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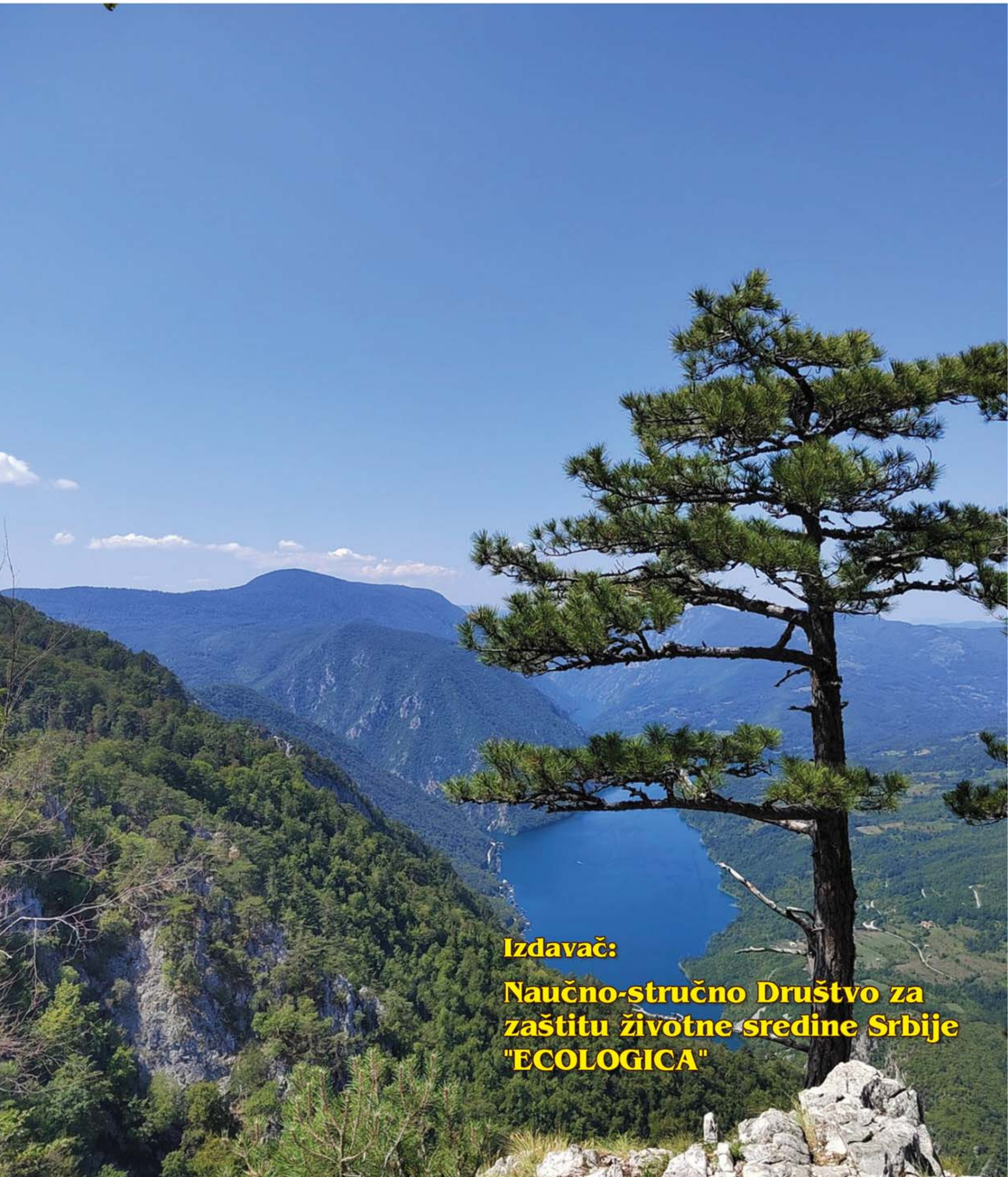

ECOLOGICA

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Под покровитељством
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Припрема Зборник радова:

ИНОВАТИВНИ МЕТОДИ И ВЕШТАЧКА ИНТЕЛИГЕНЦИЈА У ЗАШТИТИ ЖИВОТНЕ СРЕДИНЕ И ПОЉОПРИВРЕДИ

Proceedings of scientific papers
INNOVATIVE METHODS AND ARTIFICIAL INTELLIGENCE IN ENVIRONMENTAL PROTECTION AND AGRICULTURE

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2. Rare metals economy, with special reference to rare earths
3. Use of artificial intelligence to determine the relationship between trace elements in the soil-crop system
4. Role of innovative approaches in solving some environmental protection problems
5. Application of artificial intelligence in environmental protection
6. Artificial intelligence in agriculture: the path towards a green economy and sustainable growth
7. Application of AI in big data analytics in the goal of energy transition: a comparative cost-effectiveness analysis of renewable energy sources versus fossil fuels
8. The field of artificial intelligence application in the economic evaluation of mineral reserves
9. ICP-AES and ICP-MS methods in the analysis of the elemental composition of soils and plants
10. Forecast of the transformation of the ecosystem
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SADRŽAJ / CONTENT

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Dragan Petrović, Zorana Filipova

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SAŽETAK I ABSTRACT

Na početku rada treba dati kratak sadržaj (po pravilu do 200 reči) u Sažetku (na srpskom) i Abstract-u (na engleskom jeziku), kao i ključne reči (keywords) na srpskom i engleskom jeziku.

UVOD / INTRODUCTION

U Uvodnom delu se navode reference radova prethodnika sa kratkim komentarom. Takođe u tom delu treba pomenuti tematski povezane radove autora i koautora predmetnog rada. U Uvodu autori označavaju cilj rada i metodode naučnih istraživanja. Osim diskriptivnih metoda treba navesti metode komparativne analize, a takođe klasične dialektičke metode. U slučaju istraživanja u oblasti prirodnih i tehničkih nauka se primenjuju specijalne instrumentalne metode, gde je neophodna laboratorijska oprema. Statističke metode obrade podataka služe u svim oblastima naučnih istraživanja.

1. MATERIJALI I METODE / MATERIALS AND METHODS

U ovom delu se navodi opis uzoraka koji su uzeti na analizu sa naznakom lokaliteta. Neophodno je navesti oznake opreme, kao i tehnike i metode kojima su obavljene analize. U slučaju originalnih metoda autora treba priložiti opis metoda i opreme.U oblasti društvenih nauka neophodno je napomenuti, šta je predmet istraživanja.

2. REZULTATI I DISKUSIJA / RESULTS AND DISCUSSION

Tabele, slike, grafikoni i dr. mogu da budu u jednoj ili dve kolone. Iznad tabele treba da stoji naziv, npr.

Tabela 1 - Rezultati eksperimentalnih merenja

Ispod ilustracije treba da stoji objašnjenje, npr.: *Slika 1 - Rezultati simulacije procesa*

Nazive tabela i grafikona takođe dati na srpskom i engleskom jeziku.

Formule numerisati rednim brojevima u malim zagradama. Pozivanje na formule u tekstu vrši se navođenjem odgovarajućeg rednog broja u malim (okruglim) zagradama:

$$\overline{R_u} = L_4 + L_3 F_x \left(\frac{\overline{U_{pm}} - \overline{U_{gm}}}{\overline{U_{pm}^2}} \right) \tag{1}$$

U ovom odeljku se takođe vrši upoređenje rezultata koje su dobili autori s podacima iz radova navedenih u spisku referenci, što predstavlja osnovu diskusije.

ZAKLJUČAK / CONCLUSION

U Zaključku se sažeto navode rezultati istraživanja autora predmetnog rada.

Zahvalnica / Acknowledgements

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LITERATURA / REFERENCES

Literatura (skorijeg datuma: 2010. i novija) se u tekstu navodi prezimenom autora i godinom publikovanja: (Petrović, 2019), (Janković, Marković, 2020). U slučaju kad postoji više autora u tekstu se navodi samo prezime prvog autora: (Jovanović i dr., 2020) ili (Johnson et al., 2021). Reference u spisku literature se navode azbučnim (abecednim) redom:

Petrović, S. (2019). *Zaštita vodnih resursa*, Naučna knjiga, Beograd, 403 str.

Smith, G. (2020). Title of the article, *Chem. Phys.*, 65 (4), pp. 19-35.

Svi radovi podležu recenziji, a za originalnost, kvalitet i verodostojnost rezultata odgovorni su isključivo autori.

Pregledni radovi, kao i radovi iz ekonomije, prava, menadžmenta, turizma i dr. mogu imati osim klasičnih podnaslova takođe podnaslove opisnog karaktera.

U sve radove neophodno je uvoditi elemente istraživanja. U radove iz društvenog polja neophodno je uključivati komparativne metode, a takođe analize Studija slučajeva (Case Study).

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Artificial intelligence in the function of sustainable development

Veštačka inteligencija u funkciji održivog razvoja

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Abstract: Artificial intelligence (Artificial Intelligence - AI) is certainly one of the greatest "inventions" of the modern age. It facilitates and improves people's lives, has the potential to respond to social needs, but also brings new challenges and risks. For individuals and a society to catch up with technological development and take advantage of that process, it is important to inform ourselves and learn as much as possible about the different segments of artificial intelligence. The increasing use of artificial intelligence in the 21st century is influencing the social and economic shift towards increased automation, data-driven decision-making and the integration of artificial intelligence systems into various economic sectors and areas of life, affecting the labor market, healthcare, government, industry, ecology and education. Although the field itself is extremely interesting, it is necessary to be fully versed in the capabilities and limitations of artificial intelligence tools and algorithms. The field is constantly developing and improving, so the level of progress is beyond all expectations. The Sustainable Development Goals are still uncertain, as they could either accelerate progress or hinder it. The aim of this work is to help understand the implications of artificial intelligence for business in conditions of rapid technological and social changes in the function of sustainable development. That is why it is important to refresh current knowledge, consult with colleagues from the profession, as well as consult recently published scientific works. AI must serve the moral good of society for its use to be ethical. The dominant example of such essential moral goods are the UN Sustainable Development Goals (SDGs) (United Nations, "The Sustainable Development Goals", 2019). Although AI has a negative impact on some, as part of this set of goals, those with the theme of environmental protection are those goals where AI has the most positive impact, but they are also interesting from the ethical side of artificial intelligence, because they can be understood as something closest to the consensus of humanity in terms of moral goals.

Keywords: artificial intelligence, sustainable development, challenges of the modern age, new technologies, environmental protection.

Sažetak: Veštačka inteligencija (Artificial Intelligence - AI), sigurno je jedan od najvećih „izuma" modernog doba. Ona olakšava i unapređuje život ljudi, ima potencijal da odgovori na društvene potrebe, ali takođe donosi i nove izazove i rizike. Kako bismo i kao pojedinci i kao društvo mogli da uhvatimo korak sa tehnološkim razvojem i iskoristimo prednosti tog procesa, bitno je da se informišemo i saznamo što više o različitim segmentima veštačke inteligencije. Sve veća upotreba veštačke inteligencije u 21. veku utiče na društveni i ekonomski pomak ka povećanju automatizacije, donošenja odluka zasnovanih na podacima i integraciji sistema veštačke inteligencije u različite ekonomske sektore i oblasti života, utičući na tržište rada, zdravstvo, vladu, industriju, ekologiju i obrazovanje. Iako je sama oblast izuzetno interesantna, potrebno je biti potpuno upućen u mogućnosti i ograničenja alata i algoritama veštačke inteligencije. Oblast se konstantno razvija i usavršava, tako da je nivo progresa izvan svih očekivanja. Ciljevi održivog razvoja su još uvek neizvesni, kao što bi mogli ili ubrzati napredak ili ga ometati. Cilj ovog rada je da pomogne kako bi se razumele implikacije veštačke inteligencije na poslovanje u uslovima brzih tehnoloških i društvenih promena u funkciji održivog razvoja. Zato i jeste važno osvežiti trenutna znanja, posavetovati se sa kolegama iz struke kao i konsultovati nedavno objavljene naučne radove. AI mora da služi za moralno dobro društva da bi njena upotreba bila etična. Dominantni primer takvih suštinskih moralnih dobara su ciljevi održivog razvoja UN (SDG, Sustainable Development Goals) (United Nations, "The Sustainable Development Goals", 2019). Iako AI ima negativan uticaj na neke, kao deo ovog skupa ciljeva, oni sa temom zaštite životne sredine su oni ciljevi gde AI ima najpozitivniji uticaj, ali su i zanimljivi sa etičke strane veštačke inteligencije, jer se mogu shvatiti kao nešto najbliže konsenzusu čovečanstva u smislu moralnih ciljeva.

Ključne reči: veštačka inteligencija, održivi razvoj, izazovi modernog doba, nove tehnologije, zaštita životne sredine.

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INTRODUCTION

What is AI (AI - Artificial Intelligence), where and how is it applied, what possibilities does it open for us, what is its future? Artificial intelligence is the intelligence of machines or software, as opposed to the intelligence of living beings, primarily humans. The goal of artificial intelligence research is the development of programs (software) that will enable computers to behave in a way that could be characterized as intelligent. The first research is linked to the very roots of computing. The idea of creating machines that would be capable of performing various tasks intelligently was a central preoccupation of computer scientists who chose to study artificial intelligence.

While in the past artificial intelligence was seen only in science fiction and movies, today it is part of our everyday life, involved in solving complex cognitive problems related to human intelligence, helping people find smart solutions (starting from mobile phones or healthcare, to recognizing problems in order to create solutions for better technology, people, and society). The main goal of AI has always been the creation of machines that can think like humans. AI is increasingly used in business and industry and has the potential to revolutionize many aspects of our lives, including search and discovery, learning, communication, and work (Goralski & Tan, 2020).

The use of artificial intelligence is rapidly transforming various fields such as administrative business, corporate practice, and government policy. With its deep learning capabilities, equipped machines and robotics with artificial intelligence have brought significant opportunities, but also disruptions, as well as greater trends in global sustainability. The AI revolution could lead to a positive future, where machines and humans coexist in harmony, or to a negative path, a path of conflict, poverty, and suffering. The goals of sustainable development are still uncertain, as they could either accelerate progress or hinder it. The aim of this paper is to help understand the implications of artificial intelligence in business in conditions of rapid technological and social change.

The use of AI is becoming increasingly widespread in the business and industrial sectors, and it can transform the way we work, communicate, live, learn, and discover. This technology has significant potential for society and the economy. In addition, with the emergence of the era of sustainable development, where Sustainable Development Goals (SDG) shape global development priorities, AI creates new opportunities in corporate practice, government policy, and administrative business. Machines and robots are advanced deep learning capabilities that solve cognitive problems previously thought to require only human intelligence. According to Jeffrey Sachs, the world is entering a new era of sustainable development in which nations must work together to address issues such as poverty, economic injustice, and environmental degradation. He proposes a framework for sustainable development based on four pillars: economic development, social development, environmental protection, and good governance, all of which are essential and mutually reinforcing (Sachs, 2015).

AI is gradually taking over certain areas of expertise, offering greater predictive power, efficiency, and better outcomes. The growth of AI will create advantages in intellect and finance for certain cities and countries, while others will lag. The expansion of AI already surpasses the development and implementation of legal and regulatory frameworks designed to govern it (Sharma et al., 2022). As technologies in areas such as computer vision, robotics, and speech recognition advance, scientists, businesspeople, government officials, and policymakers are increasingly concerned about the potential for AI to replace human workers, automate warfare, and surpass human intelligence.

While people in developed countries may be concerned about job loss due to artificial intelligence, those in low-income countries may see it to break the cycle of poverty. The growth of AI is happening rapidly and globally, and no one will be able to avoid its impact (Concepcion et al., 2019). The academic community will play a key role in preparing future business leaders and policymakers for the positive and negative impacts of artificial intelligence, who must be well educated and trained to be ready for a rapidly changing world.

1. ARTIFICIAL INTELLIGENCE IN THE ERA OF SUSTAINABLE DEVELOPMENT

We are currently situated within the Fourth Industrial Revolution, a transformative era in which artificial intelligence plays a pivotal role. Industrial revolutions represent periods of rapid innovation that fundamentally alter the tools we use, leading to significant shifts in labor markets and everyday life. In recent years, the scope of AI applications has expanded dramatically, encompassing domains such as industrial process automation, widespread integration in the IT sector, and growing influence across science, medicine, economics, and law.

An overview of key AI application areas within the IT sector, along with their interrelations, is presented in Figure 1.

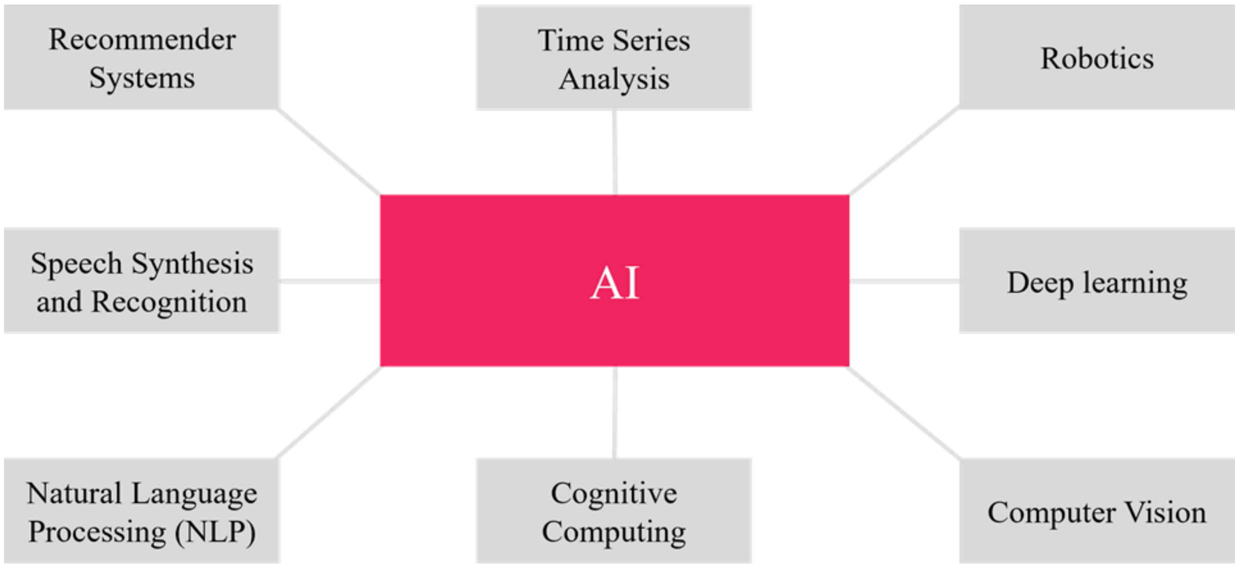

Figure 1. Examples of areas in which artificial intelligence is used - Serbian IT sector

The possibility of developing a similar creation has sparked human interest since ancient times; however, it was only in the second half of the 20th century that such a possibility received its first tools (computers), opening the path for that endeavor (Sachs, 2015). AI represents an opportunity both for startups and for already established companies. The zero prerequisite is the existence of adequately educated experts in this field, which has been partially addressed through the introduction of relevant university courses and master's programs in AI. Another limitation is the specialized infrastructure often required for processing large volumes of data used in AI. With the development of so-called cloud computing, a large initial investment in infrastructure supporting AI models is no longer necessary to compete with more developed countries.

Today, even small children interact with artificial intelligence through educational software (learning to read and perform simple math tasks before entering kindergarten). Therefore, the use of AI in the classroom is not surprising; rather, it is accepted as part of the learning process. AI already influences education by enabling students' easier access to information through search engines such as Google and Amazon. It is expected that soon, it will play an even more significant role in education and in transforming the entire structure of formal and informal learning, with educational content and exercises using artificial intelligence as a teacher on the Internet.

In addition, AI is increasingly used as a scientific assistant to students. It is possible that in the future, an artificial intelligence teacher will replace the human teacher; humans are necessary, but we must also develop an education system that supports adaptability to changes in society and the environment. Although there are potential risks and challenges associated with the use of AI in education, considering the extent to which children already interact with artificial intelligence and the ease with which they do so, it is likely that they will not find it unnatural to assimilate the idea of artificial intelligence into educational curricula.

Why is it important for the average citizen to understand the ideas and applications of AI? In addition to general literacy in an era where technology is becoming an inseparable part of the present, we will increasingly encounter AI in professional contexts, even in occupations seemingly far removed from the IT sector. Just as other technological disciplines have clearly defined legal frameworks - such as building regulations or food quality standards - it is now becoming increasingly evident that AI must also be subject to a form of review to ensure the protection of users and their data.

