations.¹²⁹, as reflected in the resolutions of the United Nations Economic and Social Council, which called for closer cooperation between the United Nations and the International Co-operative Alliance. As previously noted, since the centennial Congress of the International Co-operative Alliance in 1995, the International Day of Cooperatives has been celebrated annually. Furthermore, in 2009, the United Nations General Assembly adopted the resolution “Cooperatives in Social Development.” The year 2012 was proclaimed the International Year of Cooperatives, during which numerous cooperative organizations worldwide focused their efforts on reaffirming and strengthening the cooperative movement.

Based on the foregoing, it can be concluded that Serbia’s European integration process is a highly significant and serious matter. Within this context, special attention must be given in the coming period to agro-rural policy, which, unfortunately, has not yet been adequately recognized by decision-makers. Even more concerning is that numerous obstacles still exist along this European path. Among the most critical challenges that hinder a more effective revival of the cooperative movement, the following can be highlighted: 1) the state’s neglectful attitude toward cooperatives (failing to recognize the importance of cooperative entrepreneurship); 2) insufficient engagement of the academic community; 3) marginalization within the education system; and 4) the absence of an appropriate institutional framework for reaffirming the cooperative movement, among others.

Therefore, it is imperative to adopt a comprehensive strategy for the development of cooperatives in Serbia. This strategy must be grounded in a thorough understanding of current trends within the new European cooperative model, where the so-called “cooperative path” is considered one of the viable ways to overcome the global crisis.

5. CONCLUSION

Based on the above, it can be concluded that rural tourism represents a significant opportunity for the renewal (revitalization) of many rural areas, including those that have been devastated and abandoned due to the migration of young people from their ancestral homes. It is one of the ways to curb youth emigration and provide them with sustainable livelihoods, given that cooperation and collective organization offer better conditions for business across all sectors of social life, particularly in rural tourism.

Serbia has historically been an agricultural country, but due to political experimentation over past decades and the adoption of laws aligned with prevailing ideologies, this vital economic sector was neglected. Its traditional practitioners often moved to urban areas, seeking

¹²⁹ Since its inception, the United Nations has recognized the global significance of the cooperative movement

employment in industrial enterprises, many of which today have been privatized, sold, or closed, leaving workers without jobs or guarantees. Consequently, collective organization and cooperatives in all areas of social and economic life offer improved opportunities for success, especially in the development of rural tourism, whose positive effects have become increasingly visible over the last two to three decades.

Rural development and rural tourism in Serbia represent the most important instruments for revitalizing the agricultural sector and leveraging all the attractive tourist potential of villages. Rural tourism also enables the development of other forms of tourism, as it is interconnected with them and integrates them into the overall tourism experience.

For the accelerated development of rural tourism, the government's readiness and support are essential. This can take the form of training and educating rural populations to provide tourist services, marketing rural tourism, ensuring required standards for rural facilities on offer, supporting specialized tour operators and travel agencies, assisting existing national associations, forming new associations linked to international tourism organizations, and accessing EU funds. Rural tourism and related services present a major opportunity for Serbia to position itself as a leading tourist destination in the Balkans, given the largely preserved nature in most villages, numerous thermal-mineral springs and sources of potable water, as well as other natural and anthropogenic attractions. This represents a chance to revitalize these settlements, encourage the return of residents to their homes, involve them in agricultural development, and enable local communities to actively participate in rural tourism.

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STANDARDIZATION AND SUSTAINABILITY IN THE FOOD SECTOR: CHALLENGES OF NORTH MACEDONIAN PRODUCERS IN THE CONTEXT OF SWEDISH PRACTICES

СТАНДАРДИЗАЦИЈА И ОДРЖЛИВОСТ ВО ПРЕХРАНБЕНИОТ СЕКТОР: ПРЕДИЗВИЦИ ЗА ПРОИЗВОДИТЕЛИТЕ ОД СЕВЕРНА МАКЕДОНИЈА ВО КОНТЕКСТ НА ШВЕДСКИТЕ ПРАКТИКИ

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Abstract: This study examines quality management and sustainability practices in the food sector of North Macedonia in comparison with Sweden, highlighting structural differences, developmental potential, and strategies for improvement. While North Macedonia is in a transitional phase, aligning its legislation and institutional capacities with European Union standards, Sweden operates in a post-regulatory environment characterized by proactive quality management, advanced digital traceability, and integration of sustainability principles. The comparative analysis identifies critical gaps in implementation, institutional efficiency, technological adoption, and consumer engagement, and proposes targeted recommendations for bridging these gaps in North Macedonia. These include strengthening institutional capacities, supporting SMEs, investing in human resources, digitalizing supply chains, integrating sustainability, and promoting private standards and branding. The study underscores that quality and sustainability are not only regulatory obligations but strategic tools for achieving long-term competitiveness in global food markets.

Key words: quality management, food sector, sustainability, North Macedonia, Sweden, digital traceability, HACCP, private standards, EU integration, SMEs

Апстракт: Овој труд ја анализира праксата за управување со квалитетот и одржливоста во прехранбениот сектор на Северна Македонија во споредба со Шведска, истакнувајќи ги структурните разлики, развојниот потенцијал и насоките за унапредување. Северна Македонија се наоѓа во транзициска фаза, усогласувајќи го своето законодавство и институционалните капацитети со стандардите на Европската Унија, додека Шведска функционира во пост-регулаторна средина, карактеризирана со проактивен пристап кон квалитетот, напредна дигитална следливост и интеграција на принципите на одржливост. Компаративната анализа укажува на клучни предизвици во имплементацијата на стандардите, институционалната ефикасност, примената на дигитални технологии и улогата на потрошувачите, и нуди конкретни препораки за надминување на овие предизвици во Северна Македонија. Препораките вклучуваат зајакнување на институционалните капацитети, поддршка на МСП секторот, развој на човечки ресурси, дигитализација на синџирите на снабдување, интеграција на одржливоста, промоција на приватни стандарди и брендирање на производите. Трудот нагласува дека квалитетот и одржливоста не се само

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регулаторна обврска, туку стратешки алатки за постигнување на долгорочна конкурентност на глобалниот пазар на храна.

Клучни зборови: *управување со квалитетот, прехранбен сектор, одржливост, Северна Македонија, Шведска, дигитална следливост, HACCP, приватни стандарди, интеграција на ЕУ, МСП*

1. INTRODUCTION

Quality management in the food industry has evolved beyond a mere regulatory requirement and has become a key instrument of competitive differentiation in the global market. The transformation of this sector is driven by the parallel processes of globalization, digitalization, and increasing environmental awareness among consumers, which are redefining traditional standards of production and quality control (Food and Agriculture Organization [FAO], 2022; European Commission, 2024).

While the historical focus was primarily on hygiene and microbiological safety, modern consumers demand a significantly broader spectrum of values, including sustainability, ethical production, reduced carbon footprint, and full transparency of supply chains (World Economic Forum, 2023). In this context, the concept of quality has evolved from a technical category into a multidimensional framework encompassing environmental, social, and governance (ESG) criteria.

The contemporary food industry is therefore at a turning point between traditional production models and the imperatives of digital transformation. Technologies such as the Internet of Things (IoT), blockchain, and advanced data analytics enable the development of so-called “smart supply chains,” where real-time traceability has become a standard rather than a competitive advantage (Kshetri, 2018; Kamilaris et al., 2019).

Within this analytical framework, this paper comparatively examines two models of quality management and sustainability:

The first model represents the system of North Macedonia, which is currently undergoing intensive alignment of its national legislation with the European Union *acquis communautaire*. This process involves not only the formal adoption of regulations but also their effective implementation in practice, which poses a particular challenge for small and medium-sized enterprises (SMEs) that dominate the economic structure (European Commission, 2024; World Bank, 2023).

The second model refers to Sweden, as one of the leading European countries in integrating sustainability into the food sector. The Swedish system is characterized by a high level of institutional efficiency, a strong role of private standards, and a well-developed culture of trust among producers, regulators, and consumers. Of particular importance is the KRAV certification system, which goes beyond EU regulatory requirements and sets stricter criteria regarding organic production, animal welfare, and environmental protection (KRAV, 2023; Swedish Board of Agriculture, 2022).

The main thesis of this paper is that the differences between these two models should not be viewed as an insurmountable gap, but rather as a developmental pathway. North Macedonia

has the opportunity, through selective adaptation of advanced practices, to accelerate its transformation and avoid the lengthy evolutionary stages that developed economies have already undergone.

In conditions of global competition, merely meeting minimum regulatory standards is no longer sufficient for accessing demanding European Union markets. Increasingly, the market favors producers who demonstrate a proactive approach to quality—through reducing the use of pesticides and antibiotics, improving the microbiological quality of raw materials, and implementing digital traceability systems (OECD, 2023).

In this regard, digital traceability represents a crucial bridge between regulatory compliance and market competitiveness. Transparent supply chains not only enhance consumer trust but also enable more efficient risk management, loss reduction, and optimization of logistics processes (Tian, 2017).

The aim of this paper is to identify the key structural differences between the Macedonian and Swedish models of quality management, as well as to define concrete recommendations for bridging the existing gap. Particular attention is given to the transition from a “reactive” to a “proactive” approach to quality management, where control is not the final stage of the process but its integral component.

The paper is based on the hypothesis that investments in quality, standardization, and sustainability do not represent a cost, but rather a strategic investment that generates long-term economic and social benefits. Through the analysis of institutional frameworks, implementation practices, and market requirements, the paper seeks to demonstrate that the transformation of the food sector in North Macedonia can be accelerated through a combination of regulatory reforms, technological innovations, and the strengthening of human capital.

2. QUALITY MANAGEMENT SYSTEM IN NORTH MACEDONIA

The quality management and food safety system in North Macedonia is being developed within the framework of European integration, where harmonization with the European Union *acquis communautaire* represents a central regulatory and strategic objective. This process involves not only the formal adoption of legislation but also the transformation of institutional capacities, market mechanisms, and production practices (European Commission, 2024).

Unlike developed systems, where the focus is on optimization and innovation, the Macedonian model is still in a consolidation phase, characterized by a dualism between formally established standards and their practical implementation, particularly in the small and medium-sized enterprise (SME) sector (World Bank, 2023).

2.1. Institutional and Legal Framework

The central institution responsible for food safety is the Food and Veterinary Agency (FVA), which operates as an independent regulatory body with broad competencies in control, inspection, and risk assessment. Its organizational structure follows an integrated “farm-to-fork” approach, aligned with the principles of EU food safety policy (European Food Safety Authority [EFSA], 2022).

The legal framework is based on:

- The Food Safety Law
- The Veterinary Law
- The Plant Protection Law
- Associated subordinate legislation aligned with EU regulations

Mandatory implementation of the HACCP system represents a fundamental pillar of food safety management. However, in practice, a gap is often observed between formal compliance and the actual functionality of the system, particularly in smaller production units (FAO, 2022).

The 2024 European Commission report indicates that North Macedonia maintains a "good level of preparedness" within Chapter 12, but further improvements are needed in:

- Laboratory capacities
 - Digitalization of monitoring systems
 - Coordination between institutions
- (European Commission, 2024)

2.2. Standards Implementation and Operational Challenges

Although the regulatory framework is relatively well-established, the main challenge remains consistent implementation. This problem is especially pronounced in the SME sector, which constitutes over 90% of the overall economy and dominates the food industry (World Bank, 2023).

Financial Constraints

Implementing standards such as:

- ISO 22000
- IFS (International Featured Standards)
- BRCGS (Brand Reputation Compliance Global Standards)

requires significant investments in infrastructure, equipment, and certification. For small enterprises, these costs often constitute a barrier without access to external funding sources such as IPARD programs (OECD, 2023).

Lack of Qualified Personnel

A key structural problem is the shortage of qualified staff in quality management. In practice, this leads to:

- Formal rather than substantive implementation of HACCP systems
- Lack of real-time risk analysis
- Poor integration of standards into daily operations

This approach significantly reduces system effectiveness and increases the risk of non-compliance (FAO, 2022).

Institutional Oversight Dynamics

The traditional inspection model is based on a reactive approach, where intervention occurs

only after irregularities are detected. Modern trends, however, indicate the need for a transformation toward:

- An advisory role for inspectors
- Preventive risk management
- Continuous education of producers

Such a model, characteristic of Scandinavian countries, enables long-term quality improvement instead of short-term sanctions (Swedish Board of Agriculture, 2022).

2.3. Role of International Standards and Export Orientation

The Macedonian food industry is highly export-oriented, with a dominant share of fresh and processed fruits and vegetables. Access to European Union markets is conditioned on meeting strict quality and safety standards.

Standards such as GLOBALG.A.P. have become de facto mandatory for cooperation with major retail chains. Their implementation entails:

- Control of pesticide use
 - Product traceability
 - Protection of labor conditions
 - Environmental preservation
- (World Economic Forum, 2023)

In addition, private standards, which often exceed legal requirements, are increasingly important and serve as a key market differentiator.

2.4. Regulatory Reforms and Market Dynamics

One of the most significant recent reforms is the adoption of the Law on the Prohibition of Unfair Trading Practices. This legislation aims to:

- Protect producers from the dominant bargaining power of retail chains
 - Eliminate hidden costs
 - Improve transparency in contractual relations
- (European Commission, 2024)

It is expected that this regulation will have an indirect positive effect on product quality by providing producers with more stable financial conditions for investment in standardization and modernization.

2.5. Development Perspectives: Digitalization and Sustainability

A key development direction is the integration of digital technologies into the quality management system. Currently, the level of digitalization in North Macedonia is limited, but there is significant potential for improvement through:

- Introduction of IoT sensors in production
 - Digital traceability systems
 - Application of blockchain technology in supply chains
- (Kamilaris et al., 2019; Tian, 2017)

At the same time, sustainability is becoming a central element of competitiveness. Reducing the use of chemical inputs, rational resource management, and compliance with ESG principles are not only regulatory requirements but also market necessities (OECD, 2023).

The analysis shows that North Macedonia possesses a solid regulatory framework, but the key challenges lie in its implementation, institutional efficiency, and technological modernization. It is precisely in this space that the gap between formal compliance and real competitiveness emerges.

In the following chapter, the Swedish model will be analyzed as a reference framework demonstrating how the integration of sustainability, digitalization, and trust can transform a quality management system from a regulatory obligation into a strategic advantage.

3. QUALITY MANAGEMENT SYSTEM IN SWEDEN

Sweden represents one of the most advanced models of quality and food safety management in Europe, where the regulatory framework, market mechanisms, and social values are integrated into a coherent and highly functional system. Unlike transitional economies, where the focus is on aligning with minimum standards, the Swedish model is characterized by a proactive approach that positions quality and sustainability as central elements of competitiveness (Swedish Board of Agriculture, 2022).

The core feature of this system is a high level of institutional trust, which enables effective collaboration between the state, producers, and consumers. Quality management is not viewed as a mandatory obligation, but as an integral part of business strategy and the national identity of the food industry (OECD, 2023).

3.1. Institutional Framework and Regulatory Philosophy

The food safety system in Sweden is based on a clearly defined division of responsibilities among key institutions:

- The Swedish Food Agency
- The Swedish Board of Agriculture
- Local inspection authorities

This model allows for multi-layered oversight with high coordination efficiency. Unlike rigid control systems, the Swedish regulatory philosophy is based on a risk-based approach and trust in producer responsibility (European Food Safety Authority [EFSA], 2022).

Special emphasis is placed on:

- Preventive measures rather than punitive sanctions
- Continuous process improvement
- Transparency of information

This approach significantly reduces administrative burdens and increases the efficiency of the control system (European Commission, 2023).

3.2. Integration of Private Standards: The KRAV Case

A key element of the Swedish model is the strong role of private standards, which serve as a complement to EU regulations. The most notable among these is the KRAV certification system, which is synonymous with sustainable and organic production.

KRAV standards include:

- Strict limitations on pesticide and artificial fertilizer use

- High standards of animal welfare
 - Reduction of production-related climate impact
 - Social responsibility in the supply chain
- (KRAV, 2023)

Unlike mandatory standards, the value of the KRAV system lies in market recognition and consumer trust. Products carrying this label achieve higher market prices, directly incentivizing producers to invest in quality and sustainability.

3.3. Digital Traceability and Technological Innovations

Sweden is among the leading countries in implementing digital technologies in the food sector. Digital traceability enables full “farm-to-fork” transparency, which is a key factor in consumer trust.

Applications include:

- IoT sensors for monitoring production and storage conditions
 - Blockchain technology for immutable data records
 - Advanced analytics for risk management
- (Kamilaris et al., 2019; Kshetri, 2018)

These systems allow for:

- Rapid identification of contamination sources
- Reduction of losses in the supply chain
- Optimization of logistics

Digitalization in the Swedish model is not an isolated innovation, but an integral part of a sustainable development strategy.

