12. JEEP MEĐUNARODNA NAUČNA AGROBIZNIS KONFERENCIJA-MAK 2025
12th JEEP INTERNATIONAL SCIENTIFIC AGRIBUSINESS CONFERENCE-MAK 2025
„Climate change and ecological sustainability in agriculture and food production in Serbia, the region and Southeast Europe"
SERBIA, KOPAONIK January 30th to February 2nd, 2025.

doi:10.46793/MAK2025.090S

RENEWABLE ENERGY AND AI IMPLEMENTATION AS SUSTAINABLE STRATEGY FOR AGRICULTURE RESILIENCE TO CLIMATE CHANGE

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Abstract: Climate change has a major impact on all human activities. One of the most important is agriculture from the point of view of food production, as the starting point of survival on the globe. The negative consequences of climate change are reflected in increasingly pronounced droughts and catastrophic floods, and are also reflected in the increase in the frequency of these extremes. Multidisciplinary teams of engineers and scientists are engaged in the development of sustainable strategies, with the aim of increasing the resilience of agriculture to climate change. The application of renewable energy sources and artificial intelligence plays a significant role in the management of sustainable strategies for the protection and improvement of smart agriculture. Wind turbines and photovoltaic panels raised above agricultural land at an appropriate distance form a synergy of agricultural development and renewable energy. Their implementation in itself reduces the emission of greenhouse gases and contributes to mitigating climate change. At the same time, this energy can be used both in the system and locally for pumping water for irrigation. Hydropower and the construction of water acumulations also provide increased opportunities for solving droughts and floods and thereby improving and stabilizing agricultural production and higher resilience of agriculture to climate change. Agricultural residues can be used as a resource for renewable bioenergy. Artificial intelligence, supported by contemporary solutions of sensor technology, helps us in the optimal management of all these complex processes. This research also contains a positive case studies from international practice on the implementation of renewable energy sources and artificial intelligence and their concrete contribution to increasing the resilience of agriculture to climate change.

Key words: Sustainability, Climate Change, Smart Agriculture, Renewable Energy, Artificial Intelligence.

1. INTRODUCTION

Addressing the challenges posed by the climate crisis is one of the most critical issues facing modern society. Agriculture, as one of the most vital economic sectors (Islam et al., 2024), is particularly vulnerable to the impacts of climate change, which manifest through reduced yields, soil degradation, extreme weather conditions, and food supply instability. To enhance the resilience of agriculture to these changes, it is essential to adopt innovative and sustainable strategies that integrate renewable energy sources and advanced technologies such as artificial intelligence (AI).

The concept of "smart agriculture" is based on the integration of modern technologies that enable resource optimization, increased production efficiency, and reduced environmental impact. The use of renewable energy sources, such as solar and wind power (Kassem et al., 2024), contributes to the sustainability of production systems, while the implementation of AI provides real-time precision management of agricultural processes (Elufioye et al., 2024). The incorporation of sensor technology (Morchid et al., 2024) into agricultural practices facilitates the collection of data on soil conditions, weather patterns, and crop needs, enabling informed decision-making and mitigating the risk of losses.

Sustainable agriculture in the era of climate change requires a holistic approach that combines ecological, technological, and social dimensions . The use of renewable energy not only reduces greenhouse gas emissions but also promotes energy independence in rural areas (Wang et al., 2024a,b). On the other hand, AI offers the ability to forecast climate patterns, optimize irrigation, manage pests, and develop resilient crop varieties (Fuentes-Peñailillo et al., 2024). This synergy of technologies has the potential to transform agriculture into a sustainable and adaptive system capable of addressing the challenges of the 21st century.

This paper explores the possibilities of applying renewable energy and artificial intelligence as key components of a strategy to enhance agriculture's resilience to climate change. The focus is on analyzing contemporary technological solutions, their implementation in agricultural practices, and their potential benefits for sustainability and economic development. Additionally, the paper examines the challenges and limitations of adopting these technologies, as well as the prospects for their broader application across diverse agroecological conditions.

By combining scientific insights and practical examples, this study aims to contribute to the development of sustainable agricultural models that ensure food security and the preservation of natural resources in the context of global climate change.

2. METHODOLOGY

This manuscript summarizes the results of the latest research in the field of agriculture resilience to climate change by renewable energy and artificial intelligence implementation. The research in this paper is based on desk research and literature review, with case study methodology of the positive world practice.