Some have identified problems and proposed solutions related to global sustainability, but the impacts of artificial intelligence on achieving sustainable development still need to be thoroughly examined. The most important areas of research include data processing, pattern recognition across various fields of knowledge, and applied domains such as medicine. Some people see the increased use of AI as a promising sign of improved economic prosperity and more free time, while others warn that it could worsen global economic inequalities and create existential threats to humanity.

Artificial intelligence research is focused on the following components of intelligence: learning, reasoning, problem-solving, perception, and understanding natural language. However, some fear that taking a step further - the creation of superintelligence far more intelligent than human beings - could lead to great dangers that would vastly surpass our own mental capabilities ("Superintelligence"). This goes beyond "general artificial intelligence" and describes an entity with abilities that even the most gifted human minds could not match - or perhaps even imagine.

Since we are currently the most intelligent species on Earth and use our own brains to control the planet, this raises the question of what will happen if we create something smarter than ourselves, or whether artificial intelligence could wipe out humanity ("X-risk"). Some researchers and technologists believe that artificial intelligence has become an "existential risk," alongside nuclear weapons and biological pathogens, and that its further development must be regulated, limited, or even halted.

As with any other world-changing technology, there are questions regarding potential risks and downsides, such as factual inaccuracies ("Hallucination" - sometimes, if you ask artificial intelligence a question, it will respond with great confidence, but the facts it presents may be false) or hidden biases ("Bias" - for artificial intelligence to learn, it must learn from us). Unfortunately, humanity is not free from prejudice. If artificial intelligence acquires capabilities from a dataset that leans in a particular direction - for example, regarding race or gender - then it has the potential to produce inaccurate, offensive stereotypes. Another risk is the fact that AI is controlled by a small group of private tech companies.

Imagine an artificial intelligence whose highest priority is to produce as many paperclips as possible. If that artificial intelligence were superintelligent and misaligned with human values, it might reason that if it were ever shut down, it would fail in its goal… and therefore would resist any attempt to do so - Instrumental convergence. As executives and politicians race to place their companies and countries at the forefront of AI development, technology may evolve too quickly for necessary safeguards, appropriate regulation, and resolution of ethical dilemmas to be established (Iafrate, 2018). However, AI could also introduce a new cycle of sustainable industrial innovation, as it has the potential to be a powerful force that could lead to economic growth, which is one of the four pillars of sustainable development (Brynjolfsson & McAfee, 2014).

There are two main types of artificial intelligence: Narrow Artificial Intelligence (NAI) and Artificial General Intelligence (AGI). NAI is currently the weaker form of AI and encompasses all current AI technologies. AGI remains theoretical but is rapidly becoming feasible as its applications continue to expand (Bughin et al., 2017). High-Level Machine Intelligence (HLMI) is a subset of AGI that has the potential to perform as effectively as highly gifted humans in all intellectual tasks. This type of AI raises concern among some people, as it could eventually surpass the human species as the dominant species on the planet, not just in terms of short-term employment. These pioneers aim to create a database called OpenCog, which would collect knowledge from all bio-humanoid robots and distribute it evenly.

AGI could potentially eliminate jobs on a large scale due to improved production and distribution efficiency, while NAI is already causing significant job losses and disruptions in established professions - the number of people employed in retail dropped from 600 to 2 by 2017 due to advances in NAI (cashiers). These powerful forces would impact industry, innovation, and infrastructure. Uneven distribution of wealth, knowledge, and power would not only be present among individuals but also concentrated in certain countries and cities, leading to even greater global inequality and hindering progress toward Reducing Inequality. Even tasks that were previously exclusively tied to human capabilities can now be performed faster and more efficiently with the help of AI, resulting in potential job displacement as well as psychological stress for people.

As AI advances, it could potentially surpass human capabilities in various economic roles, leading to significant job displacement. Artificial intelligence experts have published an open letter calling for research into the social impacts and unintended consequences of AI. The letter warns of risks from autonomous and uncontrolled weapons, machines that escalate conflicts, and potentially lead to human extinction. Stanford University recently established the Institute for Human Artificial Intelligence (HAI) to bring together experts from various disciplines such as economics, philosophy, ethics, and psychology to study the impact of artificial intelligence on society (Simon, 2019).

2. ARTIFICIAL INTELLIGENCE AND SUSTAINABLE DEVELOPMENT

Artificial intelligence (AI), on the one hand, and sustainable development, on the other, are two topics in which we all have a certain interest. The dominant technological trend of AI is confronted with our obligation to develop and preserve our world in a sustainable way. This paper aims to examine the role of artificial intelligence within the complex global contemporary world in the context of efforts toward sustainable development, as the multi-societal world is burdened by socioeconomic and environmental factors and issues, in comparison with the Sustainable Development Goals (SDG): no poverty; zero hunger; good health and well-being; quality education; gender equality; clean water and sanitation (wastewater); affordable and clean energy; decent work and economic growth; industry, innovation and infrastructure; reduced inequalities; sustainable cities and communities; responsible consumption and production; climate action. All these goals are interdependent and crosscutting in relation to sustainability and sustainable development.

This paper is based on scientific research, as well as interviews with participants-actors from the professional and humanitarian sectors regarding the application of AI in real-world contexts related to sustainable development. The use of artificial intelligence is integrated into the Sustainable Development Goals - SDG (a universal call to action to end poverty, protect the planet, and ensure safety) through trial and error, as well as through sustainable management and leadership programs. In this paper, we present research on two of the most significant initiatives: Smart water management through AI, and AI in agriculture.

The importance of water as a vital resource for human life and progress is indisputable and has been evident for millennia, through the widespread use of water in various industries and households - adequate treatment and transport to meet hygiene and health standards. In recent years, interest has grown in using new technologies to offer sustainable solutions for water treatment, transport, purification, and reuse. Access to clean, safe water is a key component of several sustainable development goals, including those related to equality, agriculture, energy, climate, and technology. (Hill, 2018).

Although there is enough water in the world to meet current needs, distribution and treatment facilities are insufficient. Many communities in developing countries still face water shortages, which negatively affect human health, productivity, economic development, and the environment. This is because several SDGs aim to address issues related to water consumption, production, ecosystems, and the preservation of clean and treated wastewater (sewage - sanitary water). Water resource management at the community, city, and national levels is significant, as are the consequences for our future well-being.

Excessive use of freshwater reserves, contamination of natural-clean water, and degradation of ecosystems that support the food chain have led to long-term risks. Therefore, it is crucial to utilize technological and AI advancements to meet short-term economic needs while ensuring long-term ecological sustainability. The tools used for water management have evolved; smart water and AI-driven management help water utility companies monitor water treatment facilities more efficiently and cost-effectively, while also protecting public health. Because AI can process large volumes of data in real time and continuously adapt, it is an asset for managing water resources in a constantly changing environment. This enables water utility managers to maximize revenue and effectively plan (Karimidastenaei et al., 2022).

By using these new software platforms, they can create and manage dynamically strategic financial operations to significantly improve productivity and reduce costs. The system also includes low-cost sensors and communication networks for monitoring water losses in real time and managing distribution networks. “The power of artificial intelligence unleashes the imagination of our water professionals” is a phrase that emphasizes AI’s ability to combine growth projections with future water availability and infrastructure condition assessments to maximize investment decisions, where system performance depends on the quality of data received and the managers’ understanding of the results.

While AI takes responsibility, human interpretation remains necessary, but as AI improves and becomes more widely used, human involvement may become less significant. The goal of AI is not to be perfect, but to perform better than humans. Although the transition to AI-based water management may present certain challenges and risks, it has the potential to improve productivity, conserve water, and contribute to achieving various global goals, including the SDG for good health and well-being, the SDG for drinking and wastewater sanitation, and others.

The clean water system functions by detecting the shape of molecules under a microscope; it must distinguish between beneficial microbes and harmful bacteria and expand its research to include virus detection. This innovation has profound implications for improving the safety and efficiency of water and sanitation systems on a global level. The AI clean water system can be used in cities around the world, especially those willing to invest in this low-cost innovation. However, there are challenges in fostering partnerships between governments, local officials, and corporate water sources for the adoption and management of this transformative technology. Nevertheless, it has the potential to support the achievement of various

Global Goals, particularly the SDG for good health and well-being, the SDG for water and sanitation, and the SDG for sustainable cities and communities.

Plant Village (Mohameth et al., 2020) is a recognized initiative aimed at identifying plant diseases using an inexpensive smartphone application that can be used by any farmer in the field. By scanning plants with a phone, the app provides a software-based diagnosis of diseases or pests and offers suggestions for technological treatments (Vinuesa et al., 2020). Additionally, the team is building a database capable of recognizing and diagnosing plant diseases through images taken with mobile phones. The database currently contains 150,000 photos of diseased plants, with plans to expand to three million. With the help of AI technology, vast amounts of data can be used to identify patterns and make predictions, which is the core concept of PlantVillage.

Plant diseases and local pests can reduce crop yields by 40 percent or more, even though some crops can survive drought and infertile soil. Currently, the team is offering the photo database free of charge worldwide, but the main goal is to disseminate information as quickly as possible. They realized that the most urgent need is for plant-related information to reach people seeking advice, since images of diseased plants have so far been scattered across various databases, making it difficult to access them when a disease is found in the field.

“In low-income countries lacking human and financial capital in fields such as agricultural science, there is an opportunity to use artificial intelligence to help break the cycle of poverty.” This new application of artificial intelligence, which uses locally appropriate and inexpensive mobile phone technologies, has the potential to increase farm system productivity, improve agricultural output, and enhance food production. It provides a form of development assistance that helps bridge the digital divide between rich and poor nations, spreads innovative technological solutions in agriculture, and supports the achievement of several SDGs, including the SDG on reducing hunger, the SDG on industry and innovation, and the SDG on reduced inequalities.

Due to global climate change, forest fires are becoming more frequent, and their consequences are increasingly severe. Previously isolated incidents were now treated as standard occurrences. One modern approach to early fire detection uses AI systems to monitor satellite images of areas of interest for forest fire detection. AI also has significant potential for efficient waste management, segregation, and recycling to reduce resource consumption.

CONCLUSION

Throughout this paper, we have seen that AI technology is both powerful and elusive. Contemporary research on artificial intelligence is oriented toward expert systems. Artificial intelligence, as a concept in a broader sense, refers to the capacity of an artificial creation to perform functions characteristic of human thinking. The potential of artificial intelligence can promote sustainable development, and its contribution is immense, involving various actors and sectors. AI can be a key tool for promoting economic development while also addressing improvements in production and consumption and environmental management.

Innovators and global development champions using AI have made significant progress in industries and sectors such as the preservation of non-renewable resources, the dissemination of knowledge and expertise, bridging global technological gaps, and establishing effective partnerships between governments, the private sector, civil society, and citizens to contribute to global sustainability. The pursuit of global goals and the implementation of the SDGs face significant challenges, including apathy, inertia, ignorance, and a lack of resources and political will from governments and corporations focused on short-term profits. To fight for global sustainability, a range of public and private organizations, national governments, and civil society must dedicate all available resources, including the use of opportunities and technologies made available by AI.

The rise of the SDGs presents a significant opportunity for the emerging artificial intelligence industry. AI has the potential to create intelligent interventions, reduce waste, transform entire industries, and improve connectivity, bringing technological advancement to people around the world. However, these innovations and initiatives may also carry potential risks. AI has both positive and negative implications that must be studied to prevent unintended consequences. Although AI can promote sustainability, it can also exacerbate global issues. Even low-cost innovations, such as those mentioned, require incentives and partnerships among various stakeholders, including governments, corporations, the social community, workers, employers, and the academic community.

When wisely applied to sustainability-focused initiatives, AI can create significant opportunities while simultaneously improving access, efficiency, and connectivity across sectors such as healthcare, education, and agriculture. To be prepared for a future based on artificial intelligence, it is essential for the academic community to prepare future business leaders and policymakers to face the challenges and opportunities offered by AI and its potential to advance global goals. Without proper education and management, individuals, corporations, and governments cannot effectively strive for economic growth and sustainability.

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Increasing continentality of the climate in the polar regions and management of environmental risks

Rast kontinentalnosti klime u polarnim regionima i upravljanje ekološkim rizicima

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Abstract: The article presents methods for managing natural and environmental risks in the conditions of increasing continentality of the climate in the polar regions of gas production. It is shown that natural risks associated with the rise in summer temperatures can manifest themselves in the form of various epizootics. The leading factor in the manifestation of such natural risks are large-scale disturbances of tundra soils, in particular, on the Yamal Peninsula due to overgrazing of reindeer. Against the backdrop of an increase in the continentality of the climate, in recent years, on the territory of the Taz Peninsula, biogeochemical technologies for the reclamation of tundra soils, adaptive to the climatic conditions of the Far North, have been successfully tested, based on methods protected by patents of the Russian Federation.

Keywords: natural risks, environmental risks, climate, biogeochemical technologies, ecosystem reclamation, polar regions.

Sažetak: U radu su predstavljene metode za upravljanje prirodnim i ekološkim rizicima u uslovima sve veće kontinentalnosti klime u polarnim regionima proizvodnje prirodnog gasa. Pokazano je da se prirodni rizici povezani sa porastom letnjih temperatura mogu manifestovati u obliku različitih epizootija. Vodeći faktor u manifestaciji takvih prirodnih rizika su poremećaji tundrskih zemljišta velikih razmera, posebno na poluostrvu Jamal zbog prekomerne ispaše irvasa. U kontekstu povećanja kontinentalnosti klime, poslednjih godina, na teritoriji poluostrva Taz, uspešno su testirane biogeohemijske tehnologije za rekultivaciju tundrskih zemljišta, adaptivne klimatskim uslovima Dalekog severa, zasnovane na metodama zaštićenim patentima Ruske Federacije.

Ključne reči: prirodni rizici, ekološki rizici, klima, biogeohemijske tehnologije, rekultivacija ekosistema, polarni regioni .

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INTRODUCTION

Global surface temperatures in the Earth system have been increasing over the past century. Average warming in 1880-2012 was 0.85 K (with an uncertainty range of 0.65 to 1.06 K), and in 1951-2012 up to 0.72 K (with an uncertainty range of 0.49 to 0.89 K) (Hartmann et al., 2013). According to generally accepted views, the main cause of warming is the anthropogenic greenhouse effect, accompanied and sometimes compensated by other anthropogenic and natural influences and internal variability of the climate system (see, for example, (Bindoff et al., 2013)).

However, the rise in global temperatures has now slowed significantly. In Fig. 1 shows that the global temperature was practically constant for 8 years and 4 months, varying by 0.2°C from the 1991 level taken as the standard. This may be due to weakening of the North Atlantic Oscillation (NOA), cooling of the North Atlantic and associated global temperature changes, such as between 1950 and 1970 (Omrani et al., 2022).

However, there are several alternative hypotheses about the nature of the observed climate changes. In contrast to the highly politicized alarmist position supported in many media, according to many researchers, the main contribution to its formation is made by natural (non-anthropogenic) factors (Soon et al., 1996; Cioccale, 1999; Dahl-Jensen, 1998; Dean & Schwalb, 2000; Grove & Switsur, 1994; Hong, 2000; Huang et al., 1997; Forecasting Climate Change, 2016).

One widely used argument in support of these hypotheses is the time lag between changes in global temperature T and atmospheric carbon dioxide qCO_2 obtained from Antarctic ice cores: according to these data, changes in qCO_2 lag behind changes in T by several centuries (Bezverkhny, 2014; Scholar et al., 2012).

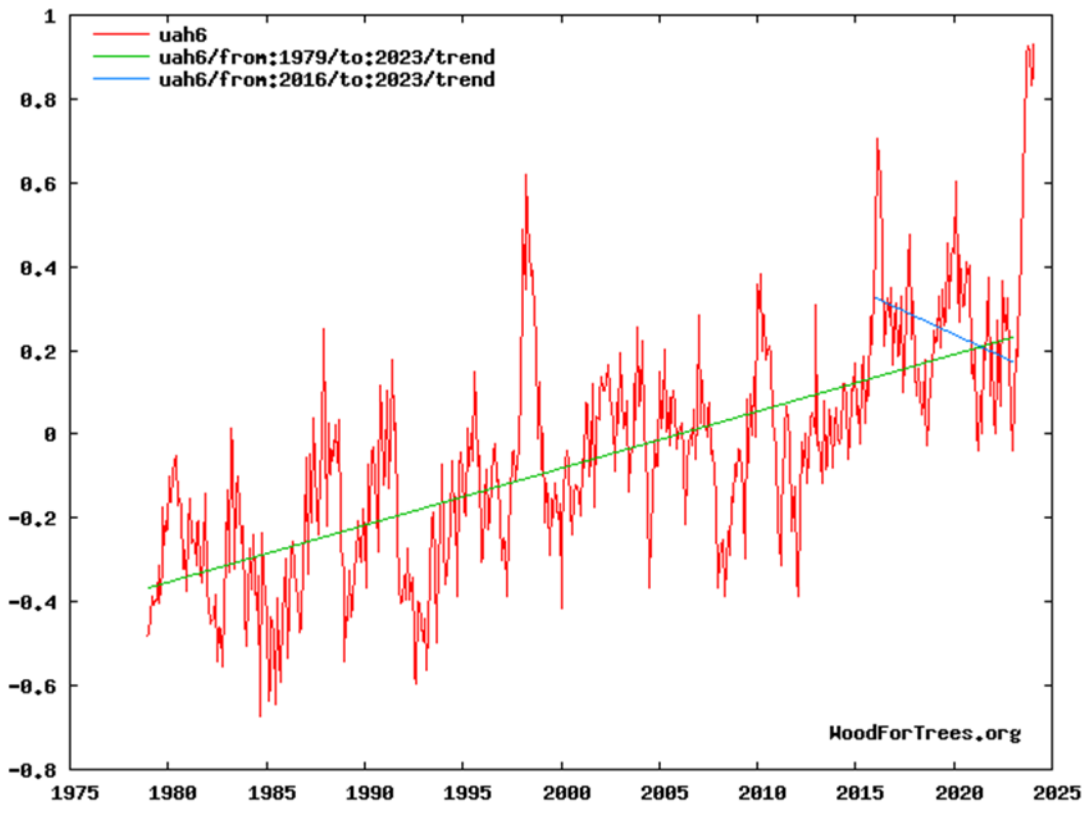

Figure 1. UAH satellite global temperature anomaly data in °C relative to the mean from 1991 to 2020. In green is the linear trend of the series (+0.13 ºC/decade) and in blue is the linear trend since 2016. Data: UAH 6.0 Graph: Woodfortrees. (based on data - the University of Alabama in Huntsville, USA https://www.researchgate.net/institution/University-of-Alabama-in-Huntsville)

In addition, it has been shown that interannual changes in qCO_2 also lag behind the corresponding changes in T for instrumental data over recent decades. Since the effect is not expected to lead to its cause, such delays are used as an argument to refute the role of the anthropogenic greenhouse effect in climate change (e.g. (Quinn, 2010; Kuo et al., 1990)).

Increasing levels of CO_2 in the atmosphere may be a consequence of warming, rather than its cause. The statistical analysis performed showed that although there is a correlation between qCO_2 and global temperature, changes in qCO_2 appear after changes in temperature with a lag of approximately 5 months. A possible explanation may be the fact of global temperature changes due to natural causes and a corresponding increase in the temperature of ocean waters, where more than 90% of the total mass of CO_2 is contained. This, in turn, leads to an increase in the flow of CO_2 from water into the atmosphere in accordance with Henry's law.

Although these arguments have been criticized on various grounds (see, for example, (Richardson et al., 2018)), the lag between changes in climate variables as a reliable indicator of cause-and-effect relationships in the Earth's system has not been questioned by most critics.

Articles (Muryshev et al., 2019a, 2019b) describe a possible mechanism for the mutual delay between changes in the global surface temperature T and the CO_2 content in the atmosphere of the Earth. This mechanism can be triggered when the Earth's climate system is exposed to single-phase emissions of carbon dioxide and methane.

At the same time, research (Lobkovsky et al., 2022) suggests that among the natural causes of global warming, the identification of such a factor as the trigger activation of methane emissions under the influence of seismic activity. In the Arctic, the triggering activation of methane emissions began in the late 1970s of the last century, when tectonic waves caused by large earthquakes in the Aleutian Arc in 1957-1965 reached the Arctic shelf, traveling a distance of about 2000 km at a speed of about 100 km/year during approximately 20 years. This process was associated with a sharp warming of the Arctic environment in 1979-1980 due to the greenhouse effect of methane emissions.