3.4. Sustainability as a Central Principle

Unlike many countries where sustainability is an added value, in Sweden it is a fundamental principle of food sector development. National policies are aimed at:

- Reducing greenhouse gas emissions
 - Rational use of natural resources
 - Development of a circular economy
- (Swedish Board of Agriculture, 2022)

Particular importance is given to reducing antibiotic use in livestock, where Sweden ranks among the lowest in Europe. This approach not only contributes to public health but also enhances the international competitiveness of products (OECD, 2023).

3.5. Role of Consumers and Market Mechanisms

One of the key differences compared to transitional economies is the high level of consumer awareness. Swedish consumers actively influence the market by:

- Preferring local and sustainable products
 - Willingness to pay higher prices for quality
 - Demanding transparency
- (World Economic Forum, 2023)

This “bottom-up” pressure further encourages producers to improve standards, creating a positive feedback loop between supply and demand.

3.6. Key Advantages and Limitations of the Model

Advantages:

- High level of institutional trust
- Integration of sustainability and quality
- Developed private standards
- Advanced digitalization

Limitations:

- High production costs
- Dependence on consumer purchasing power
- System complexity for small producers

Despite these challenges, the Swedish model remains one of the most effective in balancing economic, environmental, and social objectives.

Analysis of the Swedish system shows that competitiveness in the modern food industry is not based solely on productivity, but on the ability to integrate quality, sustainability, and innovation into a unified operational model.

Compared to North Macedonia, the key difference does not lie in the legislative framework, but in the degree of its implementation, institutional efficiency, and quality culture. While the Macedonian system seeks alignment with standards, the Swedish model demonstrates how these standards can be transformed into a market advantage.

This difference provides the basis for the comparative analysis in the following sections, where specific knowledge transfer mechanisms and adaptation of best practices will be identified.

4. COMPARATIVE ANALYSIS: NORTH MACEDONIA VS. SWEDEN

To provide a clearer understanding of structural differences and developmental potential, the following section presents a comparative analysis of the quality management systems in the food sector of North Macedonia and Sweden. The analysis covers key dimensions that determine the functionality and competitiveness of these systems—ranging from the regulatory framework and institutional efficiency, to standards implementation, the level of digitalization, and the role of consumers.

The purpose of this comparison is not merely to identify differences, but to understand the developmental logic behind them, in order to define pathways for improving the Macedonian system through the adaptation of best practices from developed economies.

The following table provides a structured comparison of key dimensions of the food quality management systems in North Macedonia and Sweden. By examining each aspect—from system development phase and regulatory alignment to digitalization, sustainability, and market dynamics—it is possible to identify both gaps and opportunities for improvement in the Macedonian context. The comparative framework highlights not only the current status of each system, but also the underlying mechanisms that enable Sweden to transform regulatory compliance into a strategic competitive advantage.

Analysis Dimension	North Macedonia	Sweden
System development phase	Transitional phase – aligning with EU regulations	Post-regulatory phase – optimization and innovation
Regulatory framework	Largely aligned with the <i>acquis communautaire</i> , but challenges in implementation	Fully aligned and complemented with additional national and private standards
Institutional efficiency	Moderate – capacities exist, but coordination and resource limitations	High – effective coordination and clearly defined responsibilities
Quality control approach	Predominantly reactive (inspection-based)	Proactive and preventive (risk-based)
HACCP system implementation	Legally mandatory, but often superficial in SMEs	Substantive and integrated into operational processes
Role of private standards	Limited, mainly export-driven	Highly developed (e.g., KRAV), key market differentiator
Digitalization and traceability	Low to medium level	High – IoT, blockchain, and analytics in practice
SME sector	Dominant, but financially and technically constrained	Stable, with high institutional and advisory support
Qualified personnel	Shortage of specialized quality experts	Highly skilled personnel with continuous education
Export orientation	High, focused on raw materials and semi-processed goods	High, focused on high-value products
Export standards	GLOBALG.A.P. and basic EU requirements	Advanced standards plus private certifications
Sustainability (ESG)	Developing, primarily regulatory-driven	Integral part of system and market strategy
Pesticide and antibiotic use	Relatively high, with decreasing trend	Among the lowest in Europe
Consumer role	Limited influence on market standards	Very strong influence and high awareness
Market structure	Dominated by large retail chains	Balance between large chains and local producers
Regulatory reforms	Ongoing (e.g., law on unfair practices)	Stable and continuously improved system
Innovation approach	Slow and fragmented	Systematic and strategically driven
Competitive strategy	Focus on price and volume	Focus on quality, sustainability, and branding
Main challenges	Standard implementation, finances, education	High costs and system complexity
Main advantages	Flexibility, potential for rapid development	Stability, trust, and high quality

Source: Author

Comparative Table Analysis

The comparative analysis reveals a substantial gap between the two observed systems, which is not primarily reflected in the legislative framework, but rather in the degree of implementation and operational efficiency.

First and foremost, there is a clear difference in the development phase of the systems. While North Macedonia is in a transitional phase, focused on aligning with European Union regulations, Sweden operates in a post-regulatory environment, where emphasis is placed on process optimization and continuous innovation. This distinction also shapes the approach to quality management – a reactive model in North Macedonia versus a proactive and preventive model in Sweden.

A particularly significant difference can be observed in institutional efficiency. Although North Macedonia has a relatively stable institutional framework, challenges in coordination, resources, and policy implementation limit its effectiveness. In contrast, the Swedish system is characterized by a high level of trust and functional coordination between institutions, enabling efficient implementation and continuous improvement of standards.

Implementation of quality management systems, particularly HACCP, represents another critical point of differentiation. In the Macedonian context, this system is often formally established but insufficiently integrated into daily operational processes, especially within the SME sector. In Sweden, however, HACCP functions as a dynamic risk management tool, deeply embedded in production and logistics processes.

Sweden achieves a significant comparative advantage in private standards and market differentiation. While in North Macedonia standards such as GLOBALG.A.P. primarily serve as prerequisites for market access, in Sweden private certifications function as instruments for strategic positioning and added value. In this way, quality is transformed from a regulatory requirement into market capital.

Digitalization is one of the most pronounced areas of divergence. The low level of digital integration in the Macedonian system limits the ability to manage risks and ensure product traceability effectively, whereas the Swedish model demonstrates how advanced technologies can enhance transparency, operational efficiency, and consumer trust.

In the area of sustainability, there is also a fundamental difference in approach. In North Macedonia, sustainability is still primarily regulatory-driven and in a developmental stage, whereas in Sweden it constitutes a core principle of the organization of the food sector. This is reflected in concrete practices, such as significantly lower use of pesticides and antibiotics. The role of consumers further amplifies this difference. While consumer influence is relatively limited in the Macedonian context, Swedish consumers actively shape the market through their preferences, incentivizing producers to continuously improve quality and sustainability.

Finally, the analysis indicates that competitive strategies differ substantially. North Macedonia still largely relies on price competitiveness and production volume, while Sweden builds its market position on quality, innovation, and branding.

Overall, the differences between the two systems should not be viewed as a static gap, but as a developmental continuum. The Swedish model confirms that long-term competitiveness emerges from the integration of standards, technology, and sustainability into a unified value system, while the Macedonian model has the potential to accelerate its own transformation in this direction through targeted reforms and investments.

Although North Macedonia possesses a solid normative foundation, its key challenge remains the transformation of “formal quality” into real market value. In contrast, Sweden demonstrates how standards can be leveraged as an instrument for strategic positioning in the global market.

The most important conclusion is that the gap between these two models is not static but developmentally conditioned – meaning it can be bridged through:

- Strengthening institutional capacities
- Investing in human resources
- Digitalizing traceability systems
- Gradual implementation of higher quality standards

5. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

The analysis of quality management systems in the food sector of North Macedonia and Sweden clearly demonstrates that the modern concept of quality extends beyond traditional regulatory frameworks and has become a key instrument for strategic positioning in the global market (OECD, 2023; World Economic Forum, 2023). In this context, the differences between the two systems arise not primarily from legislative foundations, but from the level of implementation, institutional efficiency, and the integration of innovation and sustainability into operational processes (European Commission, 2024).

North Macedonia has made significant progress in aligning with the European Union acquis, establishing a solid normative foundation for food safety and standardization (European Commission, 2024). However, the key challenge remains the transition from formal compliance to the substantive functionality of the system, particularly within the small and medium-sized enterprise (SME) sector (World Bank, 2023). In other words, although standards have largely been adopted, their application is often not deeply integrated into daily business processes, limiting their actual impact (FAO, 2022).

In contrast, the Swedish model demonstrates a high level of system maturity, where quality management functions as a proactive and dynamic process based on risk management and continuous improvement (EFSA, 2022). The integration of private standards, digital technologies, and sustainability principles has enabled the transformation of quality from a regulatory requirement into a market advantage (KRAV, 2023; Swedish Board of Agriculture, 2022).

The comparative analysis indicates that the key difference between the observed systems lies in the ability to operationalize standards and translate them into measurable economic outcomes. While the Macedonian model still largely relies on price competitiveness and

production volume, the Swedish model illustrates that long-term sustainability arises from a focus on quality, innovation, and added value (OECD, 2023).

A particularly important element of modern quality management is the digitalization of supply chains, which enables full traceability and improved risk management (Kamilaris et al., 2019; Kshetri, 2018). The application of blockchain technology further contributes to data transparency and security, enhancing consumer trust and system efficiency (Tian, 2017). Thus, the transformation of North Macedonia's food sector should not be perceived as a linear attainment of existing standards, but as a strategic modernization process involving institutional reforms, technological adaptation, and a shift in business paradigms (European Commission, 2024).

It is particularly important to emphasize that investment in quality and sustainability should not be seen as a cost, but as an investment with high multiplier effects – economically, socially, and environmentally (World Economic Forum, 2023). Transitioning from a “reactive” to a “proactive” quality management model represents a crucial prerequisite for integration into demanding EU markets and for strengthening international competitiveness (OECD, 2023).

5.2. Recommendations for Enhancing the System in North Macedonia

1. Strengthening Institutional Capacities

- Transform the role of inspection authorities from control-oriented to advisory functions
- Improve coordination among relevant institutions
- Enhance laboratory capabilities and control systems

Impact: Transition from a reactive to a preventive quality management model (European Commission, 2024)

2. Support for Small and Medium Enterprises (SMEs)

- Subsidize the implementation of standards (ISO 22000, GLOBALG.A.P., IFS)
- Facilitate access to IPARD and other EU funding programs
- Develop technical assistance and mentorship programs

Impact: Reduce the gap between large systems and the SME sector (World Bank, 2023)

3. Human Resource Development

- Introduce specialized training in quality management
- Foster collaboration between universities and industry
- Provide continuous professional development for food sector employees

Impact: Transition from formal compliance to substantive implementation of standards (FAO, 2022)

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4. Digitalization of Traceability Systems

- Implement digital platforms for product tracking
- Pilot IoT and blockchain technology projects
- Promote digital transformation through government programs

Impact: Enhance transparency, efficiency, and consumer trust (Kamilaris et al., 2019; Tian, 2017)

5. **Integration of Sustainability into Business Models**

- Reduce the use of pesticides and antibiotics
 - Encourage organic and sustainable production
 - Incorporate ESG principles into business operations
- Impact:** Access to premium markets and enhanced competitiveness (OECD, 2023)

6. **Development of Private Standards and Branding**

- Create national or regional quality certification schemes
 - Support producers in developing strong brands
 - Promote value-added products
- Impact:** Shift from price-based to quality-based competition (KRAV, 2023)

7. **Enhancing Consumer Engagement**

- Conduct educational campaigns on quality and sustainability
 - Promote domestic products
 - Ensure transparent product labeling
- Impact:** Create market pressure for quality improvement (World Economic Forum, 2023)

5.3. Final Note

Based on the overall analysis, it can be concluded that North Macedonia possesses a realistic potential to transform its food sector into a competitive and sustainable system, but only through parallel strengthening of institutions, technological modernization, and human capital development (European Commission, 2024; OECD, 2023).

The Swedish experience demonstrates that sustainability and quality are not constraints on development, but its most important drivers. The future development of North Macedonia's food industry should therefore be viewed not as a process of adaptation, but as an opportunity for a strategic leap toward higher levels of value creation (Swedish Board of Agriculture, 2022).

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INFORMAL ASSOCIATION THROUGH COOPERATIVES

НЕФОРМАЛНО УДРУЖИВАЊЕ КРОЗ ЗАДРУГАРСТВО

Hadži Dušan Trifunović, PhD¹³¹

Abstract: This paper analyzes the phenomenon of informal association within the framework of cooperatives as a significant socio-economic model of organization. Starting from the historical development of cooperatives, the study highlights the transformation from family and traditional forms toward modern formal and informal models of cooperation (Stojanović, Gnjatović, 2015). Special focus is placed on the reasons why individuals opt for informal association, including the avoidance of administrative burdens, risk reduction, and flexibility of action (Bijman et al., 2016). Furthermore, the paper examines the role of the human factor, trust, and shared interests in the success of such forms of cooperation (Saz-Gil et al., 2021). The conclusion provides concrete recommendations for the improvement of cooperatives in the Republic of Serbia through education, institutional support, and the integration of theory and practice (Zadrugarstvo u Srbiji, 2016).

Key words: cooperatives, informal association, cooperation, rural development, economy

Анстракт: Рад анализира феномен неформалног удруживања у оквиру задругарства као значајног друштвено-економског модела организовања. Полазећи од историјског развоја задруга, рад указује на трансформацију од породичних и традиционалних облика ка савременим формалним и неформалним моделима сарадње (Стојановић, Ђнјатовић, 2015). Посебан фокус стављен је на разлоге због којих се појединци опредељују за неформално удруживање, укључујући избегавање административних обавеза, смањење ризика и флексибилност деловања (Bijman et al., 2016). Такође се разматра улога људског фактора, поверења и заједничких интереса у успешности оваквих облика сарадње (Saz-Gil et al., 2021). У закључку се дају конкретни предлози за унапређење задругарства у Републици Србији кроз образовање, институционалну подршку и повезивање теорије и праксе (Задругарство у Србији, 2016).

Кључне речи: задругарство, неформално удруживање, кооперација, рурални развој, економија

1. INTRODUCTION

Cooperatives represent one of the oldest forms of human organization, emerging from the fundamental need for joint work, security, and more efficient use of available resources. Since the earliest human communities, individuals have relied on collective action to overcome the limitations of individual efforts and to achieve greater economic and social benefits (Šljukić, 1979). Through cooperation, people have been able to share risks, optimize labor, and ensure more stable living conditions.

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Throughout history, cooperative principles such as solidarity, mutual assistance, and shared responsibility have played a crucial role in shaping social and economic relations. These principles have enabled communities to function more cohesively and to respond more effectively to external challenges, including economic instability, resource scarcity, and social inequality (Ilić, 2018).

In contemporary conditions of globalization and increasing market competition, the importance of cooperatives is once again gaining prominence, particularly in the context of the survival and sustainability of small producers and local communities (Stojanović, Gnjatović, 2015). Small-scale farmers and entrepreneurs often face significant challenges in accessing markets, capital, and modern technologies. In this regard, cooperatives provide a framework that enables collective bargaining, resource sharing, and improved market positioning (Bijman et al., 2016).

However, alongside formal organizational structures, informal forms of association are becoming increasingly present. Informal cooperation emerges as a flexible and practical model that allows individuals to respond quickly to market demands, reduce administrative burdens, and minimize financial risks (Perpétuo Ribas et al., 2022). Such forms of collaboration are often based on trust, personal relationships, and shared interests, making them highly adaptable to dynamic economic environments (Saz-Gil et al., 2021).

The growing relevance of informal association also reflects certain limitations of formal cooperative systems, including complex administrative procedures, regulatory constraints, and limited institutional efficiency (Chroneos Krasavac & Petković, 2015). As a result, many individuals opt for informal collaboration as an initial or alternative form of organization.

The aim of this paper is to analyze the role and significance of informal association within the framework of cooperatives, to examine its advantages and disadvantages, and to explore its potential applications in modern socio-economic conditions. Special attention is given to the relationship between formal and informal models of cooperation, as well as their complementary roles in fostering sustainable economic development.

2. HISTORICAL DEVELOPMENT OF COOPERATIVES

Cooperatives have deep historical roots and represent one of the earliest forms of organized social and economic activity of people. Its beginnings are associated with the oldest human communities, in which collective work was the basis of survival, and the division of labor and solidarity were the established practices of the first forms of cooperative association (Šljukić, 1979).

Over time, with the development of society and the transition from a nomadic to a sedentary lifestyle, forms of association become more complex and organized (Bijman et al., 2016). In ancient and medieval societies, forms of collective work appear, such as village communities, guilds and brotherhoods, which can be considered the forerunners of modern cooperatives (Saz-Gil et al., 2021).