The goal is to answer the following questions from the perspective of the sustainable strategy management development and smart agriculture resilience strengthening to climate change:

- What are the main environmental, economic and scientific challenges associated with climate change's impact on agriculture?
- How do changes in energy policies affect the agriculture resilience to climate change?
- What are the newest strategical innovations in agriculture that are sustainable?
- How sensor technology implementation can improve the benefits of smart agriculture?
- How artificial intelligence implementation can support agriculture resilience to climate change
- What are the best representative case sudies in the world relating to renewable energy implementation in agriculture?
- What are the best representative case sudies in the world relating to artificial intelligence implementation in agriculture?

The methodological holistic approach to the research in this manuscript includes a complex and organized procedure, starting from criteria of sustainability and principles according to established questions and phases. For the purpose of finalizing this research, the following general and special scientific methods are used:

- Systematized data collection and analysis of the latest existing, world-recognized scientific results in the field of assessment and management of agriculture resilience to climate change, strategic management, environmental protection, and sustainable development.

– Methods of induction and deduction, analysis and synthesis, as well as the method of analogy.
– The collected data are processed using statistical methods using Microsoft Excel and IBM SPSS Statistics 24 software packages.

This manuscript is organised within four chapters as IMRAD structures of writing. The thirth chapter encompass results and discussion, organized in five subchapters.

3. RESULTS AND DISCUSSION

3.1. Energy and resources policy supporting agriculture resilience to climate change

Energy policies supporting the resilience of agriculture to climate change play a crucial role in ensuring sustainable agricultural production. One innovative approach is the application of **agrivoltaics**, a technology that combines solar panels with agricultural activities. Agrivoltaics enable efficient land use, where solar panels provide shade and reduce evapotranspiration while simultaneously generating electricity. This technology shows significant benefits in arid regions where soil moisture conservation is critical (Luo et al., 2024).

Wind turbines in agriculture represent another example of successful integration of renewable energy sources. Agricultural farms with favorable wind energy potential can utilize wind farms to produce energy needed for irrigation, storage, and product processing. Implementing such solutions reduces dependency on fossil fuels and increases the economic resilience of farms (Borusevich and Pisarek, 2024).

Hydropower and water reservoirs also contribute to the stabilization of agricultural systems. Reservoirs not only supply water for irrigation but also serve as reserves during drought periods and as protection from the floods. Hydropower generated from these systems can support local infrastructure, reducing energy costs for farmers. Water is esencial resource for agriculture (Schmitt and Rosa, 2024). Its cycle is showen in Figure 1.

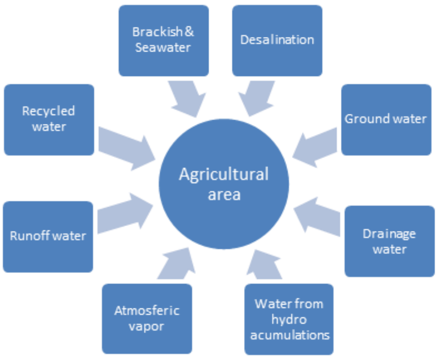

Figure 1. Integration of irrigation cycle into the natural water cycle

Bioenergy, derived from agricultural production residues such as crop leftovers and manure, represents another key component in the energy transition. Biogas plants convert waste into renewable energy while simultaneously reducing methane emissions into the atmosphere. In this way, bioenergy not only helps mitigate climate change but also enhances the circular model of resource management (Toplicean and Datcu, 2024).

Various energy policies support the implementation of these technologies through subsidies, tax incentives, and research programs. For example, the European Union, through its Green Deal, encourages the use of renewable energy sources in agriculture, while national programs worldwide offer additional incentives (Boix-Fayos and de Vente, 2023).

3.2. The newest strategical innovations in agriculture that make agriculture sustainable

The latest strategic innovations in agriculture are aimed at achieving sustainability through the use of advanced technologies and methods. One such innovation is **precision agriculture**, which utilizes sensors, satellite imagery, and IoT technology to monitor crop and soil conditions in real time. This technology allows for the optimization of water, fertilizer, and pesticide usage, contributing to a reduced ecological footprint and increased yields (Wang et al., 2024a,b).

Vertical farms offer a solution for food production in urban areas. These farms use led lighting, hydroponic and aeroponic systems to grow plants without the need for large agricultural areas. Efficient resource utilization, such as water and energy, makes vertical farms an ideal model for future agriculture under resource-limited conditions (Zhou, 2024).

The use of drones for monitoring agricultural areas is becoming increasingly common. Drones can quickly and accurately identify issues such as pests, diseases, and uneven water distribution, enabling timely responses and reducing (Das, 2024).

Genetically improved crops, resistant to drought and pests, play a crucial role in addressing the challenges of climate change. Developing plant varieties that require less water and chemical treatments contributes to both economic and ecological sustainability (Kumar et al., 2024).