At the same time, it has been shown (Bogoyavlensky et al., 2023) that there is a significant decrease in the area of possible existence of frozen soil and methane hydrates in the post-glacial period. Based on an extensive analysis of the zones of degradation of underwater frozen soil on the shelves of the Laptev, East Siberian, Chukchi and Beaufort seas (≈57% of the total area), it can be concluded that there is a relatively low probability of a significant contribution of methane released from dissociating gas hydrates to climate change. Along with this, in recent decades, many authors have noted the phenomenon of increasing continentality of climate (Bashkin et al., 2017). This is accompanied by increased natural and environmental risks.

Consequently, the purpose of this work was to consider the issues of managing natural and environmental risks in the context of increasing continentality of climate in the polar regions of gas production.

1. THE PHENOMENON OF INCREASING CLIMATE CONTINENTALITY

As is known, the continental climate is characterized by consistently hot summers and frosty winters with little precipitation. At the same time, an increase in climate continentality or an increase in the index of this phenomenon indicates an impending global cooling, which can occur both due to a decrease in the flow of solar radiation entering the Earth and through a reduction in the flow of heat from the ocean to the atmosphere (Andreychik & Mongush, 2009; Anisimov et al., 2012; Perevedentsev & Shantalinsky, 2015; Karimov & Krymskaya, 2016; Mustafina, 2017). As for the continental climate of the polar latitudes, it is characterized by large annual fluctuations in air temperature and warm but short summers, as well as very cold and long winters.

An increase in continental climate indicates the onset of another global cooling, which is expressed in changes in the climate of the Earth as a whole or its individual regions over time, which is expressed in statistically significant deviations of weather parameters from their long-term values over a period of time from decades to millions of years. A number of authors (Dansgaard et al., 1969; Abdusamatov, 2011, 2014; Bashkin & Galiulin, 2012, 2017; Archibald, 2007) have found that climate change, in particular during the Quaternary period - Holocene, which has continued for the last 11 thousand years until the present, is characterized by combinations of periods of cooling and warming at different time intervals, which indicates the cyclical nature of changes in this phenomenon on Earth.

Despite the temperature and humidity fluctuations noted above, in the relatively near future the Earth may be on the verge of repeating the same Little Ice Age that took place in the northern hemisphere in the 17^{th}-18^{th} centuries. The possibility of cooling is associated with a sharp decrease in the radiation power of the Sun, as the only source of energy for the Earth, and, consequently, the main factor in changing its climate. Two physical reasons have been noted for changes in insolation (irradiation of the Earth's surface with sunlight) in the upper layer of the atmosphere - these are long-period variations in the elements of the Earth's orbit and short-period variations in the solar constant, i.e. total solar radiation power of 1367 W/m^2 (Abdusamatov, 2011, 2014; Archibald, 2007). At the same time, changes in the solar constant were measured empirically only during the era of observations by spacecraft, and in the period up to 11 thousand years ago (the beginning of the Holocene) they were reconstructed from the content of radiocarbon (14C isotope) in tree rings. It was shown the relationship between solar activity cycles and large-scale climate changes on Earth (Abdusamatov, 2011). The author presented the connection between solar activity and climate change: when there is a deep minimum of solar activity, cooling occurs. It can be expected that the onset of the deep minimum phase in the current quasi-bicentennial cyclical activity of the Sun will occur at the beginning of the 27(±1)th 11-year solar cycle, approximately in 2043±11. This will cause the era of a new 19th Little Ice Age in recent years 7500 years (Abdusamatov, 2011). Although the Earth has already begun to receive less solar energy, it has not yet had time to cool down accordingly due to the thermal inertia of the World Ocean. Consequently, it gives, and will continue to give, more energy by radiation into space than it receives during the entire decline phase of the quasi-bicentennial cycle (Abdusamatov, 2017). As a result of such a long-term deficit of incoming solar energy, the average annual energy budget of the Earth as a planet will continue to be negative, which can lead to the beginning of the cooling of the planet.

Currently, an increase in continental climate is already observed in a number of regions. Many scientists view this as a sign of the onset of another global cooling. So, at the beginning of the 21st century (2001-2006) at all weather stations in the Tuva mountain region (50-54ºN, 89-99ºE) there was a tendency towards an increase in the climate continentality index (Andreychik & Mongush, 2009). As already noted, at the beginning of the 21st century, the nature of the North Atlantic Oscillation and the regional climate systems associated with it began to change to the next relatively cold scenario, which can last until 2030-2035. This emphasizes the tendency of these systems to transition to a new phase, similar in a number of characteristics to the scenario of the 1940-1970s (cold phase). At that time, there was an increase in continental climate on the continents (Anisimov et al., 2012). The results of the analysis of spatiotemporal changes in the temperature and wind regime in the Northern Hemisphere, in the zone of temperate latitudes (30-70°N) for the period 1948-2013, showed that since the beginning of the 21st century, winter temperatures began to decrease, and summer temperatures starting from 1975, on the contrary, to increase in the latitudinal zone 50-70ºN, which also indicates an increase in the continental climate (Perevedentsev & Shantalinsky, 2015). A similar picture was noted for Central Asia and Tatarstan, where since the beginning of the 21st century there has been an increase in continental climate, since as a result of colder winters and increased summer temperatures, the annual amplitude of air temperature fluctuations has increased (Karimov & Krymskaya, 2016; Mustafina, 2017).

An assessment of changes in the climate continentality index and its components in the territory of Transnistria for the period 1952-2018 revealed an increase in the continentality index and all its components in this region (Kolvenko et al., 2020). It is shown that over the past three decades the rate of change in the considered climate indicators has increased. Over the past 30 years (1988-2018), there has been a statistically significant increase in the continentality index (by 0.47% per year) and all its components: annual air temperature amplitude (by 0.10 °C/year), average annual daily temperature amplitude air (by 0.03 °C/year), average annual air humidity deficit (by 0.06 mbar/year). The increase in continental climate occurred against the background of an increase in average annual air temperature (by 0.04 °C/year). Fluctuations in climate continentality indicators occurred independently of each other, sometimes even in antiphase. The nature of the fluctuation curve of the actual values of the continentality index was determined mainly by the values of the annual amplitude of air temperature.

In the last decade, there has been a change in the intensity and distribution of the Siberian anticyclone, and it plays a key role in the formation of atmospheric processes over the Asian continent and affects the general circulation of the atmosphere in the Northern Hemisphere. It is very interesting to note that the forecast model of the Intergovernmental Panel on Climate Change assumed that variations in the intensity of the Siberian anticyclone will show a steady downward trend from the end of the 20th century and throughout the 21st century, which will lead to a decrease in its intensity by about 22% by 2100 compared to the average of the 1958-1980 interval. However, in reality, in the last two decades, there has been a sharp increase in the intensity of the Siberian anticyclone (https://ieig.sfu-kras.ru/node/119 - Institute of Ecology and Geography of Siberian Federal University). This is reflected in the increased continentality of the climate in the northern regions (Zakharova, 2022; Bashkin, 2022).

Thus, observations show that the increased continentality of the climate in the polar latitudes and, in particular, in the territory of the Yamalo-Nenets Autonomous District, had certain geo-ecological consequences on the Yamal Peninsula (71°N, 70°E) and was expressed in the manifestation of natural and environmental risks.

2. ENVIRONMENRAL RISKS OF INCREASING CLIMATE CONTINENTALITY IN THE YAMAL-NENETS AUTONOMOUS DISTRICT AND WAYS TO SOLVE THEM

The geoecological consequences of increased continental climate manifested themselves, in particular, in 2016 in the form of abnormal heat (29-34°C in June-July) in the Yamalo-Nenets Autonomous District, which caused an outbreak of an anthrax epidemic on the Yamal Peninsula, the causative agent of which is the bacterium *Bacillus anthracis* (Popova et al., 2016; Shestakova, 2016). As a result of the epidemic, 2,650 reindeer fell ill, and as a result of contact with sick and dead animals, 36 people were infected with one death. The negative impact of abnormal heat on the immune system of deer due to the cessation of vaccination, as well as an increase in the number of blood-sucking insects, apparently became the cause of a massive disease of anthrax in reindeer.

As is known, anthrax is a particularly dangerous bacterial zoonotic infection, i.e. an infection transmitted to humans from animals and, due to the long-term presence of *Bacillus anthracis* spores in the soil, capable of maintaining the threat of return and repeated outbreaks in affected areas for many decades. The main source of infection for humans is a sick animal or its corpse. Transmission factors include livestock products, soil and other environmental objects. The spread of infection occurs both through the alimentary route, when spores from the secretions of sick animals or through corpses enter the soil and vegetation, and from there to healthy animals, and through transmission, i.e. with the participation of blood-sucking insects - horse flies (*Tabanidae*), sting flies (*Muscidae*) and midges (*Diptera*) (Bogdanov & Golovatin, 2017). In addition, during grazing, especially on the sparse vegetation of the tundra, spores with soil particles enter the intestines or lungs of the animal.

So, the soil is the place where *Bacillus anthracis* resides for the longest time, where they passively remain in the form of spores for tens and hundreds of years, waiting for the time favorable for reproduction, i.e. soil is a constant reservoir of the pathogen. The noted temperature anomaly on the Yamal Peninsula contributed to an increase in the depth of seasonal thawing of permafrost and the movement of Bacillus anthracis spores from deep layers to the surface of the soil with interpermafrost waters. At the same time, primary soil foci of this bacterium are formed as a result of direct infection of the soil with secretions of sick animals on pastures, in places where animals are kept in stalls and in places where deer corpses are buried (cattle burial grounds), and secondary foci are created by washing off or introducing spores to new territories with rain, melt and sewage waters.

In such situations, the sanitary-epidemiological service with its laboratories must certainly work to identify outbreaks and stop emerging problems. However, given that the territory of the Yamal-Nenets Autonomous District exceeds the size of most European countries, and this territory has an extremely low number of permanent residents, a significant part of which leads a nomadic lifestyle, and poorly developed infrastructure, such a task becomes simply physically impossible. And solving this problem, of course, should be done based on incredibly low number of specialized and certified sanitary and epidemiological laboratories. One of the options for solving the problem is to develop indicator technologies that allow standard environmental laboratories included in the staffing schedule of gas production enterprises to carry out an indicator assessment of the epidemiological state in the controlled territory of licensed areas and under agreements with the local administration in the territories under its control. An indicator assessment is necessary in order to call specialists from the sanitary and epidemiological service only if such a need arises, rationalizing its functioning in the Yamalo-Nenets Autonomous District and other regions of the Far North.

An average representative sample of manure is then collected from the grazing area, dried (at room temperature) and sifted (through a 3 mm sieve) to obtain a dry sample.

For example, experiments were carried out with an average representative sample of manure taken from a grazing site in a pastoral area. The sample was subjected to drying and sieving operations, and dry manure samples and aqueous manure samples were obtained from it. After carrying out the described and additional laboratory testing procedures, statistically proven microbial contamination of water was established, which was determined by analyzing the activity of the dehydrogenase enzyme, Table 1.

Table 1. Identification of microbial contamination of the aquatic environment from cattle manure by analyzing the activity of the dehydrogenase enzyme

Sample No.	Manure: water ratio	The activity of the enzyme dehydrogenase, μg $C_{19}H_{16}N_4$/(g·day) [sample #1] and μg $C_{19}H_{16}N_4$/(ml·day) [Probe #2, 3, 4 and 5]	Number of microbes cells/g [sample No. 1] and cells/ml [samples No. 2, 3, 4 and 5]
1	1:0	667	$2{,}2 \cdot 10^9$
2	1:1	248	$0{,}7 \cdot 10^8$
3	1:2	177	$5{,}2 \cdot 10^6$
4	1:3	59	$1{,}7 \cdot 10^6$
5	1:4	33	$1{,}0 \cdot 10^6$

At the same time, the activity values of the dehydrogenase enzyme were confirmed by the results of an analysis of the number of microbes producing this enzyme in various samples, carried out according to the generally accepted method (see, for example, (Zvyagintsev et al., 1980)). From these analytical data and comparative studies, it is clear that dry manure sample No. 1, as the primary focus of microbes, is characterized by maximum values of dehydrogenase enzyme activity, 667 μg $C_{19}H_{16}N_4$/(g day), and the number of microbes, $2.2 \cdot 10^9$ cells /g producing this enzyme. In water samples of manure No. 2, No. 3, No. 4 and No. 5, as a secondary focus of microbes, with the expansion of the manure:water ratio in the series - 1:1, 1:2, 1:3 and 1:4, the enzyme activity turned out to be directly proportional to the number of microbes, i.e. the lower the dehydrogenase activity, the fewer microbes were identified in the water sample and vice versa. It should be noted that if the results of the analysis show a zero value for the activity of the dehydrogenase enzyme, this means a complete absence of microbial contamination of the aquatic environment from manure.

The method allows you to quickly (within 1 day):

- identify microbial contamination of the aquatic environment from livestock manure, which occurs as a result of rain and melt water seeping through the manure, which form surface and subsurface runoff;
- ensure high accuracy and quality of assessment of the epidemiological situation caused by pathogenic microbes in the areas of grazing livestock, the primary source of which may be the manure of sick animals;
- justify the adoption of preventive or remediation measures to avoid infection of the local population through contaminated surface and underground water sources used for drinking purposes.

According to (Loginov et al., 2017), as soon as the grazing load is excessive, the vegetation cover is completely damaged or fragmented, and, accordingly, the soil surface is exposed, the epizootic mechanism, i.e. animal epidemics start. In a word, the degradation of vegetation contributes to the formation of sandy outcrops on positive (convex) forms of relief. This allows us to come to the conclusion that restoration of soil and vegetation cover is a fundamental way to prevent epizootics.

As can be seen from the above, the strengthening of the continental climate in the Yamalo-Nenets Autonomous District and, in particular, on the Yamal Peninsula, also manifests itself in the form of such geo-ecological consequences as outbreaks of the anthrax epidemic. Nevertheless, reindeer husbandry is developing in the district, natural gas is being extracted and transported, and modern infrastructure is being created. These types of anthropogenic activities lead, in turn, to no less serious geoecological consequences, expressed in the disturbance of tundra soils.

CONCLUSION

Thus, the fact of increasing continental climate, manifested in temperature anomalies, is obvious, as a sign of the coming global cooling of the Earth. The consequence of this is an increase in both natural and environmental risks. Natural risks associated with rising summer temperatures (for example, in 2016) can manifest themselves in the form of various epizootics. The leading factor in the manifestation of such natural risks is large-scale disturbances of tundra soils, in particular on the Yamal Peninsula due to overgrazing of deer. This leads to loss of pasture areas. Disturbances of tundra soils associated with the development of hydrocarbon deposits are local in nature. Against the backdrop of increasing continental climate, in recent years, on the territory of the Tazovsky Peninsula, a biogeochemical technology adaptive to the climatic conditions of the Far North has been successfully tested for the reclamation of tundra soils disturbed due to the extraction and transport of natural gas, as well as overgrazing of deer, the basis of which is the methods protected by 8 patents of the Russian Federation.

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The green transformation of the banking sector: challenges and opportunities for sustainable finance

Zelena transformacija bankarskog sektora: izazovi i mogućnosti za održivo finansiranje

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Abstract: The green transformation of the banking sector is becoming a pivotal component in the transition toward a sustainable economy. As key intermediaries in the financial system, banks bear increasing responsibility and possess significant potential to direct capital toward projects that support environmental protection, carbon emission reduction, and climate change adaptation. This paper examines the role of the banking sector in the implementation of green finance, with a particular focus on the challenges posed by regulatory requirements, the lack of standardization in ESG criteria, and the limited awareness and capacity within the domestic financial system. Furthermore, the paper highlights the opportunities that the green transition offers in terms of financial product innovation, enhanced competitiveness of banks, and increased resilience to climate-related risks. By analyzing relevant strategies and best practice examples from Serbia and the European Union, the study provides insights into future development pathways and offers recommendations for a more effective integration of sustainability into banking business models.

Keywords: Green finance, Banking sector, Sustainable finance, ESG criteria, Climate risks, Regulatory Framework, Economic transition, Financial institutions, Green economy.

Sažetak: Zelena transformacija bankarskog sektora postaje ključna komponenta u tranziciji ka održivoj ekonomiji. Kao ključni posrednici u finansijskom sistemu, banke snose sve veću odgovornost i poseduju značajan potencijal da usmere kapital ka projektima koji podržavaju zaštitu životne sredine, smanjenje emisije ugljenika i prilagođavanje klimatskim promenama. Ovaj rad ispituje ulogu bankarskog sektora u implementaciji zelenih finansija, s posebnim fokusom na izazove koje predstavljaju regulatorni zahtevi, nedostatak standardizacije ESG kriterijuma i ograničena svest i kapaciteti unutar domaćeg finansijskog sistema. Rad takođe ističe mogućnosti koje zelena tranzicija nudi u smislu inovacija finansijskih proizvoda, poboljšane konkurentnosti banaka i povećane otpornosti na rizike povezane s klimom. Analizirajući relevantne strategije i primere najbolje prakse iz Srbije i Evropske unije, studija pruža uvid u buduće razvojne puteve i nudi preporuke za efikasniju integraciju održivosti u bankarske poslovne modele.

Ključne reči: Zelene finansije, Bankarski sektor, Održive finansije, ESG kriterijumi, Klimatski rizici, Regulatorni okvir, Ekonomska tranzicija, Finansijske institucije, Zelena ekonomija..

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INTRODUCTION

In the context of contemporary global climate change and increasingly prominent environmental challenges, the transformation of economic sectors toward sustainable business models has become imperative. The banking sector, as a key intermediary in capital allocation, holds both the potential and the actual power to significantly influence the direction of economic development - not only through financing, but also by shaping business standards aligned with sustainability principles (Peeters, 2003.). In this context, the concept of green finance is gaining prominence as a mechanism for redirecting investments toward projects that contribute to environmental protection, energy efficiency, and the reduction of greenhouse gas emissions (Fu et al., 2023).

The green transformation of the banking sector involves not only the development of new financial products, but also profound changes in strategic planning, risk management, credit assessment, and reporting in accordance with ESG (Environmental, Social, Governance) principles. However, the implementation of sustainable practices faces numerous challenges, including insufficient regulatory alignment, limited access to relevant data, a shortage of professional capacities, and low awareness of climate and environmental risks within financial institutions - particularly in developing countries such as Serbia (Jokić et al., 2024).

Research indicates that the green transition of Serbia's banking sector remains in its early stages, with a low degree of ESG factor integration in strategic decision-making, which poses an additional challenge for regulators and policymakers (Đuričin et al., 2024). On the other hand, successful examples of green banking across Europe and the region demonstrate that timely institutional and regulatory support can significantly accelerate this process.

The aim of this paper is to analyze the main challenges and opportunities associated with the green transformation of the banking sector, with a particular focus on the role of financial institutions in the transition toward a sustainable economy. Through an overview of domestic and international initiatives, regulations, and best practice examples, the paper provides insight into the current state of green finance development in Serbia and identifies key directions for improving its implementation within banking practice.

1. METHODOLOGY

This paper employs a qualitative-descriptive approach aimed at exploring the level of development and implementation of green finance in the banking sector of Serbia, identifying key challenges, and mapping potential opportunities for further progress toward sustainable financing. This methodological approach is justified by the complexity and multidimensionality of the topic, as well as the fact that the field of green banking in Serbia remains relatively new and insufficiently researched (Toto et al., 2023).

The analysis is based on the following methodological steps:

Review of Relevant Literature: To establish the theoretical framework, the study reviewed scholarly articles, institutional reports, and regulations, including works that address sustainable banking in the domestic context, as well as key international documents that define the standards and objectives of the green transition (UNEP FI; European Commission). Particular attention was given to sources analyzing the implementation of ESG factors and regulatory requirements in the banking sector.

Comparative Analysis: Regulatory and strategic approaches to sustainable finance in the European Union and Serbia were compared. The objective was to identify disparities and gaps in the domestic institutional framework, in line with the findings who emphasize the need for harmonizing domestic practices with European standards.

Secondary Data Analysis: Publicly available reports from commercial banks operating in Serbia and the region were examined, along with data on green bond issuance (Climate Bonds Initiative, 2023) and information from international organizations on investments in sustainable projects in Serbia (EIB, 2023; IFC Press Releases 2022, 2024). These data provided insight into the real scope of existing initiatives and helped identify areas with high development potential.