In the territory of Serbia and the Balkans, cooperatives developed in specific historical circumstances. The first organized agricultural cooperatives emerged in the 19th century within Serbian villages and the Austro-Hungarian administration (Stojanović, Gnjatović,

2015). Their main function was to protect the economic interests of members, regulate production and preserve the quality of products and services (Zadrugarstvo u Srbiji – istorijat, 2014). A special role was played by family cooperatives — multi-generational communities with a clearly defined hierarchy and division of roles within the household, especially in rural areas where agriculture dominates the economy (Šljukić, 1979).

Within family cooperatives, there was a clearly defined hierarchy. The head of the cooperative, usually the oldest and most experienced male member, had a key role in making decisions, organizing work and distributing goods. His authority was based on the experience, knowledge and trust he enjoyed among the members. The division of labor was precisely defined – men were engaged in heavier physical labor, women in household and lighter agricultural work, while younger members studied and gradually took on responsibilities. During the 19th and 20th centuries, cooperatives further developed through the modernization and formalization of the cooperative system, with the aim of providing small producers with better access to markets, capital, and infrastructure (Stojanović, Gnjatović, 2015). For example, the first law that legally regulated the cooperative system in Serbia was passed in 1898, which institutionalized cooperatives, with state recognition and support (Zadrugarstvo u Srbiji, 2016). After World War II, cooperatives became part of a broader system of social ownership, which affected their autonomy and functions (Šljukić, 1979).

Agricultural, viticultural and wine cooperatives have developed particularly well, enabling members to jointly produce, process and market their products. By pooling capital and labour, cooperative members manage to reduce costs, increase competitiveness and secure more stable incomes. In addition, savings and credit cooperatives are also developing, which provide easier access to financial resources and loans, which was of great importance for the development of rural areas.

In the period between the two world wars, cooperatives experienced further expansion, but also faced numerous challenges, including political and economic instability. After World War II, the role of cooperatives in the socialist system changed, becoming part of a wider system of social ownership. Although cooperatives played an important role in the organisation of production during this period, they were often under strong state influence, which limited their autonomy.

Modern cooperatives represent a combination of traditional values and modern economic principles. Although the basic principles – solidarity, trust and common interest – have remained the same, the way of organization and business has been adapted to market conditions (Bijman et al., 2016). Today, cooperatives operate in various sectors, including agriculture, tourism and services, and play a significant role in the development of rural areas (Cooperatives in Serbia, 2014)

Despite numerous changes throughout history, the essence of cooperatives has remained unchanged – joint action to achieve economic and social benefits. This continuity confirms it.

3. MODERN COOPERATIVES AND CHALLENGES

Modern cooperatives are developing in the context of globalization, accelerated technological change and increasingly pronounced market competition (Bijman et al., 2016).

Cooperatives face the need for constant adaptation in order to survive and improve the economic position of their members (Saz-Gil et al., 2021). Although cooperatives represent an important organizational model, their implementation in practice often encounters numerous obstacles and limitations.

One of the key challenges is the relationship between the formal and actual functioning of cooperatives. In many cases, cooperatives are established formally, in order to achieve incentives or a statistical representation of development, while their real activity is absent (Stojanović, Gnjatović, 2015). Such “paper cooperatives” do not contribute to economic development, but rather undermine trust in the very concept of cooperatives¹.

In addition, the lack of professional and motivated staff to manage cooperatives often negatively affects long-term sustainability (Bijman et al., 2016). The functions of directors and management structures require a wide range of knowledge – from economics and law to organization and marketing. However, in practice, these positions are often occupied by insufficiently competent or politically suitable individuals, which negatively affects the business and long-term sustainability of cooperatives.

Administrative and legal procedures represent an obstacle to the development of cooperatives, while external factors, such as climate change and market fluctuations, further increase uncertainty (Perpétuo Ribas et al., 2022). The process of founding and managing a cooperative involves certain obligations and responsibilities that discourage many potential members. Fear of financial risk, indebtedness and possible insolvency additionally influences the decision of individuals to avoid formal association.

In modern business conditions, cooperatives are also exposed to external influences, such as market fluctuations, climate change, global trends and changes in legislation. For example, in the field of agriculture, weather conditions and adverse conditions can significantly affect yields and incomes, while changes in export and import policies can further complicate the marketing of products. These factors increase uncertainty and require additional flexibility and adaptability in business.

A particular challenge is the issue of competitiveness. Cooperatives often have to compete with large companies that have significantly greater capital, resources and market influence. In such conditions, the advantage of cooperatives can be in a joint approach, local connectivity and flexibility, but this requires good management and coordination among members.

However, modern cooperatives also bring certain positive trends. One of them is the increasing inclusion of women in management and leadership positions. Their role is particularly evident in areas such as rural tourism, where they contribute to the development of authentic offers, the preservation of tradition and the improvement of the quality of services. Although they face additional challenges, such as difficult access to resources and the reconciliation of business and family obligations, their participation represents significant potential for the development of cooperatives.

The application of modern technologies and innovations is also gaining increasing importance. Digitalization of business, marketing through social networks and the application of new production methods enable cooperatives to improve their business and

increase competitiveness. However, the successful application of these tools requires education and continuous training of members. (Bijman et al., 2016).

In conclusion, it can be concluded that modern cooperatives are a complex system that requires the coordination of economic, social and organizational factors. Its success depends on the ability to adapt to change, the quality of management and the level of trust among members. Despite numerous challenges, cooperatives still have significant potential as a model of sustainable development, especially in local communities and rural areas.

4. INFORMAL ASSOCIATION AS A MODEL OF COOPERATION

Informal association is a specific form of cooperation between individuals or groups based on common interest, trust and practical need, without formal legal registration and institutional framework. (Saz-Gil et al., 2021) In modern business conditions, this model is gaining increasing importance, especially in environments where there is a pronounced distrust of institutions or fear of the administrative and financial obligations that formal organization entails.

Unlike formal cooperatives, which involve clearly defined rules, a management structure and legal responsibility, informal associations are characterized by flexibility and spontaneity. They arise in response to a specific need or problem, and their duration may be limited to the realization of a single goal or activity. It is precisely this adaptability that makes them suitable for modern conditions, in which the speed of reaction and adaptation to changes are of key importance. (Chroneos, et. Al. 2015).

One of the most common forms of informal association is the joint procurement of goods or services. (Perpétuo Ribas et al., 2022). Individuals join together to achieve quantity discounts, reduce costs and improve their negotiating position in the market. In such situations, the group functions as a single entity, although it does not formally and legally exist as organization. (Saz-Gil et al., 2021). After the purchase is made, members retain their autonomy, without additional obligations or responsibilities.

A similar principle applies to the exchange of information and experiences. Participants in informal networks often share knowledge about the market, product quality, supplier reliability and other relevant issues. In this way, they reduce the risk of making wrong business decisions and increase the efficiency of their own actions. (Stojanović, Gnjatović, 2015)

The advantages of informal associations are numerous. First of all, it does not require financial investments in terms of founding capital, membership fees or administrative costs. Also, there is no formal responsibility towards institutions, which reduces the perception of risk among participants. The flexibility of the organization allows for the rapid formation and dissolution of groups, in accordance with current needs.

Another significant advantage is the ability to adapt to different situations. Informal associations can operate in different sectors – from agriculture and trade, to tourism and ecology. For example, farmers can join forces to jointly procure raw materials, while tourism service providers can connect to promote certain destinations.

However, in addition to numerous advantages, informal associations also have certain disadvantages. The most important of these is the lack of long-term stability. Since there is no formal structure, such associations often depend on the current interest and personal relationships between members. When interest disappears, the group itself disappears.

Also, informal associations do not have access to institutional support, such as subsidies, loans or other forms of assistance that are available to formally registered entities. The lack of legal protection can be a problem in the event of disputes or disagreements between members³.

The special importance of informal associations is reflected in its role as a “transitional form” to formal organization. Through this type of cooperation, participants gain experience, build mutual trust and test the sustainability of joint activities. If the cooperation proves successful, there is a possibility of developing into a formal cooperative.

In practice, informal associations often contribute to strengthening social cohesion. Through mutual cooperation, members develop a sense of belonging and solidarity, which has a positive impact not only on economic, but also on social relations in the community. (Popović, 2017).

In modern conditions, where changes are rapid and uncertainty is high, informal association represents an important and functional model of cooperation. Although it cannot completely replace formal forms of organization, it complements them and often represents the first step towards their development. Its importance is reflected in the ability to respond quickly to market needs, with minimal costs and risks, thereby contributing to the improvement of overall economic activity.

5. RESEARCH METHODOLOGY

This paper uses a combined methodological approach, which includes the analysis of theoretical sources and practical examples from the field of cooperatives, with a special focus on informal associations. (Bijman et al., 2016) The aim of the research is to examine the importance, role and potential of informal forms of organization in modern economic conditions.

5.1. Subject and objective of the research

The subject of the research is cooperatives as a form of organization, with a focus on informal associations as its specific segment.

The aim of the paper is to:

- analyze the development of cooperatives throughout history
- identify the key challenges of modern cooperatives
- examine the importance of informal associations in practice
- propose measures to improve the existing system

5.2. Research questions and hypotheses

In accordance with the aim of the paper, the following research questions were defined:

- What are the main reasons for the emergence of informal associations?
- What are the advantages and disadvantages of this form of cooperation?
- Can informal associations represent the basis for the development of formal cooperatives?

Based on these questions, the following hypotheses were set:

H1: Informal associations arise as a response to the complexity of formal procedures and the fear of liability.

H2: Informal associations enable more efficient and flexible cooperation in short-term business activities.

H3: Informal forms of cooperation can represent the basis for later formal organization into cooperatives.

5.3. Research methods

The following scientific methods were used in the paper:

- Analysis method – used to study theoretical sources, legal regulations and professional literature in the field of cooperatives;
- Historical method – applied in the analysis of the development of cooperatives through different time periods;
- Comparative method – used to compare formal and informal associations;
- Case study – applied through the analysis of specific examples from practice (e.g. joint procurement, informal associations of producers and tourism workers);
- Descriptive method – used to describe modern forms of associations and their characteristics.

5.4. Data sources

The data used in the paper were collected from the following sources:

- professional and scientific literature in the field of economics and cooperatives
- legal and institutional documents
- practical examples and experiences from the real business environment
- internal materials and author's notes

5.5. Research limitations

The research has certain limitations, which are reflected in:

- lack of available statistical data on informal forms of association
- reliance on qualitative analysis and empirical examples
- limited to the territory of the Republic of Serbia

Despite the aforementioned limitations, the research results provide relevant insight into the importance and potential of informal association in modern business conditions.

6. COMPARATIVE ANALYSIS OF FORMAL AND INFORMAL ASSOCIATION

In order to more clearly understand the differences between formal and informal association in cooperatives, a comparative analysis through key criteria is presented below.

Table 1: Comparison of formal and informal association

Criteria	Formal association (cooperative)	Informal association
Legal status	Registered legal entity (Cooperatives in Serbia, 2014)	No legal status (Saz-Gil et al., 2021)
Establishment	Complex procedure (registration, documentation)	Spontaneous, without formality
Costs	Existing (founding capital, administration)	None or minimal
Responsibility	Legal and financial responsibility	No formal accountability
Duration	Long-term	Short-term or occasional
Organization	Clear structure (director, board of directors)	Informal, without hierarchy
Flexibility	Limited by rules and procedures	High flexibility
Trust	Institutional + personal	Mostly personal
Access to finance	Possible (subsidies, loans)	Limited or non-existent
Risk	Larger (due to responsibility and investment)	Smaller
Efficiency	Larger in long-term projects	Larger in short-term activities
Stability	Stable structure	Unstable, depends on interests
Examples of activities	Production, placement, investments	Joint purchasing, information sharing

Source: Author

Table Analysis

Based on the presented comparison, it can be concluded that formal and informal associations play different, yet complementary roles in modern cooperatives.

Formal association provides stability, legal certainty, and the possibility of long-term planning, but it requires a higher level of organization, liability, and resources. On the other hand, informal association enables quick and efficient cooperation with minimal costs and risks, but lacks long-term sustainability and institutional support.

In practice, the optimal model for cooperative development involves a combination of these two forms, where informal association can serve as an initial phase leading toward formal organization.

6.1 A Best Practice Example of Informal Association

As an illustration of the functionality and practical value of informal association, a specific example from the field of agricultural production and distribution of raw materials can be cited. This refers to the organization of presentations for "Traiko" plant-based liquid fertilizer, produced in Požarevac, which brings together a large number of agricultural producers from different regions of Serbia (Bijman et al., 2016).

In these situations, participants usually do not know each other and have no prior business cooperation. However, driven by a common interest—achieving more favorable purchasing terms—their association occurs spontaneously. Namely, since significant discounts and

additional benefits are granted for larger product quantities, participants organize themselves to aggregate their needs and act as a single buyer.

This form of association emerges quickly and without formal procedures; it is based on rational decision-making and represents a typical example of informal organizing. After the purchase is completed, each participant retains their independence without any additional obligations, membership fees, or joint asset management.

The advantages of this model are manifold. Primarily, it enables economic benefits through the reduction of procurement costs. Additionally, participants exchange experiences regarding product application, which increases the level of information and reduces the risk of incorrect decisions. In this specific case, the effects of fertilizer application are reflected in increased yields and improved product quality across various branches of agriculture, including crop farming, fruit growing, vegetable production, and viticulture.

Furthermore, such gatherings often lead to the establishment of new contacts and potential future cooperation among participants. Although no formal structure exists, a certain level of trust and connectivity is formed, which can serve as a foundation for the further development of relationships.

Similar forms of informal association are present in other fields as well. For example, textile traders often jointly import goods in large quantities to reduce costs and then distribute them according to their individual needs. Also, informal associations allow for easier information exchange and faster reactions to market changes, including the identification of low-quality products or unfair business practices.

This example clearly shows that informal association can be an efficient and functional model of cooperation, especially in situations where formal organization is unnecessary or too demanding. At the same time, such forms of cooperation can represent a basis for the development of more stable and long-term forms of association in the future.

6.2 A Poor Practice Example in Cooperatives

In addition to positive examples, there are cases in practice that point to serious issues in the functioning of cooperatives. One such example is the business operations of the agricultural cooperative "Agroland" from Čuprija, which faced financial difficulties and account blockades (Stojanović, Gnjatović, 2015).

The primary cause of the problem in this case was a combination of member insolvency and poor business decisions by the management structure. A lack of adequate planning, risk assessment, and operational control led to a situation where the cooperative was unable to settle its obligations toward suppliers. Consequently, the trust of business partners was undermined, further complicating the ongoing operations and survival of the cooperative.

This example highlights the importance of responsible management and expertise in leading cooperatives. Unlike informal forms of association, where risk is individualized and limited, the consequences of poor decisions in formal cooperatives can have broader implications and affect all members. Precisely for this reason, the selection of competent leadership and clearly defined responsibilities represent key success factors.

Furthermore, this case indicates the need for greater transparency in cooperative operations. Had the financial reports and the state of business been more accessible and clearly presented to the members and the public, there would have been a greater possibility for timely reaction and the prevention of negative consequences.

Another important aspect relates to the influence of external factors. Although internal weaknesses were of decisive importance, broader economic conditions—such as market changes, illiquidity in the payment chain, and general economic instability—cannot be ignored. However, it is precisely in such circumstances that the quality of management and the ability to adapt become most apparent.

This example clearly demonstrates that the formal existence of a cooperative is no guarantee of its success. Without adequate management, financial discipline, and mutual trust, cooperatives can become unsustainable and lose their core function. Simultaneously, such cases emphasize the need to improve systems of control, education, and institutional support to reduce the risk of similar situations in the future.

7. CONCLUSION AND RECOMMENDATIONS

Based on the analysis, it can be concluded that **cooperatives** represent one of the key mechanisms for the preservation and development of small business entities. In today's market, dominated by large systems and corporations, individual producers and entrepreneurs find it increasingly difficult to survive without **associating**. Therefore, cooperatives, as a form of organized collective action, play a crucial role in maintaining economic balance and preventing the further widening of the gap between small and large economic actors.

The introduction of cooperatives and entrepreneurship into the **educational system** is of particular importance. Educating young people on the basics of association, resource management, and market presence can significantly contribute to the development of future generations ready to apply these models in practice. In this context, forming **student cooperatives** is a vital step toward connecting theory and practice, allowing youth to gain experience and develop an entrepreneurial spirit through concrete work.

The effective functioning of cooperatives requires a clearly defined **division of labor** and responsibility among members. Without precise organization and consistent application of established rules, it is difficult to achieve desired results. Furthermore, all activities must comply with current legal norms while ensuring transparency and business sustainability.

An essential element of cooperative development is a **shift in mindset**—accepting the principle that there are no unsolvable problems, only a need to find adequate solutions. This approach encourages innovation and proactive behavior, which is critical in modern business conditions.