Digital platforms that connect farmers with markets enable more efficient production and distribution planning. These platforms provide information on prices, weather conditions, and cultivation techniques, contributing to better resource management and waste reduction (Arun and Mishra, 2024).

3.3. Sensor technology implementation in smart agriculture

Sensor technology is at the heart of smart agriculture, enabling precise and efficient management of resources. Sensors are used to measure various parameters such as soil moisture, temperature, pH levels, and nutrient content, allowing farmers to make data-driven decisions.

Example 1: A vineyard in Chile uses soil moisture sensors connected to an IoT platform (Fuentes-Peñailillo et al., 2023). The sensors provide real-time data, enabling precise irrigation only when the soil moisture drops below a critical threshold. This approach conserves water and enhances grape quality.

Example 2: In Bangladesh, rice paddies equipped with temperature and humidity sensors monitor microclimatic conditions (Islam et al., 2024). Data from these sensors alerts farmers about potential fungal infections, enabling timely intervention and reducing crop losses.

Furthermore, **weather stations** equipped with sensors predict local weather patterns, assisting in the planning of planting and harvesting activities. Combined with GPS-guided machinery, these innovations significantly improve efficiency (Vellingiri et al., 2025).

The integration of sensor technology also supports **automated systems**, such as fertigation units, which dispense fertilizers based on real-time nutrient levels detected by sensors. This reduces over-application and minimizes environmental pollution (Taseer and Han, 2024).

3.4. Artificial intelligence that makes smart agriculture smarter

Artificial intelligence (AI) is revolutionizing smart agriculture, enabling farmers to optimize processes, reduce resource consumption, and enhance productivity. By analyzing vast amounts of data collected from sensors, drones, and satellite imagery, AI provides actionable insights that were previously unattainable. Machine learning algorithms, for example, can predict crop yields, detect diseases at early stages, and recommend precise interventions, thereby minimizing losses and improving quality (Attri et al., 2024).

One transformative application of AI is **predictive analytics**. By integrating historical weather data, soil conditions, and market trends, AI-powered systems enable farmers to make informed decisions about planting, harvesting, and distribution. These insights help mitigate risks associated with climate variability and market fluctuations (Jeffrey and Bommu, 2024).

AI also enhances **robotics in agriculture**, automating labor-intensive tasks such as weeding, pruning, and harvesting. Autonomous machines, guided by AI vision systems, can distinguish between crops and weeds, ensuring precision and reducing the need for herbicides. This approach not only increases efficiency but also promotes environmental sustainability. A study by (Arockia Doss et al., 2024). showcased the financial benefits of robotics in strawberry harvesting. A robotic harvester equipped with advanced AI and vision systems was deployed on a commercial strawberry farm. The system was capable of picking strawberries with 90% accuracy at a rate of 25.000 fruits per day. Compared to manual labor, which typically achieves 15.000 fruits per day per worker, the robot demonstrated a significant productivity increase. Financially, the robotic system reduced labor costs by 40%, saving approximately $ 7.500 per hectare annually while maintaining consistent harvest quality. This example highlights the economic potential of robotics to revolutionize labor-intensive agricultural practices, ensuring both efficiency and profitability.

Moreover, **natural language processing (NLP)** assists in bridging the knowledge gap for farmers. AI-driven chatbots and virtual assistants provide real-time advice in local languages, empowering small-scale farmers to adopt advanced practices (Domínguez et al., 2024).

3.5. Environmental, economical, and scientific challenges in future agriculture

The future of agriculture faces a complex interplay of environmental, economic, and scientific challenges that demand innovative solutions. Environmental issues, primarily driven by climate change, include rising temperatures, irregular rainfall, and increased incidence of extreme weather events. These factors disrupt crop cycles, reduce yields, and threaten global food security. Additionally, soil degradation, loss of biodiversity, and water scarcity exacerbate the environmental crisis, limiting the capacity for sustainable agricultural practices (Saleem et al., 2024).

Economically, farmers worldwide confront fluctuating market conditions, rising production costs, and uncertain profitability. The transition to sustainable practices often requires significant initial investments in advanced technologies, such as precision farming tools, renewable energy systems, and resilient crop varieties. For small-scale farmers, accessing these resources remains a considerable challenge, widening the gap between large industrial farms and smaller operations. Moreover, the globalization of food markets exposes farmers to volatile trade dynamics, with shifts in demand and supply chains posing risks to economic stability (Awokuse et al., 2024).