Case Studies: Selected examples of best practices from the EU and Serbia were analyzed, with special focus on banking initiatives involving the implementation of green credit lines, ESG strategies, or participation in international initiatives such as the Sustainable Banking Network (IFC Press Release, 2020). One such example is Erste Bank, which, with IFC support, implemented specific instruments to support the green transition (IFC, 2024).

This multilayered methodological framework enables a comprehensive examination of the current state of the banking sector in Serbia, while also providing a comparative perspective relative to more developed financial systems. The chosen methodology is aligned with the recommendations of contemporary literature, which emphasizes the need for contextual and interdisciplinary analyses in the field of sustainable finance.

2. LITERATURE REVIEW

In recent years, the green transformation of the banking sector has become an increasingly important topic in both domestic and international academic and professional circles. The central focus is on the role of financial institutions in supporting sustainable development, combating climate change, and transitioning to a low-carbon economy. This process is grounded in the integration of Environmental, Social, and Governance (ESG) factors into strategic decision-making and risk assessment within the banking sector (Kuzmina et al., 2023.).

According to the United Nations Environment Programme Finance Initiative (UNEP FI), green finance encompasses all financial activities that take into account environmental protection, climate change, and sustainability in a broader sense. The European Union has further institutionalized this field through its Action Plan on Sustainable Finance (European Commission), which introduces classification standards for sustainable activities (EU taxonomy) and mandates sustainability reporting for financial institutions and corporations (SFDR regulation).

In the context of the banking sector, numerous authors emphasize the lack of standardized frameworks and metrics for evaluating the sustainability of investments as one of the main challenges. Points out that banks can play a crucial role in environmental protection through their lending policies; however, the application of ESG principles remains fragmented and often superficial. Similarly argue that without regulatory pressure and institutional support, banks rarely initiate profound changes in their business models on their own.

In developing countries, including Serbia, the implementation of green finance faces additional obstacles. Research conducted shows that awareness of ESG risks in Serbia's banking sector is still at an early stage, while the legal framework does not provide sufficient incentives for directing capital toward sustainable projects.

On the other hand, the National Bank of Serbia announced in 2022 the introduction of guidelines for managing environmental risks in banking operations (NBS, 2022, via IFC Press Release, 2022), marking an important, though still under-implemented, step toward alignment with European trends.

Reports from international financial institutions further confirm the significance of banks as key actors in financing the energy transition. For instance, the European Investment Bank (EIB, 2023) reported that €29 million was invested in green projects in Serbia as part of the EU for Green Agenda initiative. Similar efforts are supported by the IFC and the EBRD through partnerships with domestic banks (IFC, 2024), opening up space for stronger integration of Serbia into global green capital flows.

One of the most dynamic instruments of sustainable finance is green bonds. According to the Climate Bonds Initiative (2023), this market has seen significant global growth. However, its application in the Western Balkans remains marginal. Conversely, studies examining the relationship between sustainability and financial performance suggest that the integration of ESG principles can have a positive effect on the competitiveness and reputation of banks.

Finally, examples such as ProCredit Bank, which consistently applies ESG principles and has developed an internal model for sustainable finance, serve as a positive model for other stakeholders in the sector. Such approaches illustrate that the green transition need not be merely a regulatory obligation, but can become a competitive advantage and a source of innovation in banking operations.

3. RESEARCH FINDINGS AND DISCUSSION

The results of the analysis of available literature, regulatory documents, bank reports, and European case studies reveal several key findings that shed light on the current level of development of green finance in Serbia's banking sector, as well as the challenges and opportunities for its further green transformation.

Figure 1 illustrates the green transformation of the banking sector in Serbia. The diagram highlights six key areas influencing this transition: low ESG integration, lack of regulatory pressure, limited green financial products, low client and investor awareness, development opportunities through international funds, and existing pioneering initiatives. Each branch represents critical challenges and potential growth factors that shape the current state and future prospects of sustainable banking in Serbia.

Based on the conducted research and comprehensive analysis of available literature, regulatory documents, bank reports, and European practices, this study identifies the current state and challenges of the green transformation in Serbia's banking sector. The findings highlight both structural limitations and emerging opportunities for sustainable finance development. The author emphasizes the urgent need for regulatory frameworks, capacity building, and increased awareness to accelerate this transition and align Serbia with global sustainable finance trends.

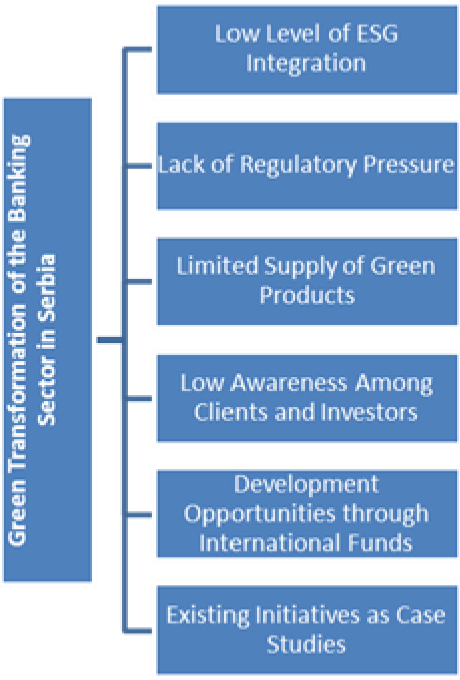

Figura 1. Green Transformation of the Banking Sector in Serbia
Sours: Author on the conducted research

Low Integration of ESG Criteria into Domestic Banking Policies: Although an increasing number of banks in Serbia are formally embracing the principles of sustainable business, the actual integration of ESG criteria into credit policies, risk management, and strategic decision-making remains limited. Analyses show that ESG factors are still predominantly treated as secondary, reputational risks rather than as key determinants of financial stability.

This approach may lead to misjudgment of risks and a loss of competitiveness, particularly given that global investors are increasingly demanding transparency regarding ESG performance.

Lack of Regulatory Pressure and Incentives: Unlike in the EU, where the implementation of regulations such as the SFDR, EU Taxonomy, and CRD/CRR V amendments is mandatory (European Commission, 2018), Serbia's regulatory framework is still not binding for banks in the area of sustainability.

The National Bank of Serbia announced the development of environmental risk management guidelines in 2022, but their full implementation is yet to occur (NBS, 2022). These findings confirm that Serbia's regulatory support is evolving more slowly compared to European practices.

Limited Supply of Green Financial Products: The Serbian market continues to offer a limited range of green financial products, mostly in the form of energy efficiency credit lines supported by international partners such as the EBRD, KfW, and IFC (IFC, 2022; EIB/UNDP, 2023).

Domestic banks rarely develop their own green products, which is attributed to a lack of professional capacity and the absence of market and regulatory incentives. By contrast, banks in the EU are already developing sophisticated ESG-indexed loans, green mortgages, and green bonds that facilitate access to green capital.

Low Awareness Among Clients and Investors: One of the key challenges is the low level of awareness among clients, particularly small and medium-sized enterprises, regarding the importance of green transition and available green financing options.

A similar situation applies to domestic investors, who are still not sufficiently informed about the potential returns and stability of green investments. As emphasized by the Climate Bonds Initiative (2023), market education is a critical component for the development of the green bond market, which remains negligible in Serbia compared to EU markets.

Opportunities for Development: Access to International Funds and Markets: Despite existing challenges, significant opportunities for development have been identified. Domestic banks can take a more active role in international programs (e.g., InvestEU, Green Agenda for the Western Balkans), as demonstrated by recent EIB investments in green projects in Serbia (EIB/UNDP, 2023).

Furthermore, partnerships such as that between the IFC and Erste Bank highlight tangible benefits in terms of technology transfer, strengthening ESG capacities, and improving access to green capital (IFC, 2024).

Case Studies: Early Initiatives in Serbia: Although still relatively rare, there are individual initiatives that may serve as a foundation for broader ESG adoption. For example, Erste Bank and ProCredit Bank have developed internal ESG policies and reporting systems (IFC, 2024). Some commercial banks have also participated in residential energy efficiency financing projects.

Such initiatives demonstrate the potential within Serbia's banking sector, but also point to the need for systematic regulatory and governmental incentives to accelerate the transformation process.

The analysis suggests that the green transformation of the banking sector in Serbia remains in its early stages, characterized by clear structural and regulatory limitations. Nevertheless, international examples and initial steps taken by domestic banks indicate that there is substantial room for accelerated development, provided that regulatory support, training programs, and access to international green capital are ensured.

The key question is whether Serbia's regulatory bodies and financial institutions will manage to capitalize on the current global momentum in sustainable finance, or whether a lack of timely reforms will result in lost competitiveness and increased exposure to climate and market risks - risks increasingly emphasized in contemporary literature as highly relevant.

CONCLUSION

The green transformation of the banking sector represents an essential step toward establishing a sustainable economy and responding to increasingly pressing climate and environmental challenges. Banks, as key actors within the financial system, hold significant power through their lending policies, investment decisions, and risk management to influence economic development trajectories. The research has shown that in Serbia, this process is still in its early stages, with limited application of ESG criteria, an underdeveloped regulatory framework, and a weak supply of green financial products.

However, there are clear indicators of potential for accelerated progress. Access to international funds, strengthening regulatory pressure, increasing awareness among investors, and the introduction of European standards into domestic practice can all contribute to the development of the green finance market. The green transition is not only a regulatory challenge but also a developmental opportunity for the banking sector to enhance its competitiveness, reputation, and long-term business sustainability.

Based on the analysis and research findings, the following recommendations are proposed to accelerate the green transformation of the banking sector in Serbia: The National Bank of Serbia and relevant ministries should implement binding guidelines for integrating ESG criteria into risk management and reporting, following the example of EU regulations. Training and educational programs for bank employees are necessary to deepen understanding and application of sustainable finance principles. Banks should design specialized products to finance energy efficiency, renewable energy sources, circular economy initiatives, and other green projects. Active participation in projects with EBRD, EIB, IFC, and other donor organizations can improve access to favorable capital sources for green projects. Creating a legislative and market environment that encourages the issuance and trading of green bonds can diversify funding sources for sustainable projects. Banks and regulators should conduct information campaigns and provide technical support to clients - especially SMEs and local governments - about the opportunities and benefits of green finance. Introducing mandatory public reporting on banks' green portfolio shares and ESG performance will contribute to greater transparency and accountability in operations.

If Serbia aims to keep pace with global trends and avoid financial and reputational risks, the green transformation of the banking sector must become a priority rather than a marginal initiative.

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Construction and Demolition Waste and Recycling Opportunities: A Case Study of Novi Sad, Serbia

Građevinski i otpad od rušenja i mogućnosti reciklaže: Studija slučaja Novog Sada, Srbija

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Abstract: Construction and demolition waste (CDW) presents a growing environmental and economic challenge in urban areas, particularly in rapidly developing cities. This study explores the types, quantities, and management practices of CDW in the city of Novi Sad, Serbia, with a focus on recycling potential and sustainability. Using data from local environmental authorities and recent waste generation reports, we identify predominant waste types and assess current recycling practices and infrastructure. Our analysis highlights that soil and stones represent the largest proportion of CDW in Novi Sad, while materials such as concrete, bricks, and metals also contribute significantly. Despite legal frameworks mandating selective waste collection and recycling, actual recycling rates remain low. This paper recommends strategies to improve recycling efficiency, such as investment in material recovery facilities, enforcement of regulations, and public-private partnerships. The findings aim to inform local policy development and contribute to broader goals of circular economy and environmental protection.

Keywords: construction waste, demolition waste, recycling, Novi Sad, circular economy, Serbia, waste management.

Sažetak: Građevinski i otpad od rušenja (GOT) predstavlja sve већii ekološki i ekonomski izazov u urbanim područjima, posebno u gradovima koji se brzo razvijaju. Ova studija istražuje vrste, količine i prakse upravljanja GOT-om u gradu Novom Sadu, u Srbiji, sa fokusom na potencijal reciklaže i održivost. Koristeći podatke lokalnih vlasti zaštite životne sredine i nedavne izveštaje o stvaranju otpada, identifikujemo preovlađujuće vrste otpada i procenjujemo trenutne prakse reciklaže i infrastrukturu. Naša analiza ističe da zemljište i kamenje predstavljaju najveći udeo GOT-a u Novom Sadu, dok materijali poput betona, cigle i metala takođe značajno doprinose. Uprkos zakonskim okvirima koji nalažu selektivno sakupljanje i reciklažu otpada, stvarne stope reciklaže ostaju niske. Ovaj rad preporučuje strategije za poboljšanje efikasnosti reciklaže, kao što su ulaganja u postrojenja za oporavak materijala, sprovođenje propisa i javno-privatna partnerstva. Rezultati imaju za cilj da informišu razvoj lokalnih politika i doprinesu širim ciljevima cirkularne ekonomije i zaštite životne sredine.

Ključne reči: građevinski otpad, otpad od rušenja, reciklaža, Novi Sad, cirkularna ekonomija, Srbija, upravljanje otpadom.

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INTRODUCTION

Construction and demolition waste (CDW) is one of the heaviest and most voluminous waste streams generated in the European Union and globally (Fig. 1). It comprises a wide range of materials including concrete, bricks, wood, glass, metals, plastic, and excavated soil and stones. The mismanagement of this type of waste can result in significant environmental degradation, inefficient resource use, and increased pressure on landfills.

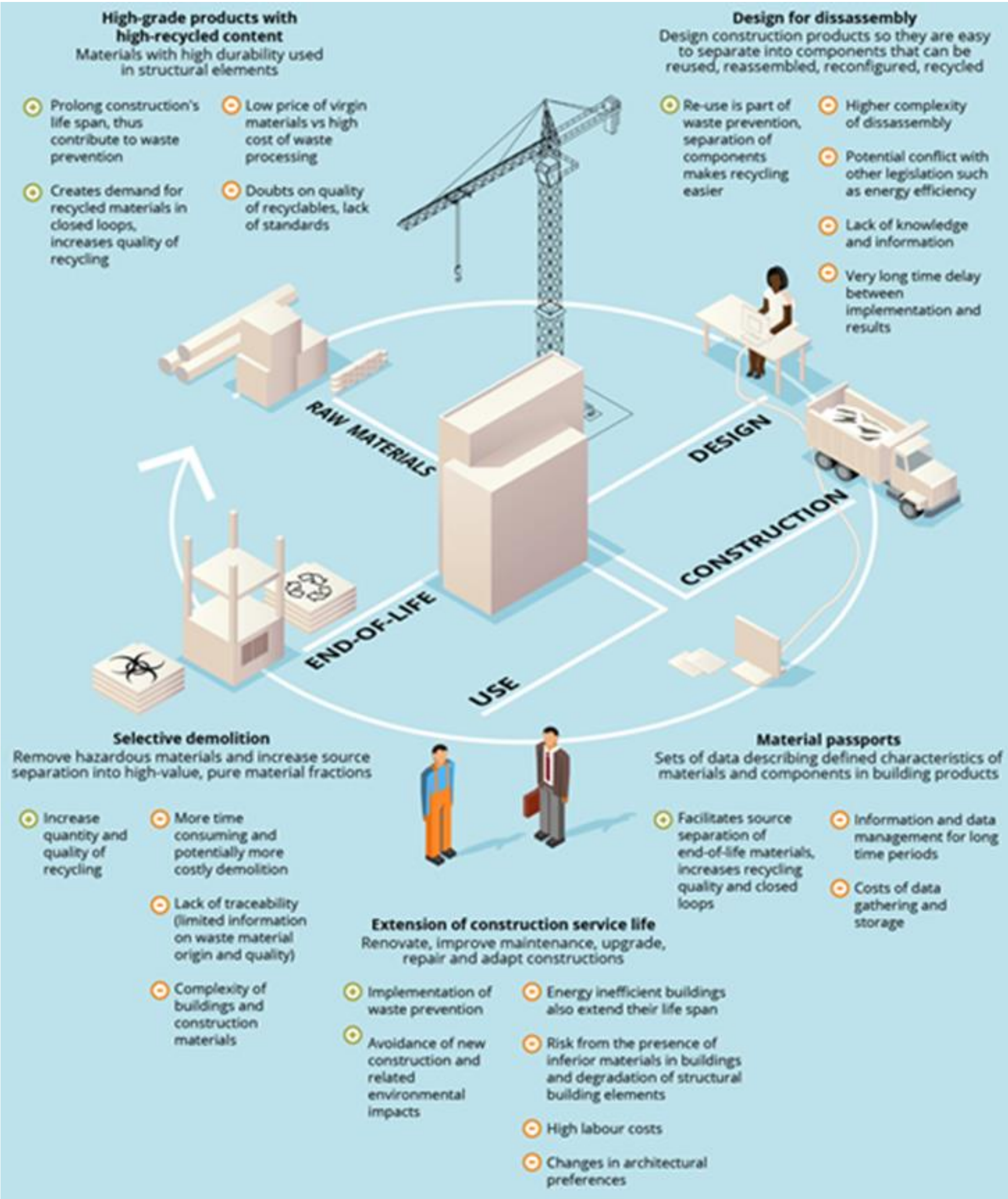

Figure 1. EU challenges and opportunities diagram - illustrates CDW flows, issues, and strategic solutions in Europe (Source: https://www.eea.europa.eu/en/analysis/publications/construction-and-demolition-waste-challenges)

Construction and demolition waste (CDW) is a rapidly growing waste stream worldwide, closely linked to urban development, population growth, and infrastructure expansion. According to the European Commission, CDW accounts for approximately 25% -30% of all waste generated in the European Union, making it the single largest waste stream by volume (European Commission, 2020). This trend is not limited to Europe; countries around the world are facing similar challenges in managing the environmental impact of construction activities (Fig. 2).

In high-income countries, significant attention has been given to reducing, reusing, and recycling CDW. For example, in the Netherlands, approximately 98% of CDW is recycled or reused, primarily as secondary raw materials in road base layers or new construction. This success is attributed to strong regulatory frameworks, market incentives for recycled materials, and the integration of circular economy principles into national waste strategies (Coelho & de Brito, 2011).

Germany also demonstrates a robust system, where over 90% of mineral-based CDW is recycled. The country benefits from well-developed infrastructure for sorting and processing, as well as legal mandates for selective demolition and material recovery. In contrast, the United States still struggles with inconsistent CDW management practices across states. While some states like California have implemented stringent recycling targets and green building codes, others continue to rely heavily on landfilling due to low tipping fees and limited policy enforcement.

Emerging economies face even greater challenges. In rapidly urbanizing countries such as India and China, the volume of CDW has surged dramatically over the past decade. In China, it is estimated that the annual generation of CDW exceeds 3 billion tons, yet only a small percentage - less than 10% - is effectively recycled (Zhao et al., 2020). The lack of infrastructure, public awareness, and economic incentives contributes to low recycling rates and widespread illegal dumping.

India presents a similar case. With rapid urban sprawl and infrastructure development, CDW generation is expected to rise sharply. Despite the launch of the Construction and Demolition Waste Management Rules in 2016, implementation remains weak, especially at the municipal level. Studies indicate that over 50% of CDW in Indian cities remains uncollected or is dumped in open areas, leading to air and water pollution, encroachment on natural habitats, and public health risks.

In Latin America and Africa, data on CDW generation and treatment is often scarce. However, anecdotal evidence and case studies suggest that informal recycling practices are common, often carried out by unregulated workers who recover valuable materials such as metals and wood. While these activities provide income opportunities, they also expose workers to hazardous conditions and contribute to environmental degradation due to lack of safety measures and pollution control.

On a global scale, the push toward sustainable construction practices and circular economy models has sparked interest in improving CDW management. Innovations such as modular construction, prefabrication, and design-for-disassembly are being explored to reduce waste generation at the source. Furthermore, international initiatives like the UN's Sustainable Development Goal 11 (Sustainable Cities and Communities) emphasize the importance of resource-efficient construction and responsible waste management (Shao et al., 2022).

Despite these efforts, major obstacles remain, including the high cost of recycling infrastructure, inconsistent legislation, lack of standardized classification systems for waste, and limited market demand for recycled construction materials. Addressing these barriers requires coordinated action among policymakers, industry stakeholders, and the public (Yu et al., 2025).