A significant issue affecting development is the lack of **transparency and control** within the public sector. Irregular spending and a lack of accountability negatively impact infrastructure and the overall business environment. Quality road, water, sewage, and digital

infrastructure form the basis for the development of cooperatives; thus, more efficient management of public resources is necessary.

Furthermore, efforts should be made to better **align working conditions** between the public and private sectors. Current disparities in labor conditions, earnings, and organization can negatively affect motivation, productivity, and overall economic stability.

One of the key practical challenges is the **lack of predictability** in the application of laws and regulations. Situations where individuals cannot exercise their rights despite a legal basis lead to a loss of trust in institutions and discourage initiatives for association.

To stimulate development, it would be beneficial to introduce the possibility of **probationary cooperative establishment** for a limited period. This would allow potential members to test the viability of a joint venture and gain management experience without high risk.

Business transparency is another critical factor. Making financial reports publicly available would provide a realistic insight into their success and prevent the creation of "paper cooperatives" that exist only formally but remain inactive.

Additionally, it is necessary to establish **institutional support** by appointing professional cooperative coordinators at the regional level. Their role would be to provide expert assistance in the formation, organization, and improvement of cooperatives, thereby increasing their efficiency and sustainability.

Finally, organizing **business fairs** and connecting with the **diaspora** can significantly contribute to the growth of cooperatives. Such events enable the exchange of experiences, the establishment of business contacts, and the promotion of domestic products in a broader market.

In conclusion, the development of cooperatives requires a **systemic approach** encompassing education, institutional support, transparency, and the strengthening of trust among participants. By combining **formal and informal forms of association**, it is possible to create a sustainable model that contributes to economic development and the strengthening of local communities.

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ASSESSING THE IMPACT OF CLIMATE CHANGE AND URBANIZATION ON RIVER NETWORK STRUCTURE AND FUNCTION IN SERBIA

ПРОЦЕНА УТИЦАЈА КЛИМАТСКИХ ПРОМЕНА И УРБАНИЗАЦИЈЕ НА СТРУКТУРУ И ФУНКЦИЈУ РЕЧНЕ МРЕЖЕ У СРБИЈИ

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Abstract: River systems in Serbia are increasingly shaped by the combined effects of climate change and accelerated urbanization, resulting in significant alterations to their structure and ecological function. This study provides a comprehensive spatial assessment of these impacts using an integrated GIS, Remote Sensing, and Artificial Intelligence (AI) framework. Multi-temporal datasets, including Sentinel-2 imagery, SRTM Digital Elevation Models, hydrological records, and open geodatabases, were analyzed to quantify changes in drainage density, tributary continuity, pollution distribution, and river-groundwater interactions. Results indicate a pronounced decline in hydrological connectivity, particularly within the Danube-Sava-Morava corridor, where urban expansion and industrial activities have intensified pressure on river systems. A reduction in drainage density and the loss of smaller tributaries were observed in peri-urban zones, reflecting increasing surface sealing and altered runoff dynamics. Smaller catchments, such as the Nišava and Timok basins, exhibit heightened sensitivity due to their limited dilution capacity and strong coupling between surface water and groundwater systems. Groundwater analysis further reveals that expanding urban areas are shifting pressure toward vulnerable aquifers, especially in valley corridors and suburban belts. Climate variability, including more frequent droughts and extreme precipitation events, amplifies these processes by reducing recharge and increasing pollutant concentrations. Scenario projections for 2050 suggest continued degradation of river network functionality under current development trends. The study highlights the importance of integrating geospatial technologies and AI for monitoring hydrological changes and supports the development of sustainable water management strategies and climate-resilient planning in Serbia.

Key words: Climate change, Urbanization; River network dynamics, GIS and Remote Sensing, Hydrological connectivity, Serbia

Анотракт: Речни системи у Србији су све више обликовани комбинованим ефектима климатских промена и убрзане урбанизације, што резултира значајним променама њихове структуре и еколошке функције. Ова студија пружа свеобухватну просторну процену ових утицаја коришћењем интегрисаног оквира ГИС-а, даљинске детекције и вештачке

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интелигенције (БИ). Анализирани су вишевременски скупови података, укључујући снимке Sentinel-2, SRTM дигиталне моделе елевације, хидролошке записе и отворене геобазе података како би се квантификовале промене у густини дренаже, континуитету притока, дистрибуцији загађења и интеракцијама река-подземних вода. Резултати указују на изражен пад хидролошке повезаности, посебно унутар коридора Дунав-Сава-Морава, где су ширење градова и индустријске активности појачале притисак на речне системе. Смањење густине дренаже и губитак мањих притока примећени су у периурбаним зонама, што одражава све веће заптивање површине и измењену динамику отицања. Мањи сливови, као што су сливови Нишаве и Тимока, показују повећану осетљивост због ограниченог капацитета разблаживања и јаке спреге између система површинских и подземних вода. Анализа подземних вода даље открива да ширење урбаних подручја помера притисак ка рањивим водоносним слојевима, посебно у долинским коридорима и приградским појасевима. Климатска варијабилност, укључујући чешиће суше и екстремне падавине, појачава ове процесе смањењем обнављања и повећањем концентрација загађивача. Пројекције сценарија за 2050. годину указују на континуирану деградацију функционалности речне мреже у оквиру тренутних трендова развоја. Студија истиче важност интеграције геопросторних технологија и вештачке интелигенције за праћење хидролошких промена и подржава развој одрживих стратегија управљања водама и планирања отпорног на климатске промене у Србији.

Кључне речи: климатске промене, урбанизација, динамика речне мреже, гис и даљинска детекција, хидролошка повезаност, Србија

1. INTRODUCTION

River systems represent one of the most dynamic and essential components of the natural environment, playing a critical role in regulating hydrological processes, maintaining ecological balance, and supporting socio-economic development. In recent decades, however, river networks worldwide have been increasingly affected by the combined pressures of climate change and rapid urbanization. These drivers alter both the structural configuration of drainage systems such as stream density, connectivity, and hierarchy and their functional properties, including flow regimes, sediment transport, and water quality. Understanding these interactions has become a central challenge in contemporary environmental and geographical research (Ouyang et al. 2006).

In Serbia, river systems are of particular importance due to the country's position within three major European drainage basins and the strong coupling between river corridors, urban development, and economic activity. Major rivers such as the Danube, Sava, and Morava form the backbone of settlement patterns, industrial zones, and transportation infrastructure. At the same time, smaller basins and tributary systems play a crucial role in maintaining local hydrological stability and ecological resilience. However, these systems are increasingly exposed to anthropogenic pressures, including land-use change, industrial expansion, and insufficient wastewater treatment, which contribute to hydromorphological alterations and declining water quality (Pincock 1969).

Urbanization represents one of the most significant drivers of these changes. The expansion of impervious surfaces reduces infiltration, accelerates surface runoff, and disrupts natural drainage patterns, leading to a decline in tributary permanence and overall drainage density. In parallel, industrial development concentrated along river corridors increases pollutant loads and modifies river morphology through channel regulation and infrastructure development. These processes are particularly pronounced in major urban-industrial axes,

where spatial concentration of human activity amplifies hydrological stress (Doody et al. 2012).

Climate change further intensifies these impacts by altering precipitation regimes, increasing the frequency of extreme events, and affecting seasonal water availability. In Serbia, recent decades have been characterized by more frequent droughts, irregular rainfall distribution, and episodic flooding, all of which contribute to increased variability in river discharge and reduced system resilience. The combined effect of climate variability and anthropogenic pressure creates complex, non-linear responses within river networks, making traditional analytical approaches insufficient for capturing these dynamics.

Recent methodological advances in Geographic Information Systems (GIS), Remote Sensing (RS), and Artificial Intelligence (AI) provide new opportunities for addressing these challenges. The integration of multi-temporal satellite data, digital elevation models, and machine learning techniques enables detailed spatial and temporal analysis of river network changes, as well as the prediction of future scenarios. In particular, physics-informed AI approaches, which incorporate hydrological principles into data-driven models, offer improved reliability and interpretability in environmental assessments (Loiseau et al. 2012).

Despite these advancements, comprehensive studies that simultaneously examine the structural and functional changes of river networks under the combined influence of climate change and urbanization remain limited in Southeast Europe. In Serbia, most existing research has focused either on water quality, land-use change, or individual river basins, without fully integrating these aspects into a unified analytical framework.

This study aims to fill this gap by providing a comprehensive assessment of how climate change and urbanization jointly influence river network structure and function across Serbia. Specifically, the objectives are: (i) to quantify changes in drainage density, tributary continuity, and hydrological connectivity; (ii) to analyze the spatial relationship between urban-industrial development and river system degradation; and (iii) to model future scenarios of hydrological change under projected climate and land-use conditions. By combining GIS, Remote Sensing, and AI-based approaches, this research contributes to a better understanding of complex hydro-spatial processes and provides a scientific basis for sustainable water management and climate-resilient planning (Valjarević 2024).

2. MATERIALS AND METHODS

2.1 Study area

The study covers the entire territory of the Republic of Serbia (88,361 km²), located at the intersection of Central and Southeastern Europe. Serbia is characterized by pronounced physiographic and hydrological diversity, encompassing lowland plains in the north (Pannonian Basin), hilly and valley-dominated central regions, and mountainous terrains in the south and east. The country belongs predominantly to the Black Sea drainage basin, with the Danube, Sava, and Velika Morava rivers forming the main hydrological axes, while smaller portions drain toward the Adriatic and Aegean basins (see Figure 1).

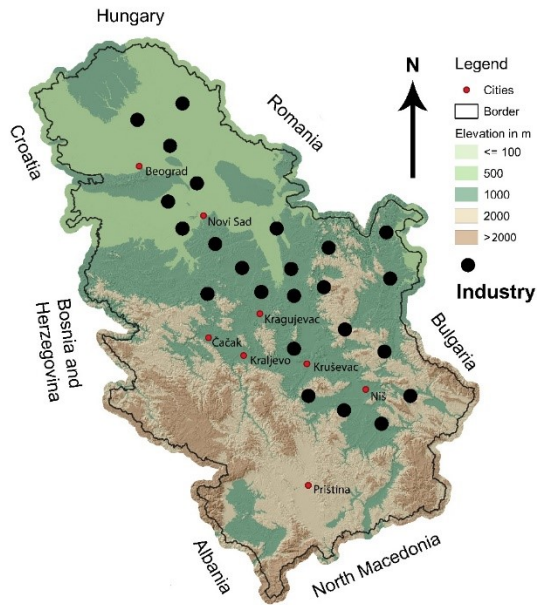


Figure 1. Spatial distribution of industrial facilities and major urban centers in Serbia

Urban and industrial development is strongly concentrated along major river corridors, particularly within the Danube–Sava–Morava axis, where the largest cities (Belgrade, Novi Sad, Niš, and Kragujevac) are located. These areas represent zones of intensified anthropogenic pressure, while upland and mountainous regions maintain relatively preserved river networks but are increasingly affected by land-use change, tourism, and small hydropower development. This spatial heterogeneity makes Serbia an appropriate case for analyzing the interactions between climate variability, urbanization, and river network dynamics (Valjarević et al. 2025).

2.2 Data sources

A multi-source geospatial database was developed to support the analysis of river network structure and function. The study integrates satellite imagery, topographic data, hydrological records, and socio-economic datasets to capture both spatial and temporal variability.

Remote sensing inputs include Sentinel-2 multispectral imagery (10–20 m resolution) and Landsat datasets, used for land-use classification and detection of urban expansion. Terrain analysis is based on Shuttle Radar Topography Mission (SRTM) Digital Elevation Models (30 m resolution), enabling the extraction of drainage networks, slope, and flow-related parameters. Historical hydrographic conditions were reconstructed using digitized topographic maps and archival data (Valjarević 2025). Hydrological and meteorological data, including precipitation, temperature, and river discharge, were obtained from national monitoring services and used for model calibration and validation. Population census data were transformed into raster density surfaces to represent spatial patterns of urbanization.

Additional datasets, such as CORINE Land Cover and open-access geodatabases (e.g., DIVA-GIS, Natural Earth), were used to ensure consistency and comparability across spatial scales. All datasets were harmonized within a unified coordinate system (UTM Zone 34N, EPSG:32634) and processed using QGIS and SAGA GIS software environments.

2.3 Methodological framework

The methodological approach is based on the integration of Geographic Information Systems (GIS), Remote Sensing (RS), and Artificial Intelligence (AI) techniques to analyze both structural and functional changes in river systems. The workflow consists of four main phases: (a) data preprocessing, (b) hydrological modeling, (c) spatial-statistical analysis, and (d) predictive modeling. Data preprocessing included atmospheric correction of satellite imagery, reprojection, and removal of topographic inconsistencies. Land-use classification was performed using supervised machine learning algorithms, while accuracy assessment was conducted using confusion matrices and kappa statistics.

Hydrological modeling was based on DEM-derived procedures, including sink filling, flow direction, and flow accumulation analyses. River networks were delineated using threshold-based extraction, and stream hierarchy was classified according to the Strahler method. Key indicators such as drainage density, stream length, and watershed boundaries were calculated to quantify structural characteristics. Spatial analysis incorporated zonal statistics and buffer analysis to examine relationships between urbanization intensity and hydrological parameters. Kernel Density Estimation (KDE) was applied to identify spatial clusters of anthropogenic pressure and pollution hotspots. Kriging interpolation was used to generate continuous surfaces of environmental indicators, reducing uncertainty in sparsely monitored areas (Tsihrintzis et al. 1996).

2.4 AI-based and physics-informed modeling

To enhance predictive capacity, machine learning models including Random Forest, Support Vector Machine, and Artificial Neural Networks were applied to analyze complex relationships between land use, climate variables, and hydrological responses. A key innovation of the study is the integration of physics-informed constraints within AI models, ensuring that predictions are consistent with fundamental hydrological processes such as flow direction, accumulation thresholds, and drainage connectivity.

Hydrological variables (slope, drainage density, flow accumulation, and groundwater interaction indices) were incorporated as weighted predictors, improving model interpretability and robustness. Post-processing procedures, including terrain correction and flow routing adjustments, were implemented to ensure physically realistic outputs.

2.5 Temporal analysis and scenario modeling

The analysis was conducted across multiple temporal reference points (1983, 2002, and 2022) to capture long-term changes in river network structure and urban expansion. Future scenarios for 2050 were generated using a combination of trend analysis and Cellular Automata–Markov chain modeling, integrating land-use change, demographic growth, and climate projections. Model validation was performed through cross-validation techniques and comparison with observed hydrological data. Accuracy metrics exceeded standard thresholds

(overall accuracy >85%), confirming the reliability of the analytical framework (Dandge and Patil 2022).

2.6 GIS and Remote Sensing Methods

Geographic Information Systems (GIS) and Remote Sensing (RS) techniques form the core analytical framework of this study, enabling the integration, processing, and interpretation of multi-source spatial data for assessing river network structure and function. The combined use of satellite imagery, digital elevation models (DEMs), and geospatial analysis tools provides a robust approach for detecting both spatial patterns and temporal changes in hydrological systems.

Remote sensing data were primarily derived from Sentinel-2 multispectral imagery (10–20 m spatial resolution), which offers high spectral sensitivity suitable for land-use classification, vegetation analysis, and identification of surface water features. Additional Landsat datasets were used to ensure temporal consistency across historical periods. Preprocessing steps included atmospheric correction, radiometric calibration, and cloud masking, ensuring comparability of multi-temporal datasets.

Topographic analysis was based on Shuttle Radar Topography Mission (SRTM) DEMs with a spatial resolution of 30 m. DEM-derived hydrological modeling included sink filling, flow direction, and flow accumulation algorithms, which were used to delineate drainage networks and watershed boundaries. River channels were extracted using threshold-based flow accumulation values, while stream hierarchy was classified according to the Strahler ordering system. These procedures enabled the quantification of key structural parameters such as drainage density, stream length, and network connectivity.

GIS-based spatial analysis was conducted using QGIS (version 3.28) and SAGA GIS (version 8.5), providing an open-source and reproducible analytical environment. Zonal statistics were applied to evaluate relationships between land-use patterns and hydrological indicators within defined buffer zones around river systems. Buffer distances (e.g., 250 m, 500 m, and 1 km) were used to assess the intensity of urban and industrial influence on river morphology and function.

Kernel Density Estimation (KDE) was implemented to identify spatial clusters of anthropogenic pressure, particularly in urban-industrial corridors. Kriging interpolation techniques were used to generate continuous spatial surfaces of environmental variables, including pollution indicators and hydrological stress, thereby addressing data gaps in areas with limited monitoring coverage.