On the scientific front, advancing agriculture necessitates breakthroughs in several domains, including genetics, climate modeling, and data analytics. Developing crop varieties resistant to pests, diseases, and extreme climatic conditions is critical but requires time-intensive research and rigorous testing. Furthermore, the integration of artificial intelligence and machine learning into farming systems is hindered by a lack of standardized frameworks and uneven technological access across regions. Ethical considerations, such as the use of genetically modified organisms (GMOs), also spark debates, slowing the adoption of potentially transformative technologies

Addressing these challenges requires a coordinated approach that combines policy support, public-private partnerships, and grassroots innovation. Governments must incentivize sustainable farming practices and ensure equitable access to technology and markets. Simultaneously, fostering interdisciplinary collaboration among scientists, economists, and environmentalists will drive the development of resilient agricultural systems capable of withstanding future adversities. Through collective efforts, agriculture can evolve to balance environmental sustainability, economic viability, and scientific advancement (Haloui et al., 2024).

4. CONCLUSION

Climate change poses a comprehensive challenge to agricultural production, but it also offers an opportunity for innovation and transformation of traditional approaches. By applying renewable energy sources and artificial intelligence, agriculture has the potential to become more resilient, efficient, and sustainable, ensuring stable food production and the preservation of natural resources.

Renewable energy sources, such as solar and wind power, provide an opportunity to reduce dependence on fossil fuels, directly impacting the reduction of greenhouse gas emissions. This energy transition is particularly significant for rural areas, where decentralized energy solutions can improve energy accessibility and stimulate local development. At the same time, artificial intelligence offers a wide range of applications, from analyzing data collected by sensors, through automated management of agricultural machinery, to optimizing supply chains. When applied synergistically, these technologies enable better-informed decision-making, cost reductions, and increased profitability.

However, the introduction of these innovations also faces certain challenges. The main obstacles include high initial implementation costs, insufficient technical training for farmers, and limited access to infrastructure in some regions. Addressing these issues requires a multisectoral approach, including government support through subsidies and regulatory frameworks, as well as collaboration between the private sector and academia to develop accessible and scalable solutions.

As demonstrated in this paper, the application of renewable energy sources and artificial intelligence in agriculture is not only a technical advancement but also an opportunity to improve the socioeconomic position of rural communities. These technologies can contribute to creating sustainable agroecosystems capable of responding to global challenges posed by climate change.

The transformation of agriculture through the implementation of renewable energy sources and advanced technologies represents a critical step towards building a resilient and sustainable agri-industrial system. Successful practices from around the world show that it is possible to achieve a balance between economic productivity and the preservation of natural resources. Future efforts should focus on adapting these solutions to local needs and broader education of all stakeholders in the agricultural sector to ensure their long-term impact and sustainability.

5. ACKNOWLEDGMENT

The results presented in this manuscript are supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, Contract 451-03-66/2024-03/200213 dated 05.02.2024.

6. REFERENCES

Arockia Doss, A.S., Jeyabalan, A., Rekha Borah, P., Lingampally, P.K., Schilberg, D. (2024). Advancements in Agricultural Automation: A Comprehensive Review of Artificial Intelligence and Humanoid Robotics in Farming. International Journal of Humanoid Robotics, 21(4), 2350012. doi.org/10.1142/S0219843623500123

Arun, D.P., Mishra, A. (2024). Enabling Digital Platforms: Toward Smart Agriculture. In Artificial Intelligence Techniques in Smart Agriculture. Singapore: Springer Nature Singapore, 237-251.

Attri, I., Awasthi, L.K., Sharma, T.P. (2024). Machine learning in agriculture: a review of crop management applications. Multimedia Tools and Applications, 83(5), 12875-12915

Awokuse, T., Lim, S., Santeramo, F., Steinbach, S. (2024). Robust policy frameworks for strengthening the resilience and sustainability of agri-food global value chains. Food Policy, 127, 102714

Boix-Fayos, C., de Vente, J. (2023). Challenges and potential pathways towards sustainable agriculture within the European Green Deal. Agricultural Systems, 207, 103634

Borusevich, A., Pisarek, L. (2024). Impact of small wind turbines on the surrounding and agricultural environment. Український журнал природничих наук, (9), 140-149.

Das, S. (2024). Transforming Agriculture: Harnessing Robotics and Drones for Sustainable Farming Solution. Journal of Experimental Agriculture International, 46(7), 219-231.