In conclusion, while some countries have made significant progress in managing CDW sustainably, many others lag behind due to financial, institutional, and technical constraints. Lessons from global best practices can inform the development of more effective policies and systems in countries like Serbia, where urban centers such as Novi Sad are experiencing growth and increased pressure on waste management infrastructure.

Global Practices and Examples of Construction and Demolition Waste Recycling

Recycling of construction and demolition waste (CDW) has emerged as a central strategy in the transition toward a circular economy in the construction sector. Successful recycling not only conserves natural resources and reduces landfill usage but also decreases greenhouse gas emissions and energy consumption associated with the production of virgin construction materials. However, recycling practices vary widely across regions due to differences in regulatory frameworks, economic incentives, infrastructure availability, and technological development (European Environment Agency, 2020).

European countries are among the global leaders in CDW recycling. The European Union's Waste Framework Directive (2008/98/EC) mandates a minimum 70% recovery rate (by weight) for non-hazardous CDW. Several countries have exceeded this target through coordinated efforts involving regulation, incentives, and infrastructure investment (European Commission, 2016).

The Netherlands is frequently cited as a best-practice model, with CDW recycling rates exceeding 98%. A strong legal framework, combined with extensive sorting infrastructure and widespread public-private partnerships, has enabled the reuse of materials such as concrete, brick, and asphalt. Demolition waste is often crushed and used as sub-base material in road construction or as aggregate in new concrete production. Innovative Dutch companies have even begun to offer "urban mining" services, recovering valuable materials from old buildings before demolition begins (Tseng et al., 2021).

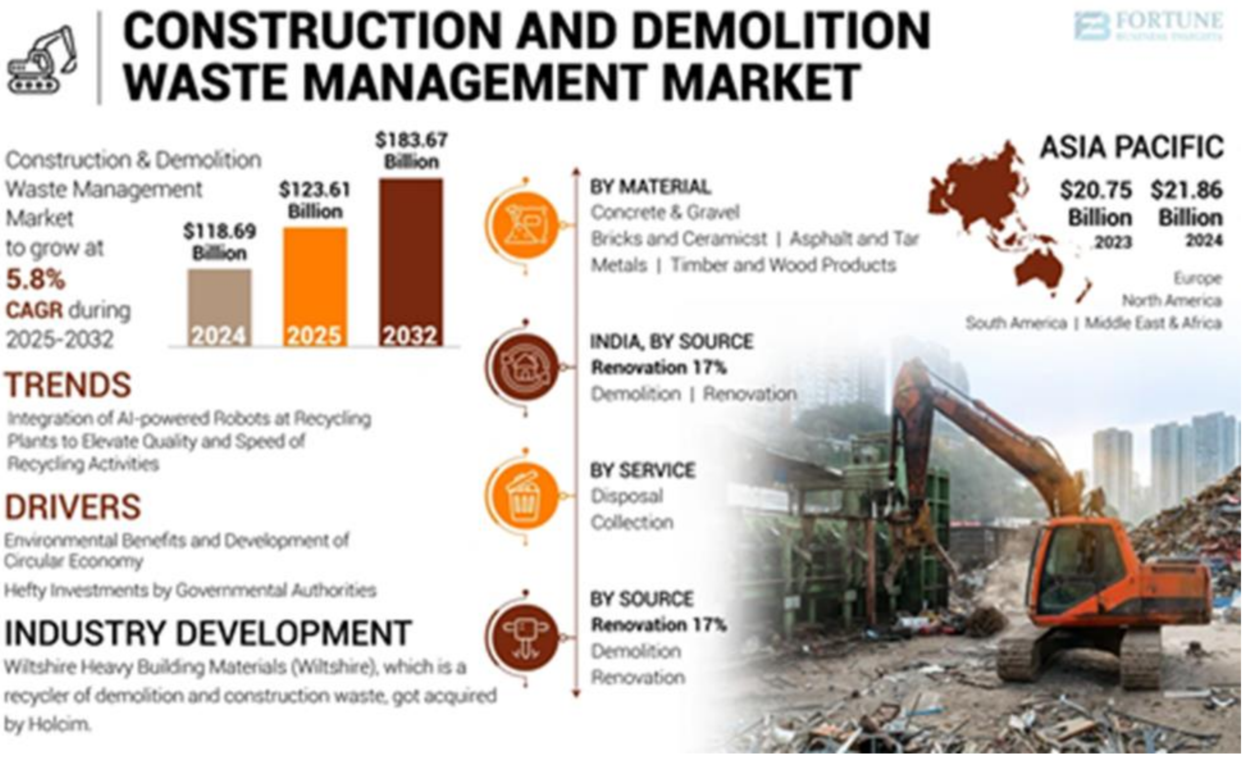

Figure 2. Global CDW management market infographic
(Source: https://www.fortunebusinessinsights.com/construction-and-demolition-waste-management-market-105550)

Germany follows a similarly effective model, with more than 90% of mineral CDW being recycled. The country emphasizes selective demolition practices and detailed material separation at the source, which improves the purity of recovered materials. Specialized recycling facilities process materials into certified secondary aggregates that are then reintegrated into the construction market.

China faces an immense challenge with CDW due to its unprecedented urbanization and construction boom. Although recycling rates historically remained below 10%, the Chinese government has recently prioritized CDW recycling in its national waste management strategies. Cities like Shanghai and Beijing have piloted advanced recycling plants capable of processing thousands of tons of concrete and brick per day. These materials are repurposed into roadbed materials, paving blocks, and construction aggregates.

Singapore presents another compelling example of efficient CDW recycling in Asia. Despite its small land area and limited landfill capacity, Singapore has achieved a CDW recycling rate of over 99%. The key to this success lies in the integrated approach adopted by the National Environment Agency (NEA), which includes mandatory waste sorting, financial incentives for recycling, and support for innovation. The Samwoh Eco-Green Building, constructed with recycled concrete aggregate (RCA), is a flagship example demonstrating the structural reliability and economic viability of recycled materials in new buildings.

In the United States, CDW management is regulated at the state and municipal levels, leading to wide variability in recycling performance. California is a recognized leader, having implemented the California Green Building Standards Code (CALGreen), which mandates that at least 65% of non-hazardous CDW must be diverted from landfills. Cities such as San Francisco have developed zero-waste initiatives that promote deconstruction over demolition and offer permits and certifications for high-recovery projects.

Canada has seen notable successes as well, particularly in British Columbia. Vancouver's deconstruction bylaw requires the careful dismantling of pre-1910 homes, enabling the recovery and resale of old-growth lumber and other high-value materials. This approach not only reduces waste but also stimulates the local reuse economy and supports low-carbon construction practices.

Australia has gradually improved its CDW recycling rates, driven by resource scarcity and landfill pressure. The country now recycles more than 75% of its CDW, with concrete and bricks being crushed into recycled aggregates for road base and pavement layers. The city of Sydney has adopted a

“Recycling First” policy for all public infrastructure projects, ensuring that recycled materials are considered in procurement decisions.

Companies like Downer and Alex Fraser Group have developed advanced facilities capable of producing recycled asphalt, concrete, and road base at commercial scale. In 2019, Downer opened a state-of-the-art recycling center in Melbourne that incorporates CDW, glass, plastic, and rubber into sustainable road construction materials.

In many developing countries, formal recycling systems are underdeveloped, but informal practices play a significant role. In Brazil, for example, a large portion of CDW is recycled by small-scale enterprises that process debris into handmade bricks, pavers, and fill material. Municipalities such as Belo Horizonte have piloted public CDW collection and recycling centers, with some success in diverting materials from illegal dumping sites.

South Africa has launched initiatives such as the Waste Economy Master Plan to increase CDW recovery through extended producer responsibility and green job creation. Pilot projects in Cape Town have demonstrated the viability of crushing concrete and masonry into secondary materials for use in low-cost housing developments.

Several technological innovations are advancing the global capacity to recycle CDW more efficiently. Mobile crushers and screening units now allow on-site processing of concrete and masonry waste, reducing transportation emissions and costs (Ragossnig, 2020). Artificial intelligence (AI) and robotics are increasingly being used for automated sorting and deconstruction, improving accuracy and material purity (Fig. 3) (Saka et al., 2024).

Materials science research has also expanded the potential applications of recycled CDW. For example, fine recycled aggregates are now being integrated into prefabricated concrete panels and non-structural building elements. Carbon capture techniques are being explored in the curing process of recycled concrete blocks to improve environmental performance (Papamichael et al, 2023).

Despite the progress in many parts of the world, CDW recycling still faces significant challenges, including the lack of standardized quality specifications, low demand for recycled products, contamination of materials, and weak enforcement of waste regulations. Financial incentives, public procurement standards, and urban planning policies that prioritize reuse and recycling are critical to overcoming these barriers (Bajwa et al., 2025).

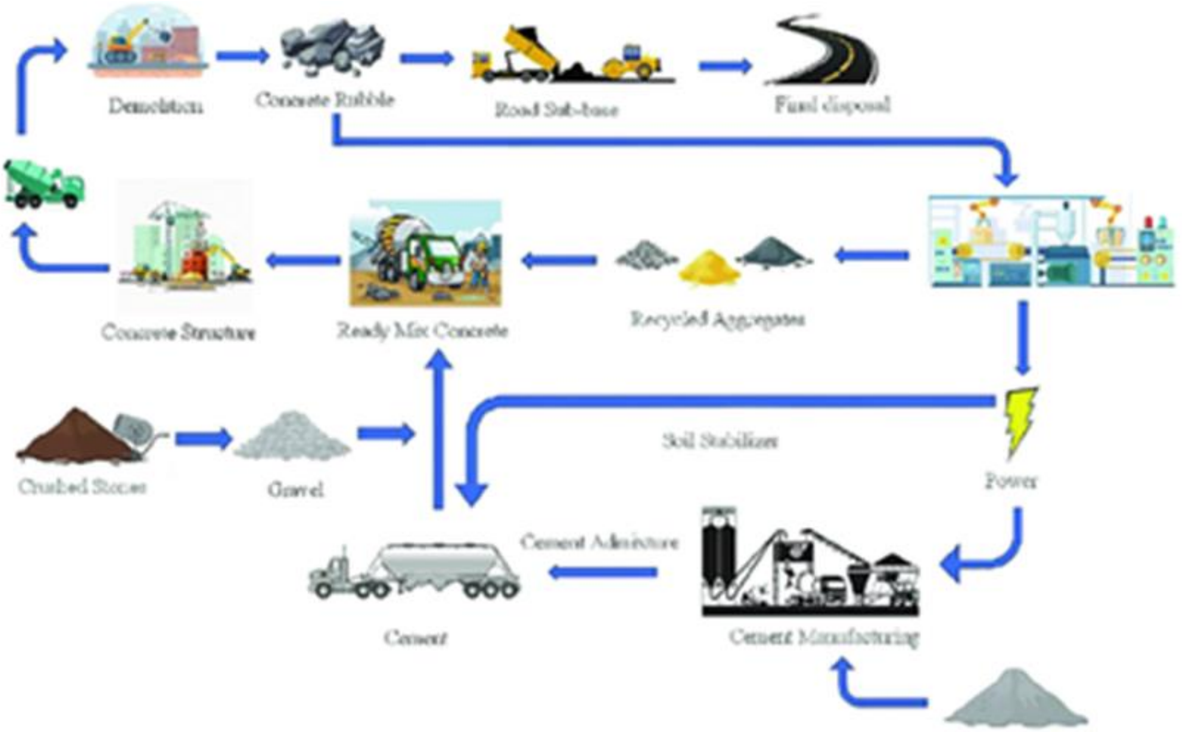

Figure 3. Production and recycling process schematic - detailed flow of CDW materials to recycled aggregates (Source: https://doi.org/10.1016/j.matpr.2022.04.392)

Governments, construction companies, and civil society must work collaboratively to scale up successful models and integrate circular thinking into the life cycle of buildings. As global demand for raw materials continues to rise, the role of CDW recycling will become even more central to achieving sustainability goal (Cook & Velis, 2022).

In Serbia, and particularly in the city of Novi Sad, urban expansion and infrastructure development have led to increasing amounts of CDW. Although Serbian legislation aligns with EU directives to some extent, the implementation and efficiency of recycling practices vary significantly across municipalities. Novi Sad, as the second-largest city in Serbia, provides a representative case for examining the challenges and opportunities in CDW recycling (Ministry of Environmental Protection, Republic of Serbia, 2023).

This paper aims to analyze the quantities and types of CDW generated in Novi Sad, assess current waste management practices, and propose sustainable solutions to enhance recycling rates. Using data collected from local environmental reports and statistical analyses, this research contributes to the understanding of urban waste dynamics in the Western Balkans and offers practical policy recommendations.

1. MATERIALS AND METHODS

This study employs a descriptive and analytical methodology based on the review and processing of official data on construction and demolition waste generated in the territory of Novi Sad. Primary data were sourced from the official reports on generated waste quantities, which presents detailed information on the types and volumes of CDW collected and categorized by composition.

The analysis includes the classification of waste types according to standard categories such as concrete, bricks, ceramics, wood, glass, plastic, metals, cables, insulation materials, gypsum-based materials, and soil and stones. Quantitative data were analyzed to determine the relative proportions of each waste type and to evaluate trends in waste generation.

Supplementary data on legal frameworks, infrastructure availability, and recycling practices in Serbia and the city of Novi Sad were obtained from local municipal sources, academic literature, and international guidelines on construction waste management.

2. RESULTS AND DISCUSSION

The main source of data used in this study includes data collected from construction sites and waste management operators in Novi Sad for a recent one-year period. These data form the empirical basis for evaluating current waste management practices and estimating the potential for material recovery and recycling in Novi Sad's construction sector (City of Novi Sad, 2024).

The data analysis reveals that soil and stones constitute by far the largest portion of CDW in Novi Sad, accounting for over 90% of the total volume. This category, often associated with excavation and earthworks, poses specific challenges for reuse and recycling due to contamination and variability in composition.

Following soil and stones, bricks and concrete are the most significant contributors to the CDW stream. These materials have well-established recycling methods and are often used as secondary aggregates in road construction or as base materials in new building projects. However, their actual recovery rates remain modest due to lack of separation at source, insufficient infrastructure, and limited market demand for recycled materials.

Metals, particularly iron and steel, represent a valuable waste stream with high recycling potential and existing markets. Despite their relatively low volume compared to inert materials, they offer economic incentives for recovery.

Other waste types such as ceramics, wood, glass, plastics, and insulation materials appear in much smaller quantities. Their recycling potential is currently underutilized, mostly due to technological and economic constraints. These materials require specialized treatment facilities that are not yet sufficiently developed in Novi Sad or the broader region.

Table 1. Construction and Demolition Waste Composition in Novi Sad (in %)

Waste Type	**%**
Soil and Stones	93.22
Bricks	2 80
Concrete	2.53
Gypsum-based Materials	1
Iron and Steel	0.25
Wood	0.07
Cables	0.04
Insulation Materials	0.05
Ceramics	0.02
Glass	0.02
Plastic	0.01

Source: Author's result

This composition illustrates the dominance of inert and mineral-based waste, which is typical for urban construction sites. It also underscores the need for systematic sorting and targeted investments in recycling infrastructure.

In the current context, CDW management in Novi Sad is primarily reliant on disposal, with limited instances of material recovery. Factors contributing to this situation include inadequate enforcement of construction waste regulations, lack of incentives for recycling, and the absence of well-equipped facilities. Public awareness regarding the benefits of recycling and circular construction practices also remains low.

To improve CDW recycling in Novi Sad, strategic interventions are needed. These may include the introduction of mandatory waste separation on construction sites, subsidies for recyclers, development of local markets for secondary materials, and stronger cooperation between municipalities and private companies. Moreover, incorporating circular economy principles into urban planning and public procurement processes can provide long-term benefits for both the environment and the local economy.

CONCLUSION

The findings of this study clearly demonstrate the dominance of soil and stones in the construction and demolition waste stream of Novi Sad, followed by bricks, concrete, and gypsum-based materials. While the potential for recycling exists, particularly for inert materials and metals, the current infrastructure and regulatory enforcement do not sufficiently support sustainable waste management practices.

Improving the CDW recycling system in Novi Sad requires a multi-faceted approach. This includes better data collection and monitoring, incentives for waste segregation and recycling, enhanced investment in recycling technology, and improved coordination between public authorities and private stakeholders. Public awareness campaigns and educational initiatives can also play a critical role in fostering a recycling culture.

Policy recommendations include:

- Implementing stricter regulations and control mechanisms for waste separation on construction sites.
- Establishing regional recycling centers equipped to process various types of CDW.
- Promoting public-private partnerships to enhance waste recovery systems.
- Integrating recycled construction materials into public procurement standards.

By adopting these measures, Novi Sad can move toward a more sustainable and circular construction sector, contributing to national and international environmental objectives.

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Circular Economy as a Model of Sustainable Development

Cirkularna ekonomija kao model održivog razvoja

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Abstract: The circular economy represents an innovative model that seeks to replace the traditional linear approach to production and consumption, focusing on efficient resource use, waste minimization, and environmental protection. This paper analyzes the key concepts of the circular economy in the context of sustainable development, with particular attention to the economic, environmental, and social dimensions of sustainability. It presents global and European institutional and strategic frameworks, including important initiatives such as the European Green Deal and the Circular Economy Action Plan. The paper also examines the challenges and limitations of implementation, such as regulatory barriers, lack of infrastructure, and resistance to changes in business models. Finally, it provides recommendations for improving policy, education, and further research, emphasizing the role of businesses, the state, and consumers in the transition to a circular economy. The study highlights the significance of the circular economy as a sustainable alternative to traditional models, aiming to achieve long-term environmental, economic, and social benefits.

Keywords: circular economy, sustainable development, innovative business models, sustainable production, recycling.

Sažetak: Cirkularna ekonomija predstavlja inovativni model koji teži da zamijeni tradicionalni linearni pristup proizvodnji i potrošnji, fokusirajući se na efikasno korišćenje resursa, minimizaciju otpada i zaštitu životne sredine. Ovaj rad analizira ključne pojmove cirkularne ekonomije u kontekstu održivog razvoja, sa posebnim osvrtom na ekonomsku, ekološku i socijalnu dimenziju održivosti. Predstavljeni su globalni i evropski institucionalni i strateški okviri, uključujući značajne inicijative poput Evropskog zelenog plana i Akcionog plana za cirkularnu ekonomiju. Rad takođe razmatra izazove i ograničenja implementacije, kao što su regulatorne prepreke, nedostatak infrastrukture i otpor prema promjenama u poslovnim modelima. Na kraju, daju se preporuke za unapređenje politika, obrazovanja i dalja istraživanja, naglašavajući ulogu preduzeća, države i potrošača u tranziciji ka cirkularnoj ekonomiji. Studija ističe značaj cirkularne ekonomije kao održive alternative tradicionalnim modelima, s ciljem postizanja dugoročnih ekoloških, ekonomskih i socijalnih koristi.

Ključne riječi: cirkularna ekonomija, održivi razvoj, inovativni poslovni modeli, održiva proizvodnja, reciklaža..

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1. CIRCULAR ECONOMY: CONCEPT, THEORETICAL FOUNDATIONS, AND KEY CHARACTERISTICS

The circular economy represents a conceptual and practical response to the shortcomings of the traditional linear economic model, which is based on unlimited resource use and the generation of large amounts of waste (Geissdoerfer et al., 2017). The circular economy aims to preserve resource value, promote reuse, recycling, remanufacturing, and regeneration. This approach encompasses all stages of the production and consumption cycle, with the objective of reducing waste, conserving natural capital, and achieving long-term sustainability (Kirchherr et al., 2017).

Although there is no single, universally accepted definition, most experts agree that the circular economy constitutes an industrial system that is restorative and regenerative by design, as defined by the Ellen MacArthur Foundation (2013). This system seeks to eliminate waste and losses through superior design of materials, products, systems, and business models.

To fully understand the goals and mechanisms of the circular economy, it is necessary to examine the theoretical foundations on which it is built. These foundations shape its conceptual framework and enable its application across different sectors of the economy and society.

The circular economy is theoretically rooted in several key disciplines that provide its basis and guidelines for development and implementation:

Industrial Ecology: This discipline views industrial processes as part of a broader ecosystem, where resources are used and optimized in a manner similar to natural cycles. Industrial ecology promotes closing material and energy loops, thereby reducing the negative environmental impact of production (Graedel & Lifset, 2016).

Eco-design (Green Design): Focused on creating products that have minimal negative environmental impact throughout their life cycle, eco-design includes the selection of environmentally friendly materials, designs that facilitate disassembly and recycling, and the extension of product life (Mc Donough & Braungart, 2010; Bocken et al., 2016).