Land-use classification was performed using supervised machine learning algorithms integrated within the GIS environment, with accuracy assessment conducted through confusion matrices and kappa coefficients. The integration of RS-derived land-cover data with GIS-based hydrological modeling enabled the detection of spatial relationships between urban expansion, climate variability, and river network transformation. Overall, the GIS and Remote Sensing methodology provides a comprehensive, scalable, and reproducible framework for analyzing complex hydro-spatial processes, supporting both scientific investigation and practical applications in environmental management and spatial planning (Clark 1998).

2.7 Statistical Methods

A comprehensive statistical framework was applied to quantify spatial relationships, detect temporal trends, and validate the robustness of the obtained results. The statistical analysis was designed to support the interpretation of GIS and Remote Sensing outputs and to ensure that observed patterns in river network dynamics are statistically significant and not the result of random variability. Descriptive statistics were first used to summarize the main characteristics of the analyzed datasets. Measures including mean, median, standard deviation, minimum, maximum, and coefficient of variation were calculated for key variables such as drainage density, stream length, slope, population density, and land-use classes. These indicators provided an initial understanding of the spatial variability and distribution of hydrological and anthropogenic factors across the study area.

To examine relationships between variables, correlation analysis was performed using Pearson's correlation coefficient (r) for normally distributed data, while Spearman's rank correlation coefficient (ρ) was applied where normality assumptions were not satisfied. This approach enabled the identification of statistically significant associations between urbanization intensity, climatic parameters, and hydrological indicators such as drainage density and runoff potential.

Regression analysis was employed to model the influence of multiple independent variables on river network characteristics. Both simple linear regression and multiple regression models were developed to assess how factors such as population density, impervious surface expansion, industrial proximity, and precipitation variability affect hydrological responses. Model performance was evaluated using the coefficient of determination (R^2), adjusted R^2 , and statistical significance (p -values < 0.05).

Temporal trends in climatic and hydrological variables were analyzed using the non-parametric Mann–Kendall (MK) test, which is widely applied in environmental studies due to its robustness against non-normal data distributions and missing values. The magnitude and direction of trends were further quantified using Sen's slope estimator, providing a reliable measure of long-term change.

To ensure the reliability of spatial predictions, geostatistical validation techniques were applied. Cross-validation procedures were used to assess interpolation accuracy, with performance metrics including Root Mean Square Error (RMSE) and Mean Absolute Error (MAE). These indicators quantify the difference between observed and predicted values and are essential for evaluating model uncertainty.

In addition, classification accuracy for remotely sensed data was assessed using confusion matrices, from which Overall Accuracy (OA), Producer's Accuracy, User's Accuracy, and the Kappa coefficient were derived. These metrics ensured the reliability of land-use classifications used in subsequent analyses. All statistical analyses were conducted using the R programming environment, enabling reproducible workflows and robust data processing. The integration of descriptive, inferential, and geostatistical methods provided a solid quantitative foundation for interpreting complex interactions between climate change, urbanization, and river network dynamics (Jin et al. 2019).

3. RESULTS

3.1 Spatial Patterns of River Network Transformation

The spatial analysis reveals significant changes in the structure of river networks across Serbia, primarily driven by urbanization and land-use transformation. The most pronounced alterations are observed along the Danube–Sava–Morava corridor, where intensive urban and industrial development has led to a measurable reduction in drainage density and fragmentation of tributary systems. In these areas, the expansion of impervious surfaces has reduced infiltration capacity, resulting in increased surface runoff and simplified drainage structures.

Quantitative results indicate a consistent decline in smaller tributaries, particularly in peri-urban zones surrounding major cities such as Belgrade, Novi Sad, and Niš. Buffer-based analysis demonstrates that areas within 500 m of urbanized zones exhibit the highest level of hydromorphological alteration, including reduced stream length and lower drainage density values compared to rural and mountainous regions. In contrast, upland and less-developed areas in western and southern Serbia maintain relatively stable and well-connected drainage networks, although localized disturbances are evident in regions affected by deforestation and infrastructure expansion.

Kernel Density Estimation (KDE) results highlight spatial clustering of anthropogenic pressure, with the highest intensity zones coinciding with major industrial corridors and transport networks. These clusters correspond to areas where river networks are most modified, indicating a strong spatial relationship between human activity and hydrological change. Furthermore, GIS-based overlay analysis confirms that urban expansion follows river valleys, reinforcing the role of hydrographic systems as primary axes of development and environmental pressure (Figure 1; Figure 2; Valjarević et al. 2025).

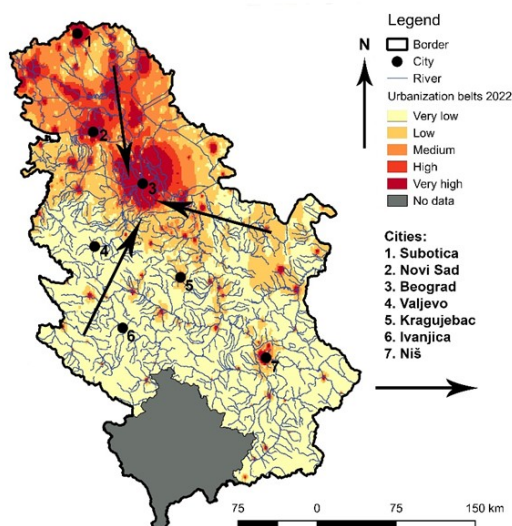


Figure 2. Spatial distribution of urbanization intensity and river network structure in Serbia (2022)

3.2 Temporal Trends and Functional Changes in River Systems

Temporal analysis reveals that river network dynamics in Serbia have undergone significant changes over the past four decades, reflecting the combined influence of climate variability and human activities. Statistical results indicate a downward trend in drainage density and tributary permanence, particularly in lowland and peri-urban regions. The Mann–Kendall test confirms statistically significant trends ($p < 0.05$) in several hydrological and climatic variables, including precipitation variability and river discharge patterns.

Regression analysis shows that urbanization intensity and land-use change are strong predictors of hydrological transformation, with higher population density and increased impervious surfaces associated with reduced hydrological connectivity. Climate-related variables, particularly changes in precipitation regimes, further amplify these effects by influencing runoff dynamics and seasonal water availability.

Functional changes are also evident in water quality and ecosystem stability. Spatial interpolation and hotspot analysis indicate increasing concentrations of pollution in urban-industrial zones, while smaller basins exhibit heightened vulnerability due to limited dilution capacity. In addition, groundwater–surface water interactions have been altered, particularly in peri-urban and valley regions, where increased water demand and reduced recharge rates contribute to declining system resilience (Figure 3; Table 1).

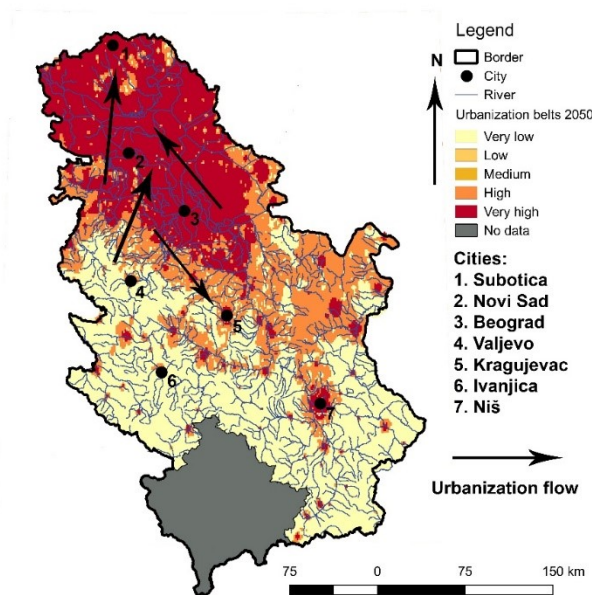


Figure 3. Projected spatial patterns of urbanization intensity and expansion flows in Serbia (2050)

Future projections for 2050 suggest a continuation of these trends, with further reductions in drainage density and increased hydrological instability under current urbanization and climate scenarios. The combined results highlight the transition from relatively stable river

systems toward more fragmented and vulnerable hydrological networks, emphasizing the need for integrated and sustainable management approaches (Table 2 and Table 3).

Table 1. Changes in drainage density across regions with included climate change effects

Region	Drainage Density Change (%)
Danube–Sava–Morava Corridor	-10.5
Peri-urban zones	-8.2
Upland areas	-2.1

Table 1 clearly demonstrates a pronounced spatial differentiation in the reduction of drainage density across Serbia, with the most significant decline observed in the Danube–Sava–Morava corridor (-10.5%), followed by peri-urban zones (-8.2%), while upland areas (-2.1%) exhibit only minor changes. This pattern indicates that hydrological degradation is strongly linked to the intensity of urbanization and industrial activity. The largest decrease in major urban corridors reflects the impact of dense infrastructure, impervious surfaces, and river regulation, which collectively reduce natural infiltration and simplify drainage networks. Peri-urban areas show slightly lower but still substantial declines, suggesting transitional zones where expanding settlements and mixed land use increasingly disrupt hydrological processes. In contrast, the relatively small change in upland regions confirms that less-developed and more natural landscapes retain higher hydrological stability and connectivity. Overall, the table highlights a clear gradient of anthropogenic influence, where river network degradation intensifies from rural to highly urbanized environments, emphasizing the critical role of land-use pressure in shaping hydrological systems (Elzwayie 2017).

Table 2. Correlation between urbanization and hydrological parameters

Variable	Correlation (r)
Population density	-0.78
Impervious surface	-0.82
Precipitation variability	-0.45

Table 2 highlights strong and predominantly negative relationships between urbanization-related variables and drainage density, indicating that increasing human pressure directly contributes to hydrological degradation. The highest negative correlation is observed for impervious surfaces ($r = -0.82$), confirming that surface sealing has the most significant impact on reducing infiltration and disrupting natural drainage networks. Similarly, population density ($r = -0.78$) shows a strong inverse relationship, suggesting that areas with higher human concentration are associated with greater modification and simplification of river systems. In contrast, precipitation variability ($r = -0.45$) exhibits a moderate negative correlation, indicating that climatic factors also influence drainage density but to a lesser extent than anthropogenic drivers. These results demonstrate that while climate variability plays an important role, urbanization processes are the dominant factor shaping river network

structure in Serbia. Overall, the table confirms that hydrological connectivity declines as human pressure intensifies, emphasizing the need for sustainable land-use planning and mitigation strategies in rapidly urbanizing regions.

Table 3. Temporal changes in river network and urbanization

Year	Drainage Density Index	Urbanization Index
1983	1.00	0.45
2002	0.93	0.62
2022	0.88	0.78

Table 3 illustrates clear temporal trends in the evolution of river network structure and urbanization in Serbia between 1983 and 2022. The results show a continuous decline in the drainage density index, decreasing from 1.00 in 1983 to 0.88 in 2022, indicating a progressive simplification and fragmentation of the river network over time. In contrast, the urbanization index exhibits a steady increase from 0.45 to 0.78, reflecting significant expansion of built-up areas and population concentration. This inverse relationship between the two indicators suggests a strong link between urban growth and hydrological degradation. The most notable changes occur after 2000, when accelerated urban development corresponds with a sharper decline in drainage density, highlighting the intensification of anthropogenic pressure in recent decades. These findings confirm that long-term land-use changes, particularly urban expansion, play a critical role in reshaping river systems. Overall, the table emphasizes a clear temporal trend in which increasing urbanization is associated with decreasing hydrological connectivity, reinforcing the need for sustainable planning and climate-adaptive water management strategies (see Figure 3).

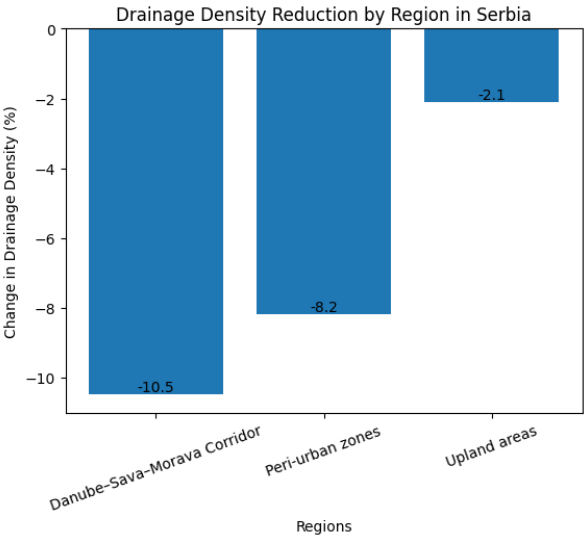


Figure 3. Spatial Variation in Drainage Density Reduction Across Different Regions of Serbia

The bar chart illustrates a clear spatial gradient in the reduction of drainage density, highlighting the dominant influence of urbanization on river network degradation. The most significant decline is observed in the Danube–Sava–Morava corridor, which represents the primary urban-industrial axis of Serbia. This reflects the impact of intensive land-use transformation, high population density, and extensive infrastructure development, all of which contribute to reduced infiltration and simplified drainage systems. Peri-urban zones also show substantial decreases, indicating transitional areas where expanding settlements increasingly disrupt natural hydrological processes. In contrast, upland regions exhibit only minor reductions, suggesting that less-developed and more natural landscapes maintain higher levels of hydrological stability and connectivity. Overall, the chart confirms that the intensity of anthropogenic pressure is the key factor controlling spatial differences in river network transformation.

4. DISCUSSION

The results of this study provide clear evidence that river network structure and function in Serbia are undergoing significant transformations driven primarily by urbanization and, to a lesser extent, by climate variability. The observed decline in drainage density, reduction of tributary systems, and increasing spatial fragmentation confirm that anthropogenic pressures are reshaping hydrological systems at multiple spatial scales.

One of the most important findings is the strong spatial concentration of hydrological degradation within the Danube–Sava–Morava corridor. This region represents the core of Serbia's urban-industrial development, where high population density, infrastructure expansion, and land sealing have significantly altered natural drainage processes. The reduction in drainage density in these areas is consistent with previous studies that link impervious surface growth to decreased infiltration and increased surface runoff. As a consequence, river networks become simplified, with smaller tributaries disappearing or becoming intermittent, which reduces overall hydrological connectivity and ecosystem resilience.

Peri-urban zones emerge as particularly critical transitional areas where hydrological changes are accelerating. These zones are characterized by mixed land use, rapid expansion of built-up areas, and incomplete infrastructure systems, which together create complex hydrological responses. The results indicate that even moderate increases in urbanization within these areas can lead to disproportionately large changes in drainage patterns. This finding highlights the importance of focusing not only on major urban centers but also on their surrounding zones, where the most dynamic and often unregulated land-use changes occur.

In contrast, upland and less-developed regions show relatively minor changes in drainage density, suggesting that natural landscape structures still play a dominant role in controlling hydrological processes. However, the presence of localized disturbances, such as deforestation and small hydropower development, indicates that these areas are not immune to change. If current trends continue, these regions may also experience increased hydrological stress, particularly under the influence of climate variability.

The statistical analysis further confirms that urbanization is the dominant driver of river network transformation. Strong negative correlations between drainage density and variables such as impervious surfaces and population density demonstrate that human activities have

a more direct and immediate impact than climatic factors. While precipitation variability and extreme events contribute to changes in hydrological regimes, their influence appears secondary compared to land-use change. This finding aligns with broader research indicating that, in many regions, urbanization can outweigh climate change as a driver of local hydrological alteration.

Nevertheless, climate change acts as an important amplifying factor. Increased frequency of droughts reduces base flow and groundwater recharge, while intense precipitation events enhance surface runoff and erosion processes. These dynamics can exacerbate existing vulnerabilities created by urbanization, leading to more extreme hydrological responses such as flash floods and prolonged low-flow conditions. The combined effect of these processes results in a more unstable and less predictable river system.

Another key aspect of the findings is the growing importance of groundwater–surface water interactions. The expansion of urban areas, particularly in valley corridors and peri-urban zones, is increasing pressure on aquifer systems. Reduced infiltration due to land sealing, combined with increased water demand, leads to declining recharge rates and potential overexploitation of groundwater resources. This not only affects water availability but also influences river base flow, further contributing to the degradation of river network function.

The application of GIS, Remote Sensing, and AI-based methods proved to be highly effective in capturing these complex interactions. The integration of multi-temporal datasets and advanced spatial analysis techniques allowed for a detailed assessment of both structural and functional changes in river systems. In particular, the use of physics-informed AI approaches enhances the reliability of predictions by ensuring consistency with hydrological processes, representing a significant methodological advancement over purely data-driven models.

Despite these strengths, several limitations should be acknowledged. The spatial resolution of available datasets may limit the detection of smaller tributaries and fine-scale hydrological processes. Additionally, the uneven distribution of monitoring stations introduces uncertainty in spatial interpolation results, particularly in less-developed regions. Future research should focus on incorporating higher-resolution datasets, expanding monitoring networks, and integrating socio-economic variables to further improve model accuracy.