Domínguez, A.G., Roig-Tierno, N., Chaparro-Banegas, N., García-Álvarez-Coque, J.M. (2024). Natural language processing of social network data for the evaluation of agricultural and rural policies. Journal of Rural Studies, 109, 103341

Elufioye, O.A., Ike, C.U., Odeyemi, O., Usman, F.O., Mhlongo, N.Z. (2024). Ai-Driven predictive analytics in agricultural supply chains: a review: assessing the benefits and challenges of ai in forecasting demand and optimizing supply in agriculture. Computer Science & IT Research Journal, 5(2), 473-497.

Fuentes-Peñailillo, F., Gutter, K., Vega, R., Silva, G.C. (2024). Transformative technologies in digital agriculture: Leveraging Internet of Things, remote sensing, and artificial intelligence for smart crop management. Journal of Sensor and Actuator Networks, 13(4), 39.

Fuentes-Peñailillo, F., Ortega-Farías, S., Acevedo-Opazo, C., Rivera, M., Araya-Alman, M. (2023). A Smart Crop Water Stress Index-Based IoT Solution for Precision Irrigation of Wine Grape. Sensors, 24(1), 25.

Haloui, D., Oufaska, K., Oudani, M., El Yassini, K. (2024). Bridging Industry 5.0 and Agriculture 5.0: Historical Perspectives, Opportunities, and Future Perspectives. Sustainability, 16(9), 3507

Islam, M.H., Anam, M.Z., Hoque, M.R., Nishat, M., Bari, A.M. (2024). Agriculture 4.0 adoption challenges in the emerging economies: Implications for smart farming and sustainability. Journal of Economy and Technology, *2*, 278-295.

Jeffrey, L., Bommu, R. (2024). Innovative AI Solutions for Agriculture: Enhancing CropManagement and Yield. International Journal of Advanced Engineering Technologies and Innovations, 1(3), 203-221.

Kassem, Y., Camur, H., Ghoshouni, E.G. (2024). Assessment of a Hybrid (Wind-Solar) System at High-Altitude Agriculture Regions for achieving Sustainable Development Goals. Engineering, Technology & Applied Science Research, 14(1), 12595-12607

Kumar, S., Singh, D., Mohan, S., Shakya, A., Diwakar, S.K., Yadav, V.K. (2024). Genetically Modified Crops: Resistant to Pest and Environmental Stress: A Review. Journal of Advanced Zoology, 45(2).

Luo, J., Luo, Z., Li, W., Shi, W., Sui, X. (2024). The Early Effects of an Agrivoltaic System within a Different Crop Cultivation on Soil Quality in Dry-Hot Valley Eco-Fragile Areas. Agronomy, 14(3), 584.

Morchid, A., El Alami, R., Raezah, A.A., Sabbar, Y. (2024). Applications of internet of things (IoT) and sensors technology to increase food security and agricultural Sustainability: Benefits and challenges. Ain Shams Engineering Journal, 15(3), 102509

Saleem, A., Anwar, S., Nawaz, T., Fahad, S., Saud, S., Ur Rahman, T., Nawaz, T. (2024). Securing a sustainable future: the climate change threat to agriculture, food security, and sustainable development goals. Journal of Umm Al-Qura University for Applied Sciences, 1-17.
Schmitt, R.J.P., Rosa, L. (2024). Dams for hydropower and irrigation: Trends, challenges, and alternatives. Renewable and Sustainable Energy Reviews, 199, 114439.
Taseer, A., Han, X. (2024). Advancements in variable rate spraying for precise spray requirements in precision agriculture using Unmanned aerial spraying Systems: A review. Computers and Electronics in Agriculture, 219, 108841
Toplicean, I.M., Datcu, A.D. (2024). An Overview on Bioeconomy in Agricultural Sector, Biomass Production, Recycling Methods, and Circular Economy Considerations. Agriculture, 14(7), 1143
Vellingiri, A., Kokila, R., Nisha, P., Kumar, M., Chinnusamy, S., Boopathi, S. (2025). Harnessing GPS, Sensors, and Drones to Minimize Environmental Impact: Precision Agriculture. In Designing Sustainable Internet of Things Solutions for Smart Industries (pp. 77-108). IGI Global.
Wang, J., Sun, X., Zhang, S., Zhang, X. (2024a). Does Addressing Rural Energy Poverty Contribute to Achieving Sustainable Agricultural Development? Agriculture, 14(6), p. 795.
Wang, J., Wang, Y., Li, G., Qi, Z. (2024b). Integration of Remote Sensing and Machine Learning for Precision Agriculture: A Comprehensive Perspective on Applications. Agronomy, 14(9), 1975.
Zhou, Y. (2024). Technological Innovation and Significance of Vertical Farming System in High-Density Urban Areas. In E3S Web of Conferences (Vol. 579, p. 03001). EDP Sciences.