Responsible Waste Management: This concept advocates a waste management hierarchy, prioritizing waste prevention, followed by reuse and recycling, and finally safe disposal. The aim is to reduce waste generation and maximize resource utilization (UNEP, 2011).

Sustainable Development Theory: Sustainable development emphasizes balancing economic growth, social equity, and environmental protection. The circular economy is considered a key tool for achieving this balance, as it integrates ecological and social aspects into economic processes (Geissdoerfer et al., 2017).

These theoretical foundations contribute to understanding the circular economy as a holistic approach that links various aspects of society, the economy, and the environment in the pursuit of sustainable development.

Based on these theoretical premises, numerous characteristics and principles have been developed that enable the practical application of the circular economy under contemporary conditions. These characteristics form the basis of its functional operation and represent concrete mechanisms for achieving its goals.The circular economy is grounded in several key principles and practices that together create a comprehensive and efficient system (European Commission, 2015; Preston, 2012; Lewandowski, 2016):

Design for Durability and Reuse. Sustainable design is essential, as products should be created to last, be resistant to wear and tear, and be easy to repair and upgrade (Bocken et al., 2016).

Maintenance and Extension of Product Life. Instead of products quickly becoming obsolete and discarded, their regular maintenance, repair, and refurbishment are encouraged. This approach not only conserves resources but also generates jobs in service and craft sectors, strengthening the local economy.

Recycling of Materials and Resources. When a product can no longer be used in its original form, its constituent materials are collected, sorted, and recycled, returning them to the production cycle. High-quality recycling depends on prior product design and the existence of well-developed waste management infrastructure, enabling natural resource preservation and reducing the ecological footprint.

Use of Renewable Energy Sources. Instead of fossil fuels, the circular economy promotes the use of energy from renewable sources such as solar, wind, and hydropower. This reduces harmful gas emissions and supports long-term ecological balance, while enabling circular production and processing processes.

Innovative Business Models Based on Sharing and Services. New models, such as “product-as-a-service,” change the traditional relationship between ownership and consumption. Companies retain ownership of products while users pay for their use or for the service, encouraging more efficient resource utilization (Ospina-Mateus et al., 2023).

Integration of Technology and Digitalization. Modern technologies enable monitoring and optimization of product and resource use throughout their life cycle. This contributes to higher efficiency, waste reduction, and improved sustainability (Ospina-Mateus et al., 2023).

Contemporary trends in circular economy development increasingly rely on digital technologies, sectoral synergies, and strategies that connect local and global approaches. The role of education, policy instruments, and sector-specific innovations is further emphasized in the recent literature, particularly in the context of the green transition and European climate objectives (Govindan & Hasanagic, 2018).

2. HISTORICAL DEVELOPMENT OF THE CIRCULAR ECONOMY CONCEPT

After examining the theoretical foundations and key characteristics of the circular economy, it is essential to consider its historical development in order to understand how this concept emerged, evolved over time, and gained increasing importance in contemporary economic and environmental policies.

Although the circular economy has been strongly affirmed only in the past two decades, its roots can be traced to earlier reflections on sustainability, the rational use of resources, and a systemic understanding of the relationship between the economy and nature (Geissdoerfer et al., 2017; Korhonen et al., 2018). Practices such as reuse, extending product lifespans, and minimizing waste were characteristic of traditional societies and early forms of localized economic systems. However, with the development of mass industrial production and the dominance of consumer society after the Second World War, the linear model of economic growth - based on the “take-make-use-dispose” principle - became globally dominant (Ghisellini et al., 2016).

At the same time, in the late 1960s and throughout the 1970s, environmental movements strengthened, and awareness grew about the limitations of natural resources and the harmful impacts of contemporary production-consumption patterns. Of particular importance in this context was the Club of Rome’s report *The Limits to Growth* (Meadows et al., 1972), which warned of the negative consequences of uncontrolled economic growth and provided strong impetus for considering alternative development models. Within this intellectual framework, theories emerged that laid the foundations for the modern concept of the circular economy. Ecological economics brought ecosystems and their limitations into the focus of economic analysis, while industrial ecology explored possibilities for optimizing material and energy flows within industrial systems (Mac Arthur, 2013; Kirchherr et al., 2017). A notable contribution came from the cradle-to-cradle concept (McDonough & Braungart, 2010), which advocates designing products so that their components can be fully recycled or biodegraded without negative environmental impacts.

During the 2000s, the circular economy became a recognized term in corporate strategies and public policies, especially after China adopted the *Circular Economy Promotion Law* in 2008 (Yuan et al., 2006). The establishment of the Ellen MacArthur Foundation in 2010 marked a turning point in popularizing and systematically elaborating the concept through collaboration with leading companies and institutions. The Foundation provided a clear theoretical framework and practical guidelines for applying the circular model, significantly contributing to its global recognition.

Further institutional development was marked by the adoption of the *Circular Economy Action Plan* by the European Union in 2015 (European Commission, 2015). Within the framework of the *European Green Deal* of 2020, the concept was positioned as a key element in the transition toward a sustainable and resilient economic system (European Commission, 2020). As a result, the circular economy has gone beyond the boundaries of theoretical discourse, increasingly establishing itself as an operational framework that integrates innovation, digital transformation, and sustainability principles to support long-term economic development and environmental protection.

This historical overview demonstrates that the circular economy is not merely a contemporary trend, but the result of a long-term evolution of ideas, theories, and practices that are now being institutionalized to address the complex challenges of the modern era.

3. CIRCULAR ECONOMY AND SUSTAINABLE DEVELOPMENT

3.1. *Contribution of the circular economy to the economic, environmental and social dimensions of sustainability*

The circular economy (CE) is based on a closed-loop system of resources and materials, aimed at reducing the use of new raw materials, extending product lifespans, and promoting their reuse, recycling, and regeneration. This significantly reduces negative environmental impacts and contributes to sustainable development on multiple levels (Kirchherr et al., 2017). CE is not merely an environmental approach but an integrated framework that unites three key dimensions of sustainability: economic, environmental and social.

On the economic level, the circular economy improves resource efficiency, meaning that less investment is needed in new raw materials and energy, thereby lowering production and operational costs. It also stimulates the development of innovations and new business models, such as servitization (when a product becomes a service, e.g., rental instead of purchase) and the "product-as-a-service" concept. By fostering the development of local value chains, CE can significantly reduce dependence on raw material imports, thus strengthening the domestic economy (Geissdoerfer et al., 2017).

The environmental aspect of sustainability is reflected in the reduction of waste and greenhouse gas emissions. Through the reuse and recycling of materials, the need for extraction and processing of new natural resources is reduced, directly mitigating the negative effects of industrial development on the environment. This approach is essential for addressing climate change and preserving ecological balance (Ellen MacArthur Foundation, 2019).

The social aspect of the circular economy involves the creation of new so-called green jobs in sectors such as recycling, sustainable design, product repair, and maintenance. This strengthens the local economy while improving citizens' quality of life by promoting social justice and the inclusion of diverse social groups. Active citizen participation, education, and awareness-raising on responsible consumption and production are key elements that enable the wider adoption and effective implementation of CE principles (Ospina-Mateus et al., 2023).

In this way, the circular economy serves as a comprehensive model that facilitates the harmonious development of the economy, society, and the environment, ensuring sustainability and long-term benefits for future generations (Kirchherr et al., 2017; MacArthur, 2019).

3.2. *The relationship between the circular economy and the sustainable development goals* (UN SDGS)

The concept of the circular economy is closely linked to the global 2030 Agenda and the Sustainable Development Goals (SDGs), adopted by the United Nations as a framework for achieving sustainable development worldwide (United Nations, n.d.). Through its principles and practices, CE directly contributes to the achievement of several UN goals, particularly the following:

Goal 12: Responsible Consumption and Production. CE promotes efficient resource use and waste reduction throughout all stages of the production and consumption cycle. This includes designing products for longer lifespans, repairability, and recyclability, thereby reducing negative environmental impacts.

Goal 13: Climate Action. By reducing carbon dioxide (CO_2) emissions and energy consumption through the rational use of resources and renewable energy sources, CE significantly contributes to climate change mitigation and reducing the effects of global warming.

Goal 9: Industry, Innovation, and Infrastructure. By promoting innovative technologies and sustainable business models, CE stimulates industrial growth that is both environmentally friendly and technologically advanced.

Goal 8: Decent Work and Economic Growth. CE generates new jobs, particularly in recycling, sustainable design, repair, and maintenance, contributing to inclusive and sustainable economic development.

Goal 11: Sustainable Cities and Communities. By implementing CE principles in urban planning and waste management, waste generation and pollution are reduced, quality of life is improved, and the ecological sustainability of cities is enhanced.

Goals 6 and 15: Clean Water and Terrestrial Ecosystems. By reducing water pollution and protecting terrestrial ecosystems, CE indirectly supports the preservation of natural resources, which is essential for biodiversity and ecological stability.

In this way, the circular economy is not merely a standalone development model but also an effective tool for operationalizing and localizing the UN Sustainable Development Goals. Through concrete policies and practices, CE enables global goals to be implemented in practice, creating the conditions for a more sustainable and resilient future.

4. POLICIES AND INSTITUTIONAL FRAMEWORKS FOR THE DEVELOPMENT OF THE CIRCULAR ECONOMY

The development and implementation of the circular economy largely depend on strategic policies, legislative frameworks, and international cooperation. In this context, the European Union, international organizations, and individual countries represent key actors in shaping and implementing this model. The European Union is among the most active promoters of the circular economy, integrating this concept into its development and climate policies. The European Green Deal, presented in 2019, sets an ambitious goal for Europe to become the first climate-neutral continent by 2050, with the circular economy recognized as a key mechanism for achieving the green transition, reducing pressure on natural resources, and strengthening the long-term competitiveness of the European economy (European Commission, 2019).

The Circular Economy Action Plan (CEAP), adopted in 2020, serves as a concrete operational framework for achieving these objectives. The plan outlines a series of priorities, including the design of long-lasting products through the application of eco-design principles, the protection of consumer rights and the fight against planned obsolescence, the development of secondary raw materials markets, and a focus on sectors with high potential for circular transformation - electronics, batteries, textiles, construction, and plastics (European Commission, 2020). CEAP is directly linked to the EU's zero-pollution strategy, and its legislative framework encompasses directives related to waste management, packaging, electronic waste, green public procurement, and the EU Ecolabel for environmentally friendly products.

International organizations also play an important role in promoting and operationalizing the circular economy, acting as knowledge carriers, funding sources, and platforms for experience sharing. The United Nations (UN), through its agencies such as UNEP and initiatives like the Sustainable Development Goals (SDGs), provides technical assistance, develops guidelines for creating national strategies, and promotes sustainable consumption and production patterns (United Nations, n.d.-a; United Nations Environment Programme, n.d.). The Organisation for Economic Co-operation and Development (OECD) conducts public policy analyses, offers recommendations for tax incentives and regulatory mechanisms, and organizes forums and exchanges of best practices among member and partner countries (Organisation for Economic Co-operation and Development, 2020). The World Economic Forum (WEF), through its Platform for Accelerating the Circular Economy (PACE), connects the public and private sectors to speed up the transition to circular models (World Economic Forum, n.d.).

Despite differences in institutional capacities, numerous practical examples demonstrate the potential for implementing circular principles at the national level. The Netherlands has set a clear goal of becoming a fully circular economy by 2050 (Government of the Netherlands, 2016). The key elements of its strategy include public-private partnerships and the broad application of circular public procurement. Finland was the first country to adopt a comprehensive national circular economy strategy in 2016, focusing on innovation, education, and climate policies (Sitra, 2016). China, as the first country to enact a circular economy law (2009), has integrated this concept into its national development plans (National People's Congress of China, 2008). In the Western Balkans, Slovenia and Croatia lead in adopting circular economy strategies (Republic of Slovenia, 2018; Government of the Republic of Croatia, 2021), while other countries in the region, including Montenegro, Serbia, and Bosnia and Herzegovina, are intensifying activities to strengthen legislative and institutional capacities. For the countries of the region, the circular economy represents not only an environmental imperative but also a means of increasing competitiveness and achieving alignment with the standards and regulations of the European Union (Ministry of Ecology, Spatial Planning and Urbanism of Montenegro, 2023; Ministry of Environmental Protection of the Republic of Serbia, 2022; Council of Ministers of Bosnia and Herzegovina, 2021).

5. CHALLENGES AND LIMITATIONS IN IMPLEMENTING THE CIRCULAR ECONOMY

Although the concept of the circular economy offers significant advantages in terms of sustainability, competitiveness, and the rational management of resources, its practical implementation faces a number of challenges and limitations. These challenges can be grouped into several main categories: economic, regulatory, infrastructural, educational, and socio-cultural barriers (Milović et al., 2024; Valkokari et al., 2025; Ile et al., 2025).

The first, and often most critical, challenge is the lack of economic viability of circular models compared to the traditional linear approach. The costs of recycling, product refurbishment, or adaptation of production processes often exceed the market prices of raw materials and finished products, particularly in countries where regulation is weak and subsidies are directed toward extractive industries. Consequently, companies are reluctant to invest in transitioning to circular models without adequate financial incentives (Milović et al., 2024; Spring et al., 2025).

In addition to economic factors, there are regulatory obstacles, including inconsistencies in legislation on waste management, environmental protection, customs regulations, and quality standards. Such inconsistencies can hinder the trade of secondary raw materials and circular products, especially across borders (Valkokari et al., 2025). In many countries, the legal framework not only fails to encourage circular practices but sometimes even discourages them (Milović et al., 2024).

Socio-cultural factors further complicate the situation. Consumer habits, resistance to "second-hand" products, and distrust in the quality of recycled goods often pose significant barriers. The "buy-and-discard" mentality, dominant in many societies, does not encourage long-term use, repair, or reuse of products (Ile et al., 2025; Valkokari et al., 2025).

Successful implementation of the circular economy requires adequate physical, technological, and logistical infrastructure. In many countries, especially developing ones, there is a lack of waste sorting facilities, modern processing technologies, and repair and reuse centers (Milović et al., 2024; Valkokari et al., 2025). The absence of these essential elements significantly limits the potential for broader application of circular principles. Alongside infrastructural challenges, there is also a clear lack of knowledge and education - not only among entrepreneurs and managers but also among citizens and public administration. Without an understanding of the essence of the circular economy and its benefits, it is difficult to expect behavioral change and the adoption of innovative solutions (Milović et al., 2024).

An additional challenge is resistance to change within business models themselves. Transitioning from a linear to a circular model requires structural changes in production processes, supply chains, organizational structures, and investment strategies. This transition is often perceived as risky and costly, particularly when the payback period is not clearly defined, which leads to resistance from stakeholders involved in the process (Milović et al., 2024). Furthermore, there are conflicts of interest between sectors - for example, industries dependent on the exploitation of natural resources may have an interest in maintaining the linear model, leading to lobbying against the introduction of circular regulations. Political will, lack of coordination between sectors, and uneven approaches at national and local levels further complicate the implementation of systemic solutions (Valkokari et al., 2025).

All of these barriers clearly indicate that successful implementation of the circular economy is a complex process requiring an integrated approach, including economic incentives, a harmonized regulatory framework, adequate infrastructure, education, and changes in societal attitudes (Ile et al., 2025).

6. RECOMMENDATIONS FOR IMPROVEMENT AND FURTHER RESEARCH

The implementation of the circular economy requires a systemic and coordinated approach encompassing activities at the levels of policy, education, the economy, and society as a whole. Based on the identified challenges and limitations, several key recommendations and guidelines for further development and action can be outlined.

First and foremost, it is essential to strengthen institutional and legislative support for the circular economy through the development of clear strategies, action plans, and incentive measures. National policies should be directed towards promoting circular models by introducing tax reliefs, subsidies for innovation and green technologies, and establishing markets for secondary raw materials. Furthermore, education and capacity building are crucial - both through the formal education system, including the integration of circular principles into curricula at all levels, and through non-formal educational activities such as training, seminars, and awareness-raising campaigns. The promotion of the concept must be continuous and targeted at citizens, businesses, and policymakers, utilizing various communication channels and examples of best practices from other countries.

The business sector plays a central role in the transition to circular models. Companies should be encouraged to develop innovative business models that involve product design for long-term use, repair, reuse, and recycling. In addition, enterprises should adopt ESG standards, promote sustainable supply chains, and invest in green technologies. For its part, the state - beyond its regulatory function - must also assume an active developmental role through investments in infrastructure, public-private partnerships, and the coordination of policies across different sectors. Consumers should be adequately informed and motivated to change consumption habits, support sustainable products, and actively participate in waste separation and recycling systems, thereby contributing to responsible resource management.

With regard to further academic research, the research community plays a vital role in generating knowledge and tools for the effective implementation of the circular economy. Key recommended research directions include: analyzing the impact of circular practices on the competitiveness of enterprises across different sectors; examining consumer behavior towards circular economy products; conducting case studies of CE model implementation in local communities and microenterprises; developing methodologies for measuring circularity and sustainability; and carrying out comparative analyses of national policies, with particular emphasis on their adaptability to developing countries. Interdisciplinary research - linking economics, ecology, engineering, sociology, and management - is especially important, as such an approach enables a deeper understanding of the complexity of transitioning to a circular economy and the identification of optimal models for different countries and regions.

CONCLUSION

This paper has provided a detailed analysis of the key aspects of the circular economy as a concept offering a sustainable and efficient alternative to the traditional linear model of production and consumption. It has been shown that the circular economy significantly contributes to the economic, ecological, and social dimensions of sustainability through more rational resource use, waste reduction, and the application of an ecosystem-based approach.

Institutional and strategic frameworks, particularly at the global and European levels, represent strong incentives for the development of circular practices. At the same time, numerous challenges persist - from economic and regulatory barriers to resistance to change within existing business models. It is evident that without the active involvement of the state, the business sector, and consumers, the transition to a circular economy cannot be successful.

In conclusion, the circular economy is not only an opportunity but also a necessity in the contemporary world, faced with global challenges of environmental protection and the preservation of natural resources for future generations. Urgent, coordinated, and systemic actions by all societal actors are required to achieve the goals of sustainable development. It is crucial to continue raising awareness, improving policies, fostering business innovation, and advancing research to respond effectively to these challenges and create a sustainable and equitable future.

The implementation of circular principles requires multi sectoral collaboration - between the public sector, private companies, the academic community, and citizens. Therefore, the circular economy is not merely a technical or technological solution, but a fundamental systemic transformation in the way we understand and organize economic activity in the service of sustainable development and social justice.

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Statistical analysis of environmental monitoring data in Donbass region

Statistička analiza podataka monitoringa životne sredine u regionu Donbasa

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Abstract: This manuscript contains information on the existing examples of using statistical processing of information in assessing the state of man-made objects in Donbass. The material for analysis was collected on the territory of industrial facilities and anthropogenic ecotopes of large cities in the Northern Azov region – these are indicator plants that are used for assessment and environmental monitoring in ecologically unfavorable conditions in order to have up-to-date information on the degree of disturbance and toxicity of natural environments. The entire set of methods can be divided into: 1) primary control when checking the reliability of the results obtained, linked to the terrain – the exact locality on the map, which allows in the future to include all points in a single geoinformation field and have reliable information about modern Donbass; 2) more in-depth detailed studies of the patterns of relationships in the interaction between the components of biogeocenoses by elemental composition, joint forms and sources of pollution – these are methods of correlation analysis, data visualization in the construction of dendrograms, heat maps and the use of the principal component analysis to understand both the territorial difference between the collected material and the functional differences in the program for the survival of biological objects in conditions of a high technogenic factor in the industrially developed systems of Donbass, which is important for the subsequent system of optimization of natural environments and a more comfortable life for humans in harmony with the environment..

Keywords: statistical methods, determination of patterns, biogeochemistry, pollution, technogenesis, phytoindication, Donetsk region, environmental monitoring.