From a policy perspective, the findings emphasize the urgent need for integrated water management strategies that consider both land-use planning and climate adaptation. Protecting riparian zones, reducing impervious surface expansion, and improving wastewater treatment infrastructure are essential measures for maintaining hydrological connectivity and ecosystem stability. Furthermore, the identification of peri-urban zones as critical areas of change suggests that targeted interventions in these regions could significantly reduce overall hydrological degradation.

In conclusion, this study demonstrates that river network transformation in Serbia is a result of complex interactions between human activities and climatic factors, with urbanization playing the dominant role. The observed trends toward reduced connectivity and increased vulnerability highlight the need for sustainable and adaptive management approaches. By combining advanced geospatial technologies with statistical and hydrological analysis, this research provides a comprehensive framework for understanding and managing river systems in the context of ongoing environmental change (Gobo 2010; Aniebo et al. 2009).

5. FUTURE WORK

Future research should focus on advancing both the methodological framework and the empirical understanding of river network dynamics under the combined influence of climate change and urbanization. One of the key directions is the integration of higher-resolution datasets, including LiDAR-based Digital Elevation Models and very high-resolution satellite imagery, which would enable more precise detection of small tributaries, micro-topographic features, and localized hydrological processes that are not fully captured at the current spatial scale.

Another important avenue involves the expansion of monitoring networks, particularly in underrepresented regions such as mountainous and rural basins. Increasing the density of hydrological and water quality stations would improve the accuracy of spatial interpolation and model validation, reducing uncertainty in areas where current data availability is limited. In parallel, the incorporation of real-time sensor data and Internet of Things (IoT) technologies could support continuous monitoring and early detection of hydrological anomalies.

From a methodological perspective, future studies should further develop physics-informed and hybrid AI models by integrating additional hydrological constraints and process-based components. The coupling of machine learning with physically based hydrological models would allow for more reliable simulation of complex interactions between climate variables, land-use change, and river network behavior. Additionally, the use of advanced algorithms such as deep learning and spatiotemporal neural networks could improve predictive performance, particularly for long-term scenario analysis.

Socio-economic factors should also be more explicitly incorporated into future analyses. Variables such as urban planning policies, infrastructure development, water consumption patterns, and industrial regulation play a critical role in shaping hydrological systems and should be integrated into multi-criteria modeling frameworks. This would enable a more comprehensive assessment of human–environment interactions and support policy-oriented decision-making.

Future scenario modeling should be expanded to include multiple climate pathways and urban growth scenarios, allowing for comparative analysis of potential development trajectories. Such approaches would provide valuable insights into the long-term sustainability of river systems and help identify critical thresholds beyond which hydrological degradation becomes irreversible. Finally, interdisciplinary approaches combining hydrology, geography, environmental science, and urban planning are essential for addressing the complexity of river network transformation. The development of decision-support systems based on GIS and AI could provide practical tools for policymakers, enabling more effective implementation of climate-resilient and sustainable water management strategies in Serbia and beyond.

6. CONCLUSION

This study provides a comprehensive assessment of the impacts of climate change and urbanization on river network structure and function in Serbia, demonstrating that

hydrological systems are undergoing significant spatial and temporal transformations. The results reveal a consistent decline in drainage density, reduced tributary continuity, and increasing fragmentation of river networks, particularly within major urban-industrial corridors. These structural changes are closely linked to intensified land-use pressures, including the expansion of impervious surfaces, industrial activity, and population growth.

The findings clearly indicate that urbanization is the dominant driver of hydrological degradation, while climate variability acts as an amplifying factor, increasing system instability through altered precipitation patterns, droughts, and extreme events. The combined effects of these processes lead to reduced hydrological connectivity, declining ecological resilience, and increased vulnerability of both surface water and groundwater systems.

The integration of GIS, Remote Sensing, and AI-based approaches proved to be highly effective in capturing complex hydro-spatial interactions and identifying key areas of environmental stress. The applied methodological framework offers a scalable and reproducible tool for monitoring river network dynamics and supporting data-driven decision-making.

From a practical perspective, the results emphasize the urgent need for sustainable land-use planning, improved wastewater treatment, and protection of riparian zones, particularly in rapidly developing peri-urban areas. Without such measures, current trends suggest further degradation of river systems by 2050, with potential consequences for water security and ecosystem stability. Overall, this study contributes to a deeper understanding of the interplay between climate change and urbanization in shaping river networks and provides a scientific basis for developing climate-resilient and sustainable water management strategies in Serbia and similar regions.

Limitations of the Study

Despite the comprehensive methodological framework and multi-source data integration, several limitations should be acknowledged. First, the spatial resolution of the available datasets, particularly the 30 m Digital Elevation Models and medium-resolution satellite imagery, may limit the accurate detection of small tributaries, ephemeral streams, and fine-scale hydrological features. As a result, certain localized processes and minor drainage elements may be underrepresented in the analysis.

Second, the uneven spatial distribution of hydrological and water quality monitoring stations introduces uncertainty in model calibration and validation. This limitation is particularly evident in mountainous and less-developed regions, where data scarcity may affect the reliability of spatial interpolation and predictive modeling outputs. Third, the study relies on historical datasets and generalized land-use classifications, which may not fully capture rapid or recent changes in urban development and infrastructure expansion. Temporal inconsistencies between datasets could also introduce minor discrepancies in trend analysis.

Fourth, although advanced statistical and AI-based methods were applied, model performance is inherently dependent on input data quality and the selection of variables. Some potentially important factors, such as detailed socio-economic indicators, policy measures, and local water management practices, were not explicitly included due to data limitations.

Finally, future scenario projections are based on current trends in urbanization and climate variability and therefore carry a degree of uncertainty. These projections do not account for potential policy interventions, technological advancements, or unexpected environmental changes that could significantly alter future outcomes. Recognizing these limitations is essential for interpreting the results and provides a foundation for improving future research through higher-resolution data, expanded monitoring networks, and more integrated modeling approaches

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GERMINATION RESULTS OF WINTER WHEAT, OATS, AND MUNG BEAN WITH THE APPLICATION OF NEW ENERGIZED FERTILIZER (GVG)

РЕЗУЛТАТЫ ПРОРАЩИВАНИЯ ОЗИМОЙ ПШЕНИЦЫ, ОВСА И МАША С ПРИМЕНЕНИЕМ НОВОГО ЭНЕРГЕЗИРОВАННОГО УДОБРЕНИЯ (GVG)

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Abstract: A laboratory experiment was conducted to study the effect of a new complex energized fertilizer (GVG), based on natural raw materials – alkaline salts of naphthenic acids – on the germination and seed vigor of winter wheat (*Triticum aestivum*), variety Tanja, oats (*Avena sativa* L.), variety Valdin 765, and the leguminous crop mung bean (*Vigna radiata*), variety Tajikistani 1. On the seventh day of winter wheat germination in the experimental variant, seedling length was 28.0% higher compared to the control. For oats, seedling length in the experimental variant was 23.6% greater than in the control. In the experimental group of mung bean, seedlings were 13.4% longer than the control. Since the new energized fertilizers (GVG) contain a high number of micronutrients essential for proper plant development (Na, Cu, Mg, Ca, Zn, Al, Si, Ti, Pb, Sn, Cr, Mn, Fe, Co, Ni), seeds of these crops treated with GVG solution showed improved results compared to the control. This study indicates that the new energized fertilizer is justified for use in pre-sowing seed treatment of various crops to increase their yield.

Key words: growth stimulator, winter wheat, oats, mung bean, seed vigor, germination.

Абстрактный: Произведен лабораторный опыт по изучению влияния нового комплексного энергизированного удобрения (GVG) в основе которых лежит природное сырьё - щелочные соли нафтенновых кислот на всхожесть и энергию прорастания, семян озимой пшеницы (*Triticum aestivum*) сорта Таня, овса (*Avena sativa* L.) сорта Валдин 765 и бобовой культуры маша (*Vigna radiata*) сорта Таджикский 1. На седьмой день проращивания озимой пшеницы в опытном варианте длина проростков превышала контрольный вариант на 28,0 %. У овса длина ростков опытном варианте на 23,6 % длиннее, чем в контрольном варианте. В опытной группе ростки маша на 13,4 % длиннее контроля. За счет того, что в состав новых энергизированных удобрений (GVG) входит большое количество необходимых для полноценного развития растений микроэлементов (Na, Cu, Mg, Ca, Zn, Al, Si, Ti, Pb, Sn, Cr, Mn, Fe, Co, Ni), семена данных культур, обработанные раствором GVG, показали лучший результат по сравнению с контролем. Это исследование позволяет утверждать, что новое энергизированное удобрение

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целесообразно использовать в производстве в предпосевной обработке семян разных культур с целью повышения их урожайности.

Ключевые слова: ростовое вещество, озимая пшеница, овёс, маис, энергия прорастания, всхожесть.

1. INTRODUCTION

With the ongoing intensification of agriculture, and particularly crop production, the question of how to increase the productivity (yield and quality) of various agricultural crops, while simultaneously improving soil condition on farmland without significantly increasing costs, remains pressing. It is known that the condition of arable land in Russia is deteriorating year by year, which is associated with the fact that harvests remove more nutrients from the soil than are returned through fertilizers. An increasing number of soils are becoming degraded and susceptible to erosion each year. In Russia, less than half of the sown areas receive fertilization, and less than 50 kg per hectare is applied, which is 4–5 times less than in Western Europe. The stabilization of humus content in the soil depends on the input of organic matter. Under agricultural land use conditions, organic fertilizers play a significant role in this process (Ushachev, 2017).

In 2019, research on this pressing issue led to the patenting of a new energized preparation GVG by scientists of the Kuban State Agrarian University named after I. T. Trubilin. This discovery belongs to the field of plant growth stimulators. The organic growth agent contains sodium salt of naphthenic acids (35–45 wt.%), rapeseed oil (0.005–0.015 wt.%), and water (remainder). It is obtained by dissolving the sodium salt in water at 20–24°C with the addition of rapeseed oil.

2. MATERIALS AND METHODS

This preparation is used for crop treatment by seed soaking, foliar spraying, or soil application.

The aqueous solution can be combined with fungicides. The preparation has a pronounced stimulatory effect on plant growth (Grigulevski, 2019).

The best effect is achieved by soaking seeds for 2–5 days in a solution of 0.01–0.05%, or by applying the solution to the soil (50–100 ml/ha). GVG (Grivlag) increases yield, quality, and plant resistance to lodging (Sidorenko, et al. 2016).

The preparation is a colloidal reddish-brown liquid, denser than water, requiring the preparation of a stock solution. More than 50 growth stimulators are known, which stimulate growth in small doses and inhibit it in larger doses (Grigulevski, Lukyanova, 2000).

Research from 1960–1975 showed that these compounds:

- stimulate growth and increase yield in small doses,
- have selective effects depending on the crop,
- act by activating physiological processes (increasing chlorophyll, assimilation surface, nitrogen). (Kugatova-Shemyakina, et al. 1965; Kugatova-Shemyakina, et al. 1967; Shenker, et al. 1972)

The raw materials for obtaining the growth substance were petroleum products from the Krasnodar Oil Refinery (Krasnodar) and the Baku Oil Refinery (Baku). Naphthenic acid salts can be extracted from petroleum products by the action of an aqueous solution of sodium

hydroxide (KOH). (Griguletskiy, 2018) The physiological action of fatty salts of naphthenic acids is described in detail in fundamental monographs by P. Boysen-Jensen, (Boysen-Jensen, 1938) K.Z. Hamburg, (Gamburg, 1970; Gamburg, 1976) V.I. Kefeli, (Kefeli, 1973) and, especially, S.S. Medvedev. (Medvedev, 2015) This study was conducted on crops typically grown in the Krasnodar Krai—winter wheat and oats—as well as on a legume crop atypical for this region—mung bean.

Winter wheat (*Triticum aestivum*) variety Tanya is one of the most common semi-dwarf hard wheat varieties in Kuban. It is highly resistant to lodging, early maturing, and heads and ripens simultaneously. It was developed by the Krasnodar Research Institute of Agriculture named after P.P. Lukyanenko. The variety was submitted for testing in 2001. The ear shape ranges from cylindrical to pyramidal, of medium length and density. It is resistant to shattering. The glumes are ovoid, 3.5-4.5 mm wide, and 8-9 mm long. The shoulder is medium and straight. The keel is moderately pronounced. The grain is large and ovoid. 1,000-kernel weight is 45.4-46.5 grams. It is a valuable wheat. The variety is highly resistant to yellow rust, powdery mildew, and loose smut. (Romanenko, et al. 2017)

Spring oats (*Avena sativa* L.), variety Valdin 765, was bred at the Kuban Experimental Station of VIR (developed by D.F. Tantsyura). This early-ripening variety (from germination to commercial maturity takes 83-97 days). The bush is erect. The stem is low-growing, 86-100 cm, rarely up to 125 cm. It is of medium thickness, hollow, and strong. The grain is large, semi-long, bright yellow, and valuable for its cereal quality. The 1,000-kernel weight is 27-38 g, and the grain density is 434-524 g/l, ensuring consistently high grain yields. In the Krasnodar Territory, the yield reaches 72 c/ha. It differs from cultivated varieties in its resistance to lodging, bacterial spot, crown rust, loose smut and smut. (Kobylyanskiy, et al. 1992)

Mung bean (*Vigna radiata*), Tajik 1 variety. An annual herbaceous plant; a species of the genus *Vigna* in the legume family; a legume crop native to India. The seeds are small, green, and oval-shaped. In Russia, varieties 30-50 cm tall are cultivated. The stem of the mung bean is herbaceous, sometimes woody at the base, green, gray-green, and may have anthocyanin coloration. The fruit is a pod thin, cylindrical, with appressed pubescence, without a beak at the end, 6-18 cm long, containing 6-15 seeds. The seeds are small, barrel-shaped, tuberculate, smooth, matte, or shiny, 3-6 mm long. Mung bean seeds are widely used as food in many countries. In recent years, there has been a surge of interest in this crop in Slavic countries, primarily as a dietary food product high in complete protein, vitamins, and minerals. Healthy eating advocates also value mung beans because they are free of substances harmful to the human body, which are present in soybeans and some types of beans. The Tajik 1 variety is a Central Asian variety, developed in the Soviet Union. It is rarely affected by disease, has relatively large seeds, and a relatively high yield (25 centners/ha). (Lavrenko, et al. 2019)

The aim of the study was to determine the effect of GVG on seed vigor (3rd day) and germination (7th day)

3. RESULTS AND DISCUSSION

The experiment was carried out under laboratory conditions in Petri dishes at 20–22°C. Seeds were soaked for 8 hours in a solution (0.01 ml GVG/L water), then placed on filter paper.

Each dish contained 100 seeds. The experiment was conducted in three replicates according to GOST 12038-84.

On the third day, seed vigor and seedling length were measured, and germination was assessed on the seventh day. All results were statistically analyzed.

The experimental design is shown in Table 1.

Table 1. Seed germination in Petri dishes according to GOST 12038-84

Solution Name	Phase	
Water	Determination of germination energy (3rd day) according to GOST 12038-84	Determination of seed germination (7th day) according to GOST 12038-84
New Energized Fertilizer GVG		

The subject of this study is the seeds of three agricultural crops, which are commonly grown both in Russia and worldwide (wheat, oats, mung bean), as well as their response to the new energized fertilizer GVG (Grivlag), with the aim of providing recommendations for its further use.

Discussion of the experimental data and research results shows that, based on the data presented in Table 2, treatment with the GVG preparation leads to a significant increase in seed vigor.

Table 2. Germ length, % (3rd day) according to GOST 12038-84, n=3

Solution name (0.01/1 l)	Type of agricultural seed		
	Sprout length (average for 100 pcs.), mm		
	Winter wheat	Winter wheat	Mash
Control (water)	8,14±0,3	1,6±0,15	20,65±0,33
Inspection (new energized fertilizer GVG)	9,56±0,37**	2,09±0,15**	25,64±0,39***

Note:***- $p < 0,001$

The reliability of the data for wheat and oats is moderate, while the data obtained for mung bean show a high degree of reliability. Germination energy represents the seed's ability to germinate quickly and uniformly. Since all the tested crops began to form sprouts by the third day, their measurement and comparison of results were carried out.

For 100 germinated winter wheat seeds, the sprout length in the experimental variant was 17.4% greater (9.56 mm) compared to the control (8.14 mm). For spring oat seeds, the sprout length in the experimental variant (2.09 mm) was 30.6% greater than in the control (1.6 mm). Mung bean seeds in the experiment had an average sprout length of 25.64 mm, which is 24.2% higher compared to the control (20.65 mm).

The tested seed material was also measured by mass. Data on the mass of seeds on the third day of germination are presented in Table 3. The results indicate that the mass of germinated seeds is significantly higher due to water absorption and the intensity of germination.

However, the mass of 100 germinated seeds in the experimental variant was slightly higher than in the control (seeds germinated in distilled water).