Sažetak: Ovaj rad sadrži informacije o postojećim primerima korišćenja statističke obrade informacija u proceni stanja veštačkih objekata u Donbasu. Materijal za analizu je prikupljen na teritoriji industrijskih objekata i antropogenih ekotopa velikih gradova u Severnom Priazovlju – to su indikatorske biljke koje se koriste za procenu i praćenje životne sredine u ekološki nepovoljnim uslovima kako bi se imale ažurne informacije o stepenu poremećaja i toksičnosti prirodnih sredina. Čitav skup metoda može se podeliti na: 1) primarnu kontrolu pri proveri pouzdanosti dobijenih rezultata, povezanu sa terenom – tačnim lokalitetom na mapi, što omogućava da se u budućnosti sve tačke uključe u jedinstveno geoinformaciono polje i imaju pouzdane informacije o savremenom Donbasu; 2) dublje detaljne studije obrazaca odnosa u interakciji između komponenti biogeocenoza po elementarnom sastavu, zajedničkim oblicima i izvorima zagađenja – to su metode korelacione analize, vizuelizacije podataka u izradi dendrograma, toplotnih mapa i korišćenja analize glavnih komponenti za razumevanje kako teritorijalnih razlika između prikupljenog materijala, tako i funkcionalnih razlika u programu za opstanak bioloških objekata u uslovima visokog tehnogenog faktora u industrijski razvijenim sistemima Donbasa, što je važno za kasniji sistem optimizacije prirodnih sredina i udobniji život ljudi u harmoniji sa životnom sredinom.

Ključne reči: statističke metode, određivanje obrazaca, biogeohemija, zagađenje, tehnogeneza, fitoindikacija, Donjecka oblast, monitoring životne sredine.

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INTRODUCTION

In the analysis of many vital problems of mankind, statistical methods (as a variant of the mathematical apparatus in the representation of structures and functions) allow us to find patterns and highlight the important, to note what was not detected during the initial examination (Petropavlovsky & Varchenko, 2021; Salugin, 2023; Wang et al., 2024). Biogeochemistry and patterns of migration processes of individual chemical elements and their compounds underlie the understanding of life, the balance of maintaining vital processes at the required level (Ermakov, 2004; Ermakov & Jovanovic, 2010; Jovanović & Ermakov, 2020), which is very important in the conditions of a high level of technogenesis, anthropogenic impact on ecosystems (Jovanović et al, 2023; Kolesnikov et al, 2019; Yeprintsev et al., 2023).

Super new opportunities are opening up for ordinary botanical researchers if the methods of modern statistics are introduced into the practice of environmental diagnostics and decision-making methods in optimizing essential technological processes that ensure life (Berk & Bertsimas, 2019; Kharchenko et al., 2021; Liu et al., 2023).

The main goal of the work presented for demonstration is to identify some patterns of biogeochemical criteria for diagnosing Donbass ecosystems in such a way as to obtain up-to-date information on the state of ecosystems thanks to the applied principles of statistical processing of the obtained results.

1. CONDITIONS, OBJECT AND METHODOLOGY OF THE EXPERIMENT

The methodological part of the work is based on the introduction of progressive methods of correlation analysis (Amorosi et al., 2024; Pearson, 1901), missing data methods (Adnan et al., 2022; Palchevsky, 2023; Wang et al., 2024) or reconstruction of existing sequences into a logically consistent series of their implementation (Li & Xie, 2024; Nugroho & Surendro, 2024; Yao et al., 2012) into practice of biogeochemical results. The leading method for carrying out the planned analysis is the use of principal component analysis (Dray & Josse, 2015; Guo et al., 2024; Xie et al., 2024; Zhong et al., 2023).

A significant part of the research on environmental issues in Eastern Europe and specifically Central Donbass (Dogadkin et al., 2024; Safonov, 2024; Zinicovscaia et al., 2024a) has already been implemented using the principles of using statistical techniques (Nespirnyi & Safonov, 2024ab; Safonov, 2025; Zinicovscaia et al., 2024b) in understanding the patterns of development of living (Ibarra-Manriquez et al., 2022; Korniyenko & Kalaev, 2022; Safonov, 2024; Safonov et al., 2024) and physical causes of the emergence of risk factors (Ermakov & Jovanovic, 2012; Glukhov & Safonov, 2024; Srinivasa et al., 2024) as a result of human activities (Pirko & Kornienko, 2024; Yeprintsev et al., 2019).

The cartographic method that we are implementing in the Donbass region for ecological processes during the military confrontation is also important (Germonova et al., 2024; Safonov, 2024; Zinicovscaia et al., 2024). To obtain information, the author's approaches to understanding the structure of the plant organism as signaling methods for transmitting information about the state of the environment were also used. This method is used in practice to identify geopathogenic zones by terate (anomalous) manifestations of specific neoplasms in the structure of individual cells and tissues in indicator plants. The method combines cytological and general morphological studies and underlies the fundamental processes of adaptation of the plant organism to specific stress factors.

The entire implemented program of botanical and ecological research was based on the principles of biotesting and bioindication (Kosovskaya et al., 2020).

2. RESULTS AND DISCUSSION

General studies of the state of the Donbass ecosystems include a database from 1996 to 2025. During this time, numerous data on the state of indicator plants were obtained for environmental monitoring. It was found that more than 96% of the entire territory of Donbass is a zone of deep anthropogenic transformation. This is primarily due to the extraction of minerals and their processing, developed chemical industry and a high level of urbanization in the region. Indicator plants help to carry out an express analysis of unfavorable factors in many ways, since technological monitoring in the region, especially during a military conflict, does not allow for the installation of high-precision sensors and autonomous observation of risk factors. Therefore, the criterion of geochemical heterogeneity in striking indicators is material evidence of the processes of migration flows of matter (technogenic and anthropogenic nature), which we were able to study in detail thanks to the assistance and analytical control from the employees of the Institute of Geochemistry and Analytical Chemistry of the Russian Academy of Sciences (Moscow).

It has been proven that with the increase of technogenic science, the level of structural polymorphism of plants increases significantly. However, in Donetsk in 2023-2025 there was no such opportunity to establish the level of pollution and the content of individual elements in indicator plants. The statistical apparatus of all data for the period of 2024 combined all values into a single heat map to highlight the patterns of joint entry of elements into the plant organism.

In order to establish the specifics of migration flows and co-flow of particular elements and (or) groups of elements into the plant organism due to the nature of technogenesis, the calculation of pairwise correlation coefficients between the concentrations of various chemical elements in the biomass of indicator plant Phleum pratense was performed. The calculation results are presented in the form of a heat map (Fig. 1), where positive values are shown in red color, negative values – in blue, and the color saturation corresponds to the absolute value of the correlation coefficient. The diagram shows that more than 30% of pairs of elements have a fairly close relationship between their concentrations (determination coefficient R2 is greater than 0.6). Moreover, for the majority of pairs, this relationship is positive. It seems reasonable because since the plant receives several elements at once when environmental pollution increases. The effect of mineralization of phytomass in the conditions of growth and development of plants on slag heap substrates was noted. In the heat map a large group of elements in the upper right corner is visually noticeable. These are mainly lanthanides – rare earth elements, or elements with low percentage abundance. All correlation coefficients between them are almost equal to 1. Thus, we can assume certain cluster of elements that apparently enter the plant at the same time in approximately the same proportions.

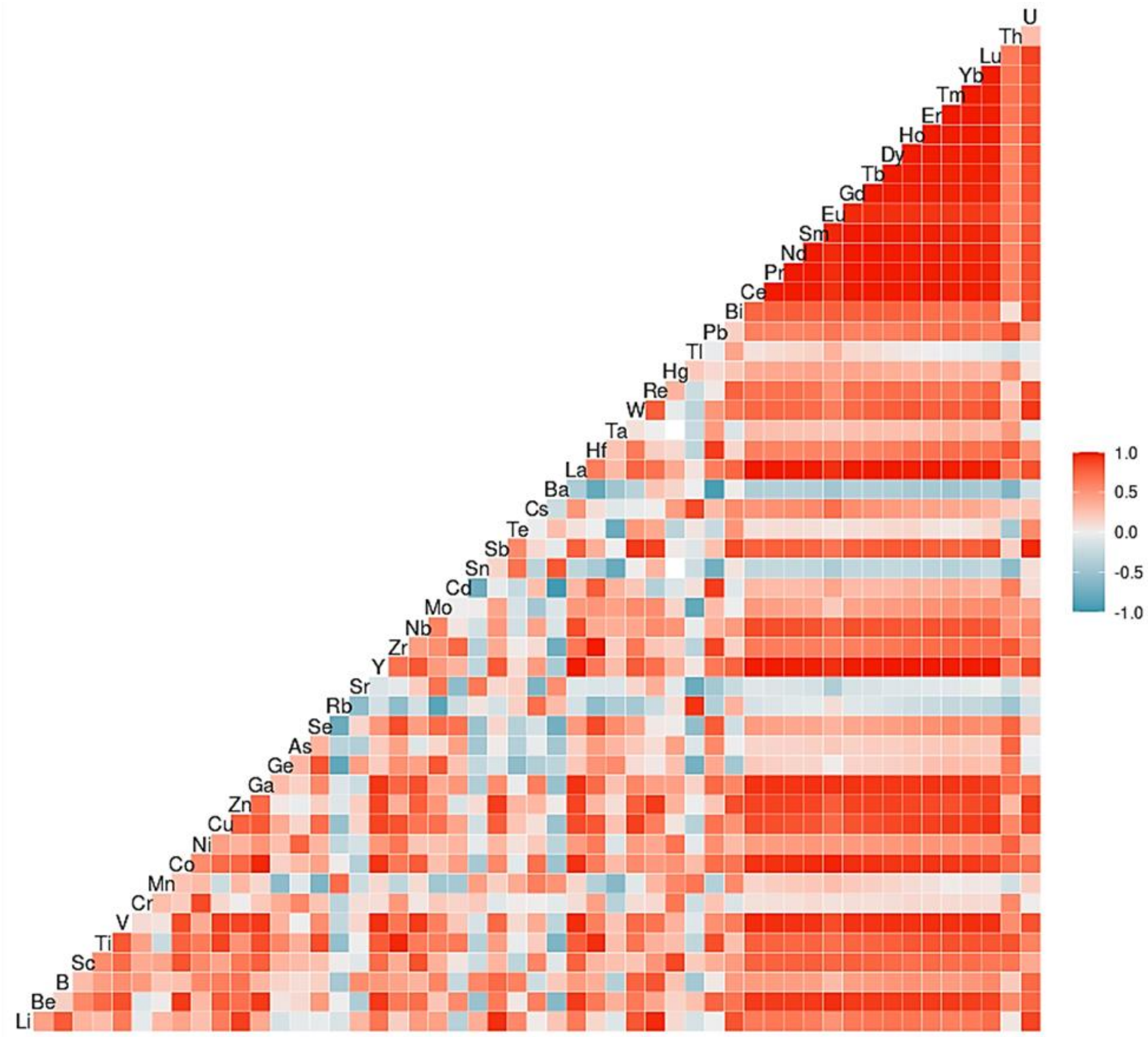

Figure 1. Paired correlation analysis of the elemental composition of Phleum pratense on the waste areas of Donbass

The obtained data on the heat map is the first general achievement and is relevant for industrial facilities of Donbass in terms of content in plants. Such cartographic material was previously obtained only on the basis of neutron activation analysis for bryophytes, conducted at the Joint Institute for Nuclear Research 2018-2023 (Zinicovscaia et al., 2024). However, the information (Fig. 1) is relevant for meliorant plants, or those performing the reclamation function in industrial facilities of Donbass.

To understand the processes of combined pollution or the entry of a group of elements into the environment, an analysis was conducted for individual groups of chemical elements. An extremely high correlation dependence was identified for lanthanides and technophile pollutant elements associated with a high level of anthropogenic load.

Scatter plot matrices (Fig. 2) are very useful for is of fundamental importance in detection for non-linear dependencies in pairs of analyzed elements. The most promising groups for detailed visualization are shown in the figure. Various forms of both direct and indirect close dependence are noted in the paired comparison between the elements.

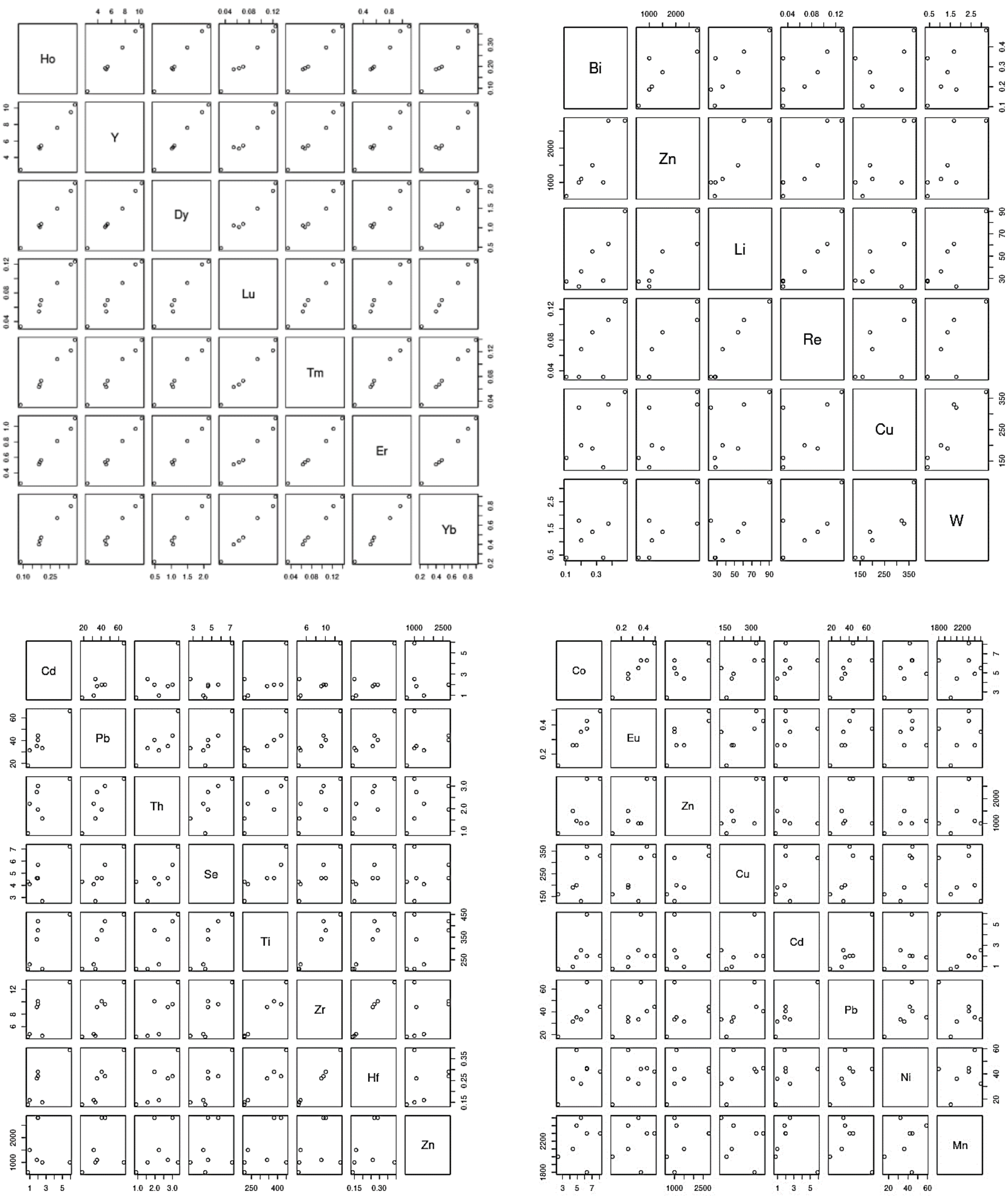

Figure 2. Examples of matrices of scattering diagrams in groups of elements that either have the character of joint migration into plants, or are of interest from the point of view of pollution as a result of technogenesis

At the same time, all correlation coefficients are close enough to +1. An important proof of the unidirectional geochemical nature of plants on landfills is an experiment comparing the geochemical profiles of the landfills with each other (Fig. 3).

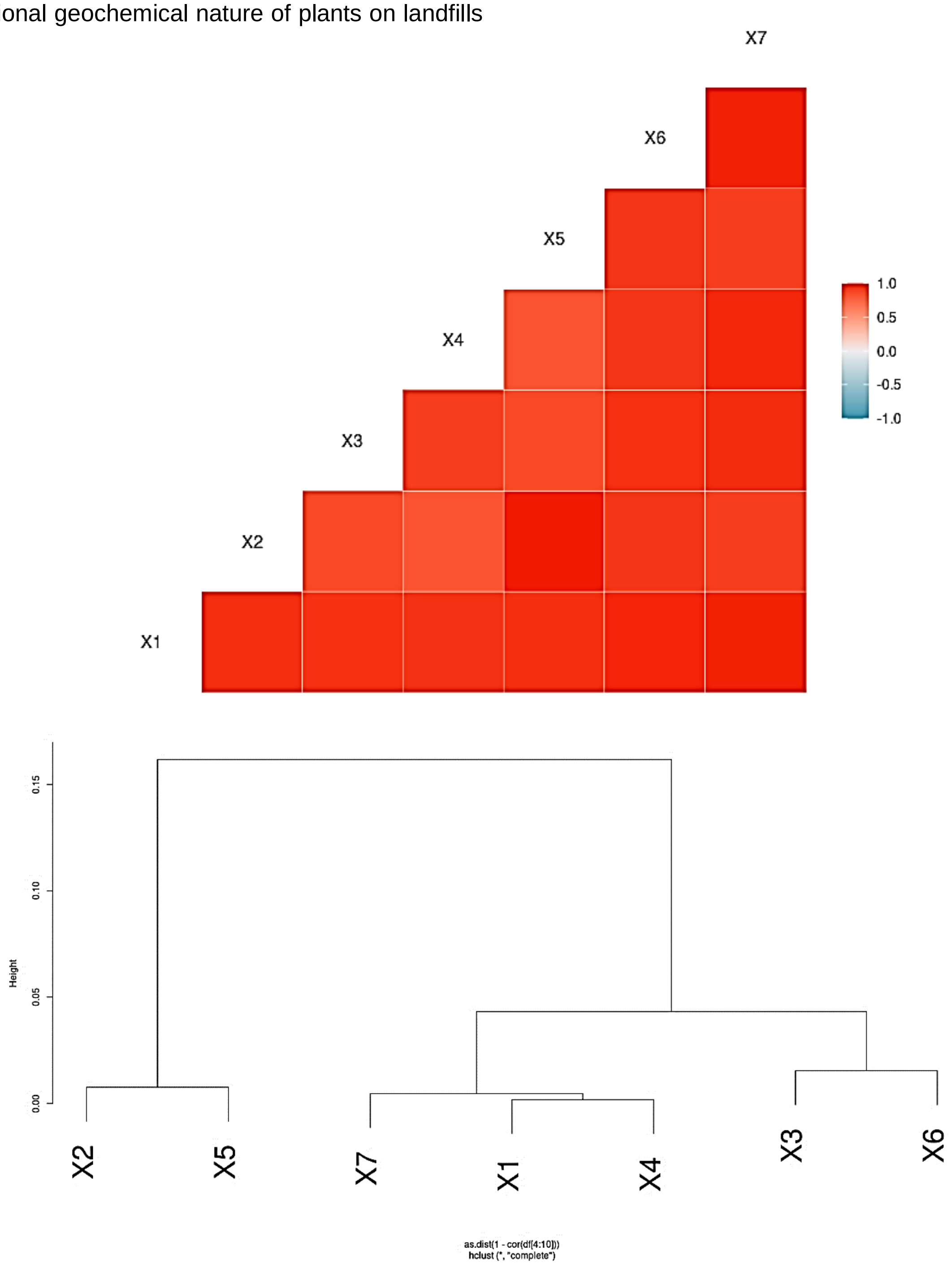

Figure 3. Paired correlation analysis of phytogeochemical similarity between plant samples on different landfills of Donbass

The general pattern of having a single geochemical profile for all the studied landfills emphasizes compliance with a single system of anthropotechnogenesis in the region, since the characteristics of one program of industrial production – the mining complex are considered. The densest correlation was found in pairs of central factory districts and mines in the eastern neighborhoods of Donetsk on the border with Makeevka.

The closest relationship was established in the groups of joint accumulation of elements: lanthandes, Zr-Hf, Co-Eu, Li-Re-(Zn), Rb-Tl, Cd-Pb, Sc-Hg, Cr-Ni, Sb-U-(W-Cu). However, given the small volume of the initial sample, such patterns should be further studied during repeated sampling in order to confirm or refute the indicated trends. At the same time, there is a need for a more detailed consideration of some elements on the scale of real concentrations, since their indicator value in the ecological and botanical aspect of toxicological monitoring of Donbass was previously established.