Specifically, winter wheat seeds treated with the GVG preparation had a mass 61.5% higher (6.30 g) compared to the dry control (3.90 g), while seeds germinated in water showed an increase of 48.7% (5.80 g). Thus, seeds treated with the GVG preparation had 12.8% greater mass compared to those germinated in water.

For oats, the results were as follows: grains germinated in the GVG solution had a mass 16.1% higher (3.25 g) compared to the dry control (2.8 g), while grains germinated in distilled water showed an increase of 10.7% (3.1 g). Comparing these two germinated variants, the experimental (GVG) variant was 5.4% heavier than the control.

The mass of 100 mung bean seeds germinated in the GVG solution was 175.6% higher (15.85 g) compared to the dry control (5.75 g), while seeds germinated in water (control) showed an increase of 173% (15.70 g). Germinated mung beans in the experimental variant had 2.6% greater mass compared to those germinated in water.

Table 3. Weight of 100 seeds on the third day of germination, g

Variant	Types of agricultural seed		
	Weight of 100 seeds, g		
	Winter wheat	Winter wheat	Mash
Control (dry control)	3,90	2,80	5,75
Control (water)	5,80	3,10	15,70
Review (new energized fertilizer GVG)	6,30	3,25	15,85

Laboratory seed germination was determined on the seventh day of germination. By this time, both the root and shoot had already developed in cereals (wheat and oats), while in the leguminous crop mung bean, only the sprout increased, without a clear differentiation into root and stem.

The results of sprout length measurements on the seventh day of testing are presented in Table 4.

Table 4. Germ length, % (seventh day) according to GOST 12038-84, n=3

Name of the solution (0.01/1 l)	Types of agricultural seed		
	Sprout length (average for 100 seeds), mm		
	Winter wheat	Winter wheat	Mash
Control (water)	9,42±0,25	18,47±0,23	26,77±0,2
Experiment (new energized fertilizer GVG)	12,06±0,31***	22,82±0,24***	30,35±0,26***

Note:***- $p < 0,001$

All studies demonstrated a high degree of reliability of the results. Table 4 shows the sprout lengths measured on the seventh day of testing.

For winter wheat in the experimental variant, the average sprout length (12.6 mm) was 28.0% greater compared to the control (9.42 mm). For oats, the sprout length on the seventh day in the experimental variant was 22.82 mm, which is 23.6% higher than the control (18.47 mm). In the experimental group of mung bean, the average sprout length was 30.35 mm, representing a 13.4% increase compared to the control (26.77 mm).

For winter wheat and spring oats, root lengths were also measured on the seventh day (Table 5).

Table 5. Root length, % (7th day) according to GOST 12038-84, n=3

Name of the solution (0.01/1 l)	Types of agricultural seed	
	Root length (average for 100 pcs.), mm	
	Winter wheat	Spring oats
Control (water)	5,66±0,1	8,25±0,26
Review (new energized fertilizer GVG)	7,48±0,13***	10,65±0,28***

Note:***- $p < 0,001$

The data presented in Table 5 show a high degree of reliability. The average root length of winter wheat on the seventh day of germination in the experimental variant was 32.2% greater compared to the control, measuring 7.48 mm, while in the control variant it was 5.66 mm.

For spring oat seeds, the average root length in the experimental variant was 29.1% greater than the control, measuring 10.65 mm, whereas in the control variant it measured 8.25 mm.

CONCLUSIONS

Based on the results obtained during the study, several conclusions can be drawn regarding the positive effect of the new energised fertilizer GVG (Grivlag) on seeds of agricultural crops under laboratory germination conditions:

1. For 100 germinating seeds of winter wheat on the third day of germination, the length of the sprouts in the experimental variant was 17.4% greater than in the control. Seeds of spring oats in the experimental variant had sprouts 30.6% longer than the control, and mung bean seeds in the experimental variant exceeded the control sprouts by 24.2%.
2. Seeds of wheat germinated with GVG had a mass 12.8% higher than seeds germinated in water. For oats, seeds germinated in the GVG solution were 5.4% heavier than those germinated in water. Germinated mung beans in the experimental variant had a mass 2.6% higher compared to those germinated in water.
3. On the seventh day of germination, sprouts of winter wheat in the experimental variant were 28.0% longer than in the control. For oats, the sprouts in the

experimental variant were 23.6% longer than the control. Sprouts of mung beans in the experimental group were 13.4% longer than the control.

4. The average root length of wheat on the seventh day of germination in the experimental variant exceeded the control by 32.2%. For oats, the average root length in the experimental variant exceeded the control by 29.1%.

Based on the stable and positive effect of applying the solution of the new energised fertilizer during the germination of winter wheat, spring oats, and mung beans, as well as on the basis of previously conducted trials, it can be stated that GVG (Grivlag) is a fertilizer (growth stimulator) capable of increasing the yield of agricultural crops under field conditions.

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OPTIMIZATION OF AGRO-INDUSTRIAL WASTE SUBSTRATES FOR ENHANCED MYCELIAL GROWTH OF *PLEUROTUS* *OSTREATUS*

ОПТИМИЗАЦИЈА НА СУПСТРАТИ ОД АГРОИНДУСТРИСКИ ОТПАД ЗА ПОДОБРЕН МИЦЕЛИУМСКИ РАСТ НА *PLEUROTUS OSTREATUS*

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Abstract: Agro-industrial residues represent a sustainable resource for fungal cultivation. This study aimed to optimize substrate composition for the growth of *Pleurotus ostreatus* using wheat bran, brewery spent grain, oat bran, and coffee waste. Mycelial growth was evaluated on agar plates and analyzed using statistical modeling to assess the effects and interactions of substrate components. Results showed that substrates based on wheat bran and brewery spent grain achieved maximum colonization, indicating a strong synergistic effect. In contrast, increasing proportions of coffee waste inhibited growth, while oat bran showed a moderate, composition-dependent effect. The findings demonstrate that balanced substrate formulation is essential for optimal mycelial development and highlight the potential of agro-industrial waste valorization in sustainable mushroom production.

Key words: *Pleurotus ostreatus*, agro-industrial waste, brewery spent grain, substrate optimization, mycelial growth

Анстракт: Агроиндустриските нуспроизводи претставуваат одржлив ресурс за култивација на габи. Целта на ова истражување беше оптимизација на составот на подлогата за раст на *Pleurotus ostreatus* со примена на пченични трици, пивски троп, овесни трици и отпад од кафе. Растот на мицелиумот беше следен на агар-подлоги и статистички анализиран со цел да се процени влијанието и интеракцијата на поединечните компоненти. Резултатите покажаа дека подлогите базирани на пченични трици и пивски троп овозможуваат максимална колонизација, што укажува на изразен синергетски ефект. Наспроти тоа, зголеменото учество на отпад од кафе доведе до инхибиција на растот, додека овесните трици покажаа умерен ефект зависен од составот. Добиените резултати потврдуваат дека балансираниот состав на подлогата е клучен за оптимален развој на мицелиумот и го нагласуваат потенцијалот за валоризација на агроиндустриски отпад во одржливо производство на печурки.

Клучни зборови: *Pleurotus ostreatus*, агроиндустриски отпад, пивски троп, оптимизација на подлога, раст на мицелиум

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1. INTRODUCTION

Pleurotus ostreatus, commonly known as the oyster mushroom, is one of the most widely cultivated mushroom species worldwide due to its rapid growth, high adaptability, and short production cycle (Drężek & Możejko-Ciesielska, 2025; Miśkiewicz et al., 2025). Its popularity is attributed not only to its high gastronomic value but also to its nutritional composition, which includes significant levels of proteins, essential minerals, and vitamins (Hoa et al., 2015). In addition, *P. ostreatus* exhibits important medicinal properties, including antioxidant and immunomodulatory effects associated with bioactive compounds such as β -glucans (Drężek & Możejko-Ciesielska, 2025).

The successful cultivation of *P. ostreatus* depends largely on the vegetative phase, during which rapid and uniform mycelial colonization determines substrate utilization efficiency and overall productivity (Miśkiewicz et al., 2025; Wani & Lemi, 2026). As a white-rot basidiomycete, *P. ostreatus* possesses an extensive extracellular enzymatic system, including lignin-degrading enzymes such as laccases and peroxidases, which enable the degradation of lignocellulosic materials (Alexopoulos et al., 1996; Carlile et al., 2001; Elisashvili et al., 2008). This enzymatic capability allows the fungus to efficiently utilize a wide range of organic residues as substrates.

The use of agro-industrial wastes for mushroom cultivation represents a sustainable and economically viable strategy that contributes to waste management and circular bioeconomy development (Deschamps et al., 2024; Miśkiewicz et al., 2025; Wani & Lemi, 2026). Numerous studies have demonstrated that agricultural and food-processing by-products can be effectively converted into valuable biomass through fungal cultivation (Philippoussis et al., 2001; Shashitha et al., 2016). However, the efficiency of this process is highly dependent on substrate composition, particularly the balance between carbon and nitrogen sources, which significantly affects mycelial growth and enzyme production (Hoa et al., 2015; Gao et al., 2013; Marzluf, 1997).

Among the available agro-industrial residues, brewery spent grain (BSG) is one of the most abundant by-products of the brewing industry and is characterized by high protein and fiber content, making it a suitable substrate for fungal growth (Mussatto et al., 2006; Aliyu & Bala, 2011). Its use in mushroom cultivation has been associated with enhanced colonization rates and improved substrate degradation efficiency (Deschamps et al., 2024). Wheat bran is commonly applied as a nitrogen-rich supplement that improves nutrient availability and accelerates mycelial colonization (Hoa et al., 2015). Similarly, oat bran has been reported to support mycelial development, although its effect is strongly dependent on concentration and interaction with other components (Soto-Cruz, 1999).

In contrast, coffee waste, including spent coffee grounds, represents a widely available residue with potential for valorization, but its application in fungal cultivation requires careful optimization. High concentrations have been associated with inhibitory effects on mycelial growth due to the presence of bioactive compounds such as caffeine and phenolics (Alsanad et al., 2020; Laursen, 2018). Therefore, understanding the interactions between different substrate components is essential for developing optimized formulations that maximize fungal growth while avoiding inhibitory effects.

Despite the availability of various agro-industrial substrates, optimal formulation remains a key challenge, as interactions between components can significantly influence growth

performance and system stability. Therefore, the aim of this study was to evaluate and optimize substrate formulations based on brewery spent grain, wheat bran, oat bran, and coffee waste in order to identify combinations that promote enhanced mycelial growth of *Pleurotus ostreatus*. This approach contributes to improving the sustainability and efficiency of mushroom cultivation through the valorization of agro-industrial residues.

2. MATERIALS AND METHODS

2.1 Microorganism and inoculum preparation

The fungal species *Pleurotus ostreatus* was used as a model organism due to its well-established ability to colonize lignocellulosic substrates and valorise agro-industrial residues. The inoculum was prepared from fresh fruiting bodies under aseptic conditions. Internal tissue sections (~5 mm diameter) were excised from the sterile inner part of the mushroom to minimize contamination and ensure active mycelial growth.

Primary cultivation was performed on potato dextrose agar (PDA) at 25 °C to obtain actively growing mycelium for subsequent inoculation experiments.

2.2 Preparation of culture media and nitrogen supplementation

PDA was prepared by boiling 200 g of peeled and chopped potatoes in 1 L of distilled water for 30 min, followed by filtration to obtain the potato extract. The volume was adjusted to 1 L, and glucose (20 g/L) and agar (15 g/L) were added. The medium was heated until complete dissolution and sterilized at 121 °C for 15 min.

To evaluate the effect of nitrogen availability on mycelial growth, two media variants were prepared: (i) PDA without supplementation and (ii) PDA supplemented with ammonium sulfate ((NH₄)₂SO₄, 0.2 g/L).

Mycelial growth was monitored over a 22-day incubation period by measuring colony diameter at regular intervals.

2.3 Agro-industrial waste substrates and experimental design

Agro-industrial by-products were selected as substrate components, including:

- brewer's spent grain (BSG)
- wheat bran
- oat bran
- coffee waste

These materials were sourced from local food processing facilities, ensuring relevance to regional circular bioeconomy strategies.

A mixture design approach (Design of Experiments, DOE) was applied using Statgraphics Centurion software to systematically evaluate the effect of substrate composition on mycelial growth. Four components were defined as independent variables, expressed as percentage of total substrate mass, with the following constraints:

- wheat bran: 30–100%
- BSG: 0–70%

- oat bran: 0–20%
- coffee waste: 0–20%

An extreme vertices mixture design with linear model was employed to generate experimental combinations, ensuring comprehensive coverage of the formulation space. Each experimental condition was performed in triplicate to ensure statistical robustness.

2.4 Substrate preparation and physicochemical adjustment

Prior to substrate preparation, the moisture content of each raw material was determined gravimetrically by oven drying at 105 °C until constant mass. Based on these values, substrate formulations were adjusted to achieve consistent moisture levels across all experimental conditions.

Substrates were prepared in 720 mL glass containers, with a total mass of 250 g per sample. Calcium carbonate (CaCO_3) was added at 2% (w/w) to stabilize pH and improve buffering capacity during fungal growth.

To ensure adequate aeration, container lids were modified with a 9 mm opening filled with sterile cotton plugs, allowing gas exchange while preventing contamination.

2.5 Sterilization and inoculation of substrates

Prepared substrates were sterilized by autoclaving at 121 °C for 3 h under 15 psi pressure. Extended sterilization time was applied due to the high density and complex structure of lignocellulosic materials, ensuring complete elimination of contaminating microorganisms.

After cooling, substrates were inoculated with actively growing *P. ostreatus* mycelium using sterile tools. Agar plugs containing mycelium were transferred directly into the substrate under aseptic conditions.

2.6 Incubation conditions and growth evaluation

Inoculated samples were incubated at 25 °C under controlled conditions. Mycelial growth was monitored over a 22-day period.

The primary response variable was defined as:

- mycelial growth (cm) — measured as the vertical colonization distance within the substrate

Complete colonization of the substrate (i.e., mycelium reaching the bottom of the container) was used as an indicator of optimal substrate performance.

2.7 Statistical analysis and optimization

Experimental data were analyzed using Statgraphics Centurion software. A linear mixture model was applied to evaluate the individual and interactive effects of substrate components on mycelial growth.

Response surface methodology (RSM) was used to identify optimal substrate compositions. Model adequacy was assessed based on statistical significance and goodness-of-fit parameters.

3. RESULTS AND DISCUSSION

3.1 Effect of Nitrogen Availability on Mycelial Growth Kinetics

The growth of *Pleurotus ostreatus* on potato dextrose agar (PDA) was significantly influenced by nitrogen availability, affecting both radial expansion and colony morphology. The growth curves (Figure 1) exhibited a typical sigmoidal pattern, with three distinct phases: lag (Day 1–6), exponential (Day 6–13), and stationary phase (Day 15–22), consistent with established fungal growth behavior (Alexopoulos et al., 1996; Carlile et al., 2001).

Nitrogen-supplemented media resulted in faster and more uniform mycelial expansion compared to nitrogen-deficient controls. Colonies grown with ammonium sulfate reached full plate colonization (~9 cm) by Day 15–18, whereas control samples showed delayed and incomplete growth.

This effect is clearly illustrated in Figure 1, where nitrogen supplementation leads to steeper growth kinetics and reduced variability between replicates. These results confirm that nitrogen is a key limiting factor in early fungal development, as also reported for *Pleurotus ostreatus* (Gao et al., 2013; Laursen, 2018).

From a biochemical perspective, ammonium ions (NH_4^+) represent a readily assimilable nitrogen source, supporting amino acid biosynthesis and hyphal extension through central nitrogen metabolism pathways (Marzluf, 1997). Although final colony diameters were similar, nitrogen supplementation significantly improved colonization rate and structural uniformity, indicating its primary role in accelerating early growth.

Figure 1 clearly illustrates this effect, showing steeper growth curves and reduced dispersion under nitrogen-enriched conditions.

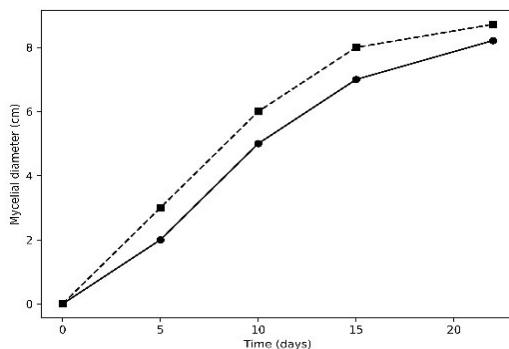


Figure 1. Growth kinetics of *Pleurotus ostreatus* on PDA with and without nitrogen supplementation over 22 days.

3.2 Optimization of Agro-Industrial Waste Substrates

Substrate composition was identified as the primary determinant of mycelial growth and colonization efficiency. A total of 39 substrate combinations were experimentally evaluated as presented in Appendix A; however, Table 1 includes only the most representative and high-performing formulations, selected for detailed analysis.

As shown in Table 1, the highest mycelial growth of 10 cm was achieved in substrates composed of 100% wheat bran, as well as in mixtures of wheat bran and brewery spent grain, particularly at a ratio of 30:70. Similarly, balanced formulations containing both components with minor additions of other substrates also resulted in complete colonization. These results indicate a strong synergistic interaction between wheat bran and brewery spent grain. Wheat bran provides readily available nutrients, while brewery spent grain contributes structural lignocellulosic components and protein-rich residues that support fungal metabolism and enzymatic activity (Mussatto et al., 2006; Aliyu & Bala, 2011). Such complementary effects are consistent with previous studies highlighting the importance of substrate balance in optimizing *Pleurotus* cultivation (Philippoussis et al., 2001; Elisashvili, 2012). In addition, recent research confirms the suitability of brewery spent grain-based substrates for efficient mycelial growth and biomass production (Deschamps et al., 2024; Miśkiewicz et al., 2025). In contrast, the inclusion of coffee waste resulted in a clear reduction in mycelial growth. While lower concentrations were tolerated, higher proportions led to reduced colonization or complete inhibition, as reflected in the experimental data presented in Table 1. This inhibitory effect is attributed to the presence of compounds such as caffeine and phenolics, which can interfere with fungal metabolism and enzymatic processes (Alsanad et al., 2020).

Oat bran exhibited an intermediate effect on mycelial development. Although its inclusion at lower levels supported growth, certain combinations resulted in decreased colonization efficiency. This suggests that excessive incorporation of oat bran may alter substrate structure, aeration, or nutrient availability, thereby limiting hyphal expansion. Similar trends have been reported in studies examining the influence of substrate composition on *Pleurotus ostreatus* growth (Hoa et al., 2015; Soto-Cruz, 1999).

Overall, the results demonstrate that balanced substrate formulation, particularly the combination of wheat bran and brewery spent grain, plays a critical role in maximizing mycelial growth, whereas excessive inclusion of coffee waste or oat bran can negatively affect colonization performance.

Table 1. Effect of agro-industrial substrate composition on mycelial growth of *Pleurotus ostreatus*

Sample	Wheat bran(%)	Brewery spent grains (%)	Oat bran (%)	Coffee waste (%)	Growth (cm)
1	100	0.0	0	0	10
2	30	70	0	0	10
3	42.5	47.5	5	5	10
4	80	0	0	20	9.5
5	30	50	20	0	9.5
6	30	40	10	20	8
7	55	25	20	0	1.5
8	80	0	10	10	0
9	70	0	20	10	0

3.3 Statistical optimization of substrate composition (Statgraphics analysis)

To evaluate interaction effects between substrate components, the experimental data (Appendix 1) were analyzed using **Statgraphics Centurion**, generating 39 substrate combinations and corresponding response surface contour plots. This analysis enabled visualization of optimal and limiting growth regions and provided insight into component interactions .

The contour plot in Figure 2 shows the interaction between wheat bran, brewery spent grain, and coffee waste in the absence of oat bran. The highest predicted growth values (approximately 9–10 cm) occur in regions dominated by either wheat bran or brewery spent grain, while intermediate combinations provide stable growth. Increasing the proportion of coffee waste shifts the response toward lower values, indicating a composition-dependent inhibitory effect. This observation is consistent with reported negative effects of spent coffee grounds on *Pleurotus ostreatus* growth due to bioactive compounds such as caffeine and phenolics (Alsanad et al., 2020).

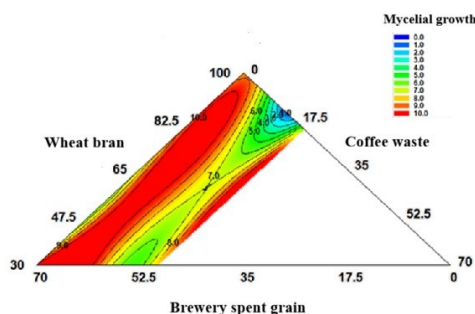


Figure 2. Contour plot showing the effect of wheat bran, brewery spent grain, and coffee waste on mycelial growth in the absence of oat bran.

The response surface in Figure 3, generated in the absence of coffee waste, shows that the inclusion of oat bran modifies the growth response by introducing a broader region of reduced colonization. Nevertheless, zones of high predicted growth are still observed, particularly in formulations enriched with brewery spent grain. This indicates that oat bran does not act as a strictly inhibitory component, but its effect depends on the overall substrate balance, in agreement with previous studies emphasizing the importance of substrate composition in *Pleurotus* cultivation (Hoa et al., 2015; Soto-Cruz, 1999).

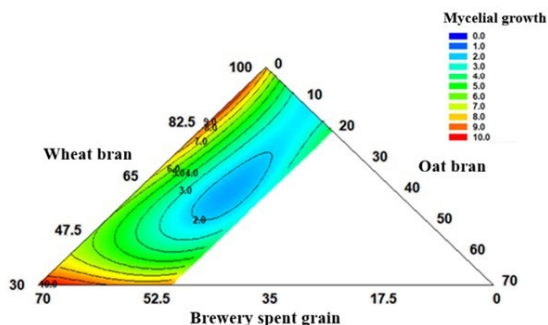


Figure 3. Contour plot showing the effect of wheat bran, brewery spent grain, and oat bran on mycelial growth in the absence of coffee waste.

In Figure 4, where brewery spent grain is excluded, the response surface shows a contraction of optimal growth regions and an expansion of lower-growth zones. Although localized areas of higher predicted growth remain, the system becomes less robust compared to formulations containing brewery spent grain. This confirms the key role of brewery spent grain as a nutrient-rich and structurally supportive component, widely recognized for its suitability in mushroom cultivation (Mussatto et al., 2006; Aliyu & Bala, 2011).

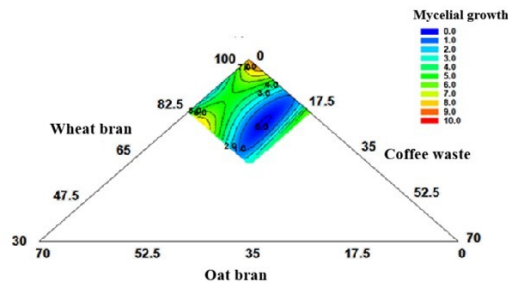


Figure 4. Contour plot showing the effect of wheat bran, oat bran, and coffee waste on mycelial growth in the absence of brewery spent grain.

Overall, the statistical modeling demonstrates that optimal mycelial growth of *Pleurotus ostreatus* is achieved through balanced combinations of wheat bran and brewery spent grain, while the inclusion of coffee waste and oat bran must be carefully controlled to avoid reductions in colonization efficiency.

3.4. Morphological characteristics and practical implications

Morphological observations supported the quantitative growth results. Mycelia grown on nutrient-rich substrates, particularly those containing wheat bran and brewery spent grain, were denser, more compact, and exhibited well-developed hyphal networks. In contrast, colonies grown under nitrogen-deficient or suboptimal substrate conditions appeared thinner and less structured, indicating reduced metabolic activity.

These differences are consistent with the role of nutrient availability in regulating hyphal development and biomass formation (Carlile et al., 2001; Hoa et al., 2015). Substrates combining wheat bran and brewery spent grain likely provided a more balanced nutrient composition, supporting efficient colonization and stable growth.

From a practical perspective, rapid and uniform colonization is essential in mushroom cultivation, as it reduces contamination risk by limiting the available niche for competing microorganisms (Pathmashini et al., 2008). Therefore, both nitrogen availability and optimized substrate composition contribute to improved growth performance, process stability, and scalability.

These findings further support the use of agro-industrial residues as sustainable substrates for *Pleurotus ostreatus* cultivation, contributing to resource valorization within a circular bioeconomy framework (Deschamps et al., 2024; Miśkiewicz et al., 2025).

4. CONCLUSION

Substrate composition significantly influenced mycelial growth of *Pleurotus ostreatus*. Wheat bran and brewery spent grain showed a strong synergistic effect, enabling rapid and complete colonization. In contrast, higher levels of coffee waste inhibited growth, while oat bran showed moderate effects depending on concentration. Statistical modeling confirmed that balanced formulations are essential for optimal performance. The results highlight the potential of agro-industrial residues as sustainable substrates, supporting efficient mushroom cultivation and contributing to circular bioeconomy approaches.

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Appendix A. Mycelial growth of *Pleurotus ostreatus* on different substrate formulations

Sample	Wheat bran (%)	Brewery spent grain (%)	Oat bran (%)	Coffee waste (%)	Growth (cm) – Day 7	Growth (cm) – Day 14
1	100.0	0.0	0.0	0.0	6.5	10.0
2	30.0	70.0	0.0	0.0	6.5	10.0
3	80.0	0.0	20.0	0.0	6.0	10.0
4	30.0	50.0	20.0	0.0	5.5	9.5
5	80.0	0.0	0.0	20.0	4.3	9.5
6	30.0	50.0	0.0	20.0	3.5	8.0
7	60.0	0.0	20.0	20.0	4.0	8.0
8	30.0	30.0	20.0	20.0	3.0	8.0
9	77.5	12.5	5.0	5.0	3.0	8.5
10	42.5	47.5	5.0	5.0	5.0	10.0
11	67.5	12.5	15.0	5.0	4.5	10.0
12	42.5	37.5	15.0	5.0	4.7	10.0
13	67.5	12.5	5.0	15.0	1.0	4.0
14	42.5	37.5	5.0	15.0	3.0	10.0
15	57.5	12.5	15.0	15.0	1.0	3.0
16	42.5	27.5	15.0	15.0	1.5	5.0
17	65.0	35.0	0.0	0.0	2.2	8.0
18	90.0	0.0	10.0	0.0	0.0	0.0
19	90.0	0.0	0.0	10.0	0.0	0.0
20	30.0	60.0	10.0	0.0	3.3	10.0
21	30.0	60.0	0.0	10.0	4.2	10.0
22	55.0	25.0	20.0	0.0	1.0	1.5
23	80.0	0.0	10.0	10.0	0.0	0.0
24	70.0	0.0	20.0	10.0	0.0	0.0
25	30.0	50.0	10.0	10.0	4.5	10.0
26	30.0	40.0	20.0	10.0	4.0	10.0
27	55.0	25.0	0.0	20.0	3.0	10.0

Sample	Wheat bran (%)	Brewery spent grain (%)	Oat bran (%)	Coffee waste (%)	Growth (cm) – Day 7	Growth (cm) – Day 14
28	70.0	0.0	10.0	20.0	0.0	0.0
29	30.0	40.0	10.0	20.0	3.0	8.0
30	45.0	15.0	20.0	20.0	0.0	0.0
31	30.0	60.0	10.0	0.0	0.0	0.0
32	30.0	60.0	0.0	10.0	2.5	8.0
33	80.0	0.0	10.0	10.0	1.5	9.0
34	30.0	50.0	10.0	10.0	7.0	10.0
35	50.0	20.0	20.0	10.0	5.3	10.0
36	50.0	20.0	10.0	20.0	4.5	10.0
37	100.0	0.0	0.0	0.0	2.5	8.0
38	30.0	70.0	0.0	0.0	7.0	10.0
39	80.0	0.0	20.0	0.0	–	–

MISSION AND PERSPECTIVE OF THE SCIENTIFIC COMMITTEE ON THE TOPICS OF THE PROCEEDINGS

The Proceedings of the Second International Scientific-Agrobusiness Conference “AGRO MAK 2026” are devoted to the theme “Local Resources and Global Challenges: Integrated Approaches to Sustainable Rural Development in the Era of Climate Change”, providing a rigorous, multidisciplinary examination of contemporary development trajectories within agriculture and rural systems.

This volume underscores the critical necessity of aligning endogenous rural development potentials with overarching global challenges, notably climate change, which constitutes a primary determinant in the resilience and sustainability of rural livelihoods. The collection comprises 29 scholarly contributions, including 8 invited papers and 21 peer-reviewed submissions, reflecting a high standard of scientific inquiry and methodological diversity.

The contributions systematically explore integrated approaches that interconnect agriculture, food systems, rural tourism, education, and advanced technological applications, with the objective of strengthening the socio-economic sustainability and adaptive capacity of rural communities. Particular emphasis is placed on the strategic valorization of local resources—natural, economic, and socio-cultural—as foundational elements for the creation of competitive and enduring development models.

Furthermore, the volume addresses mechanisms for responding to contemporary challenges through innovation, digitalization, and cross-sectoral collaboration, demonstrating that the convergence of multiple sectors—including organic and functional food production, information and communication technologies, and rural tourism—represents a decisive pathway toward sustainable rural development. In this context, education and scientific research are pivotal in generating actionable knowledge, evidence-based solutions, and policy frameworks tailored to emerging socio-environmental and economic realities.

The proceedings also highlight the indispensable role of coordinated engagement among academia, industry, and policy-makers to optimize the utilization of local and regional potentials. The Southeast European region, with particular attention to the Republic of North Macedonia, possesses considerable resources capable of serving as a catalyst for inclusive and resilient rural development.

By presenting empirically grounded analyses, comparative studies, and innovative approaches, this volume contributes significantly to the advancement of scholarly discourse, the dissemination of best practices, and the formulation of evidence-based policy interventions. It serves as a substantial resource for researchers, practitioners, and decision-makers engaged in shaping sustainable rural futures.

I wish to extend my deepest gratitude to all contributing authors, peer reviewers, and conference organizers for their unwavering commitment to scientific excellence and for enhancing the intellectual rigor of this publication.

Chairperson of the Scientific Committee

Prof. PhD. Saša Stepanov
Agro-Mak 2026

APPENDIX

Appendix A: Authors - co-authors in alphabetical order

(Прилог A: Автори - коавтори по азбучен ред)

No. R. Br.	AUTOR - KOAUTOR		AUTOR - KOAUTOR
	A		R
1.	Aljić Merima	36.	Ristić Ivan
	B		P
2.	Blazhevska Tatjana	37.	Pandurević Juliana
3.	Bardakovski Zoran	38.	Pavlovska Gorica
4.	Boshkovska Diana	39.	Petković Todor
5.	Biočanin Rade	40.	Petković Mirko
6.	Bataveljić Dragan	41.	Petkoska Trajkovska Anka
	V		S
7.	Velkovski Valentina	42.	Samet Aksu
8.	Vasiljević Saša	43.	Selamovska Ana
9.	Vasiljević Jovan	44.	Selamovski Filip
10.	Valjarević Aleksandar	45.	Stojanov Popovska Despina
	G	46.	Stepanov Saša
11.	Garić Ratko	47.	Stepanov Nemanja
12.	Georgievich Grigulecki Vladimir	48.	Skamarokhova Alexandra Sergeevna
	D	49.	Stojanoski Aleksandar
13.	Dimkovski Pavlovska Martina	50.	Selamovski Filip
14.	Dimitrovski Darko	51.	Selamovska Katerina
15.	Dimitrov Lazo	52.	Shyian Anatolii
16.	Daniloska Natasha	53.	Shapcheska Doneva Donka
17.	Dabić Ljubiša		T
18.	Damjanović Stefan	54.	Taseska-Gjorgijevski Milena
19.	Dzinevski Leonid	55.	Tahiraj Xhevdet
	Đ	56.	Todorovski Aleksandar
20.	Đorđević Milan	57.	Trifunović Hadži Dušan
	I		Č
21.	Ivanović Miroljub	58.	Čosić Milivoje
	J		H
22.	Jugović Zorka	59.	Haliti Arben
23.	Jovanović Stanić Sara		C
24.	Jakovljević Radović Marina	60.	Cvetković Dragan
25.	Jankovski Despina Kostadinova		
	K	61.	Cvetkovik Gavrilovska Blagica
26.	Kovachevikj Gjoshеva Marija		Č
27.	Krsteovski Aleksandar	62.	Čabilovski Đorđe
28.	Krsteovski Olivera	63.	Čavar Lucija
29.	Knights Vesna		Š
	L	64.	Šević Đeković Milica
30.	Lučanović Paun		
31.	Lutovac Mitar		
	M		
32.	Mijač Dodevska Maja		
33.	Matejić Tijana		
37.	Miladinovski Sreten		
35.	Milenkovski Ace		

Appendix B: Authors – Participating Countries
(Прилог Б: Автори – земји учеснички)

No. (Р. Бр.)	Countri (Земја)	Number of authors (Број на автори)
1.	Serbia	10
2.	North Macedonia	9
3.	Russia	3
4.	Ukraine	2
5.	Canada	1
6.	Croatia	1
7.	Sweden	1
8.	BiH	1
9.	Bulgaria	1
10.	South Korea	1
11.	Montenegro	1
12.	Kosovo*	1
	Totally (Целосно)	32

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