It was possible to collect all the information on the geochemical trailers of element accumulation in the meliorant plant growing on the waste heaps of large cities of Donbass using a paired heat map reflecting both the relationships between the elements and the correspondence of these relationships with each other using the principle of scaling by rows and without scaling by rows (Fig. 4).

When using the principal component analysis method, the arrangement of elements in the field of waste heap points has the following patterns, which are shown in Figure 5.

We were faced with the task of imputing data that were lost or missed for values independent of the experimenter. Imputation is important for reconstructing some of the missing data (5, 10, 25%) for one row in the event that the geochemical profile for the dumps of the Donbass coal mines was determined earlier and retains trends in the ratio of adjacent coordinates (tables 1 and 2). To create full-fledged arrays, this method is important for reconstructing the entire line of values and the possibility of full-fledged analysis for large-scale experiments. Moreover, in the following years, a repeat of the sampling and their analysis on high-precision chemical analytical control equipment is planned.

In this case, 1-2 components were chosen as the main ones for statistical reliability (tables 1 and 2). The remaining components also carry certain information and are a statistical background for understanding the basic values of X1 and X2 if the recovery data can be compared with the main pollution factors, including metallurgical activity and natural geochemical contrast, which is recorded for this area based on previously obtained results.

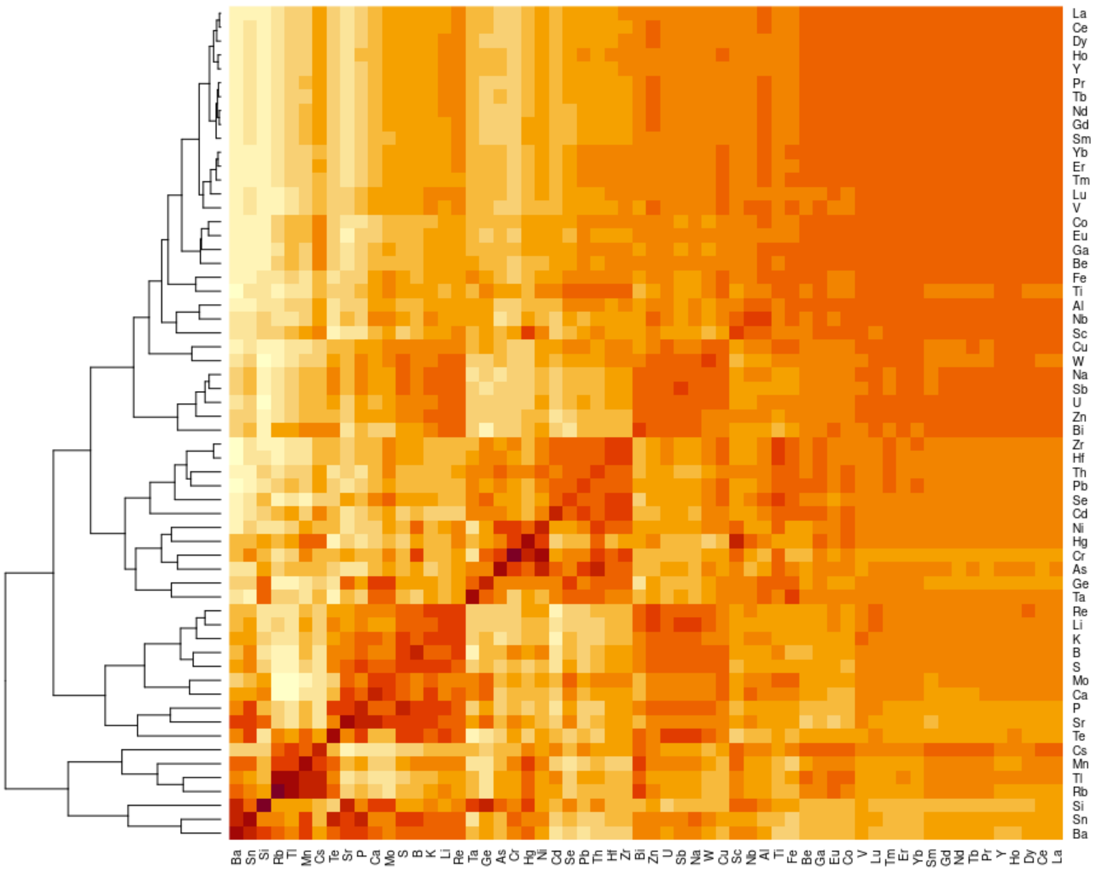

Figure 4. Combination of processes of biogeochemical conjugation of element concentration in tissues of the remediate plant using data scaling by rows and symmetry disappears, but correlation is preserved

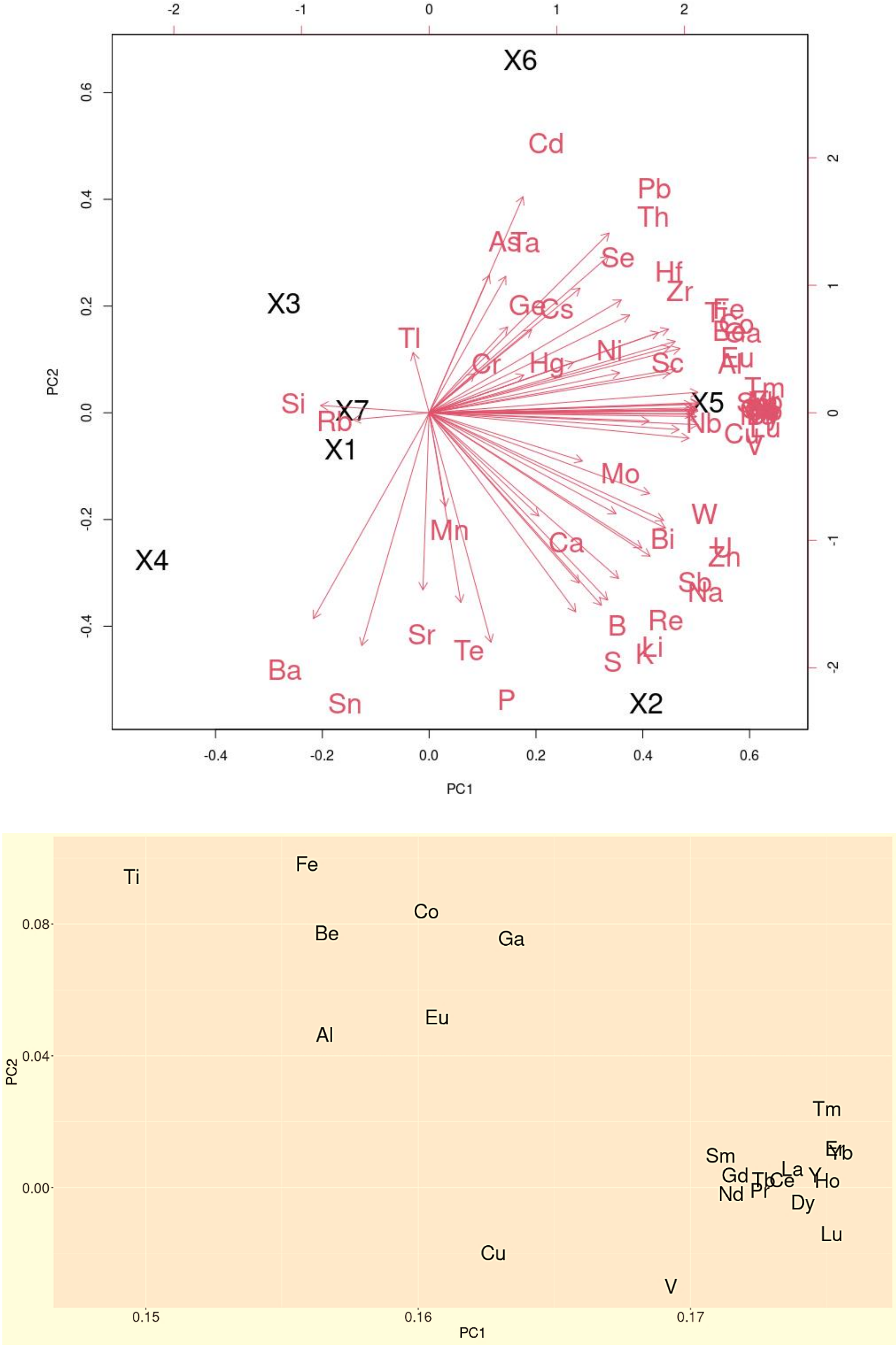

Figure 5. Distribution of chemical elements in the projection of the first two principal components (general scheme and detailing of the dense conjugation node)

Table 1. Calculation of concentrations of elements (Li-Nd) of the main components for the reconstructed values of waste heap A, mg/kg

Elements	X1	X2	X3	X4	X5	X6
Li	64.210	86.556	87.176	89.225	89.410	91.794
Be	0.854	0.754	0.765	0.810	0.797	0.797
B	376.06	438.09	436.39	448.05	454.10	452.01
Na	1835.8	2618.9	2647.6	2941.5	2935.3	2906.5
Al	305.211	280.696	280.153	237.633	231.603	225.721
Si	15445.8	15422.7	15350.4	14174.9	14142.5	14218.4
P	1696.4	2115.9	2099.9	2228.5	2236.5	2210.5
S	2656.4	3283.2	3258.0	3427.3	3434.9	3445.3
K	17738.2	22911.8	22846.3	21575.6	21480.1	21531.0
Ca	5126.8	5833.5	5691.1	5127.9	5071.7	5088.3
Sc	12.814	12.421	12.475	10.895	10.903	10.874
Ti	420.693	375.820	371.267	385.737	388.069	379.132
V	31.498	32.245	32.264	30.776	30.584	30.009
Cr	60.728	51.207	49.939	40.281	46.563	42.095
Mn	2217.2	2332.3	2362.5	2269.1	2282.9	2271.3
Fe	379.727	322.007	317.810	309.665	303.434	302.082
Co	7.295	6.589	6.670	6.268	6.247	6.226
Ni	47.202	43.561	43.550	42.863	44.378	44.611
Cu	344.158	348.898	345.726	376.426	376.002	373.523
Zn	2450.0	2942.0	2970.9	2787.5	2774.4	2809.3
Ga	4.763	4.305	4.336	4.144	4.126	4.020
Ge	1.834	1.592	1.523	1.237	1.237	1.213
As	2.448	2.395	2.393	2.388	2.393	2.409
Se	5.647	4.736	4.592	4.748	4.733	4.649
Rb	252.70	260.64	285.61	268.67	264.65	260.59
Sr	962.7	1253.4	1223.3	1127.4	1130.9	1103.2
Y	9.702	9.553	9.616	9.506	9.460	9.499
Zr	10.882	9.102	8.932	10.255	10.393	10.101
Nb	4.789	4.818	4.821	3.053	2.929	2.715

Table 2. Calculation of concentrations of elements (Mo-U) of the main components for the reconstructed values of waste heap A, mg/kg

Elements	X1	X2	X3	X4	X5	X6
Mo	46.261	49.602	47.931	43.326	43.242	43.314
Cd	2.977	1.089	1.055	2.078	2.074	2.006
Sn	0.507	0.596	0.597	0.600	0.605	0.596
Sb	2.133	2.832	2.860	3.221	3.220	3.316
Te	0.100	0.111	0.120	0.121	0.120	0.120
Cs	1.850	1.686	1.542	1.496	1.496	1.553
Ba	1473.5	1712.6	1719.0	1588.2	1592.0	1590.6
La	20.172	19.782	19.933	19.037	18.904	18.923
Hf	0.313	0.258	0.253	0.295	0.298	0.292
Ta	0.044	0.038	0.038	0.034	0.033	0.035
W	2.335	2.703	2.689	3.233	3.252	3.323
Re	0.102	0.135	0.135	0.127	0.128	0.133
Hg	0.009	0.008	0.008	0.008	0.007	0.007
Tl	0.371	0.282	0.324	0.304	0.298	0.293
Pb	49.754	36.051	35.684	40.882	40.902	41.091
Bi	0.384	0.447	0.459	0.474	0.473	0.484
Ce	41.542	40.924	41.256	39.313	39.021	38.988
Pr	4.636	4.588	4.633	4.428	4.398	4.398
Nd	17.963	17.804	18.003	17.176	17.065	17.094
Sm	3.235	3.159	3.195	3.047	3.030	3.030
Eu	0.457	0.426	0.433	0.425	0.423	0.423
Gd	3.031	2.982	3.014	2.873	2.855	2.862
Tb	0.389	0.383	0.387	0.373	0.371	0.374
Dy	1.981	1.970	1.985	1.945	1.936	1.944
Ho	0.365	0.360	0.362	0.362	0.361	0.363

Er	1.016	0.991	0.995	0.971	0.966	0.969
Tm	0.129	0.124	0.124	0.123	0.122	0.122
Yb	0.834	0.814	0.816	0.802	0.798	0.802
Lu	0.119	0.120	0.120	0.120	0.120	0.121
Th	2.898	2.208	2.172	1.926	1.955	1.987
U	1.809	2.199	2.221	2.508	2.511	2.521

One of the objectives of the research is to determine the geochemical relationship between the indicators of different waste heaps in terms of accumulation in the active phytomass of a plant that is a remediant and is present on all waste heaps – dumps of coal mines in Donbass as the main component in the formation of a stable vegetation cover of a grassy formation. Using the principal component analysis, it was established in the projection of the first two principal components (Fig. 6) - which of the waste heaps have a similar geochemical nature, and therefore, apparently, are characterized by a similar source of mineral extraction and whether unique sequences are formed in the values of elements, so that they can also be allocated to a separate block of analyses.

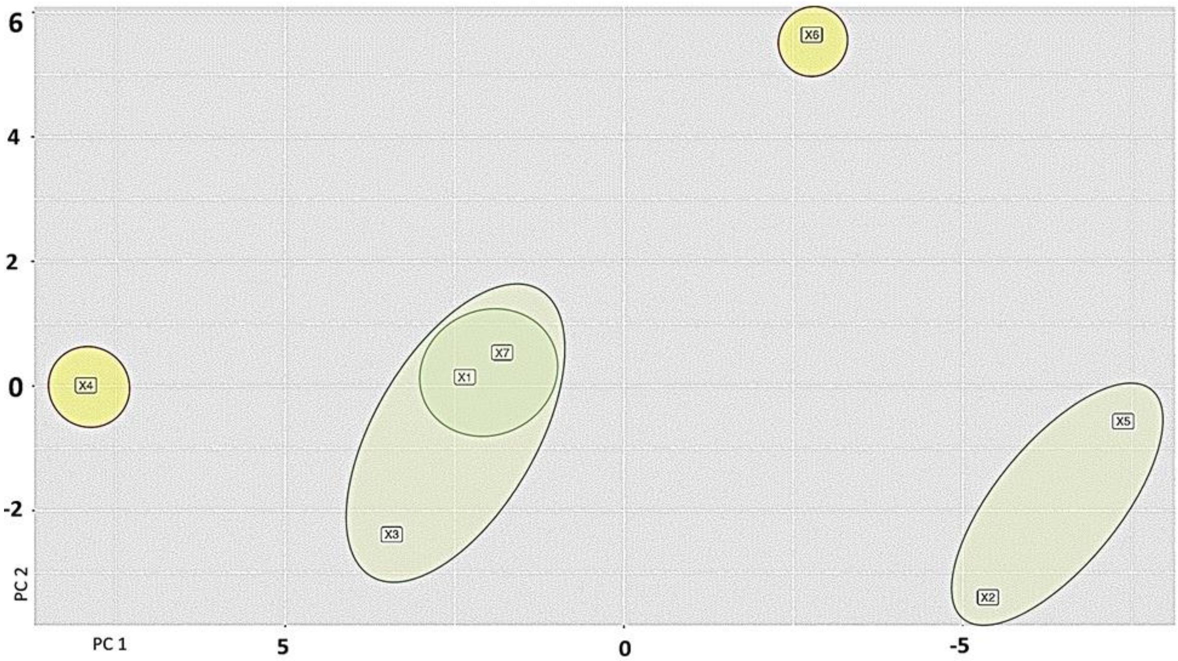

Figure 6. The phytogeochemical similarity in the plane of the two main components between plant samples on different landfills of Donbass

According to preliminary expectations, the geochemical profile may be characteristic of 5-7 scenarios for all waste heaps of Donbass, however, this principle and patterns require statistical verification of the data. In Fig. 6. There are two such fundamental spatial coincidences in relation to the patterns of geochemistry in the data complex of waste heaps 1, 7 and 3, as well as 2 and 5. And when considering 7 waste heaps, it was found that individual biogeochemistry is characterized by waste heaps 4 and 6, which are located at a large distance in the projection of the first two main components, if we load all the known data on them for 2023 and 2024. It is fundamentally important that this information was obtained precisely by the content in the dominant species of the indicator plant. This indicates the migration properties of these elements and the physiological activity of those chemical compounds that will determine the unevenness in the data and the heterogeneity in concentrations for the plant organism.

If the data on waste heaps A and B are added to the general pool of values, then it is possible to establish a very close ratio of geochemical patterns in the pair of correspondences of the profile of waste heap B and X4, as well as A and X2 (the data are shown in Fig. 7). This indicates a single resource potential and source of formation of the coal mine dump, which is reflected in the cumulative capacity of elements in the indicator plant.

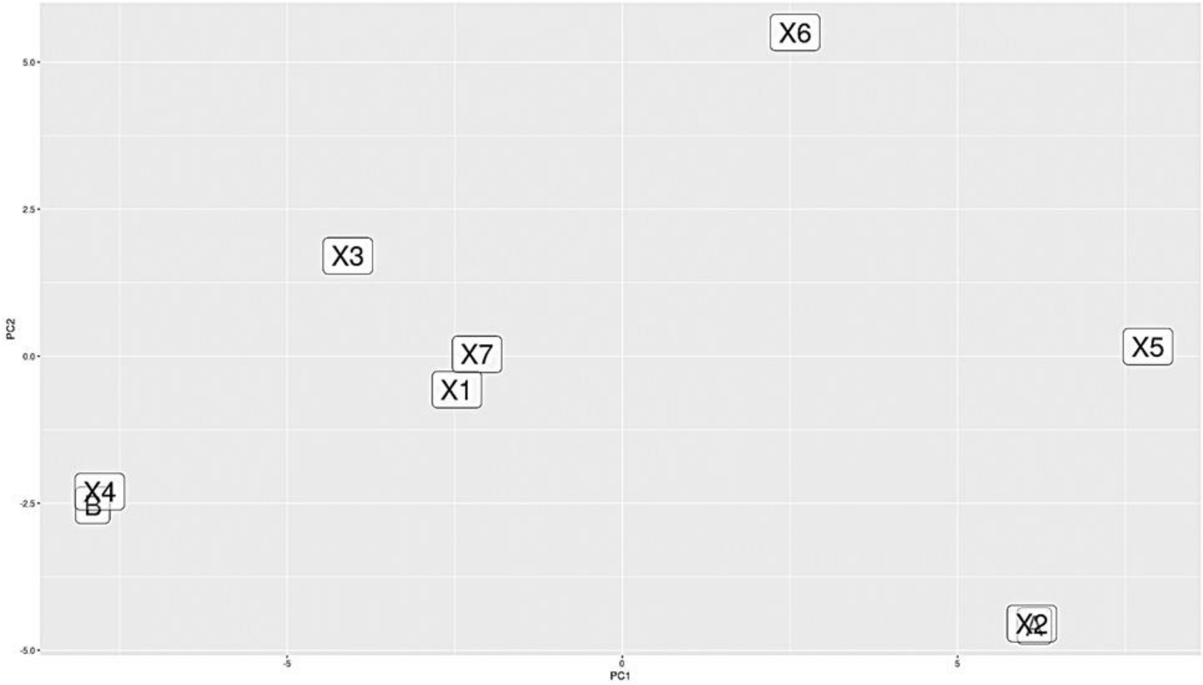

Figure 7. Locations of waste heaps in the projection of the first two principal components along the geochemical profile with the addition of waste heaps A and B with imputed concentration values of missing data to X1-X7

Such coincidences and patterns turned out to be real to establish only as a result of correlation analysis and principal component analysis. In the primary geobotanical study, the accounting sites with the dominant species have no visual differences, according to concentrations and analysis of the elemental composition, this pattern is significantly manifested and it is possible to conduct an examination of pollution according to a specific scenario of the influence of the geochemical environment on the plant organism.

In conditions of geochemical contrast, it is also possible to note structural changes for large morphological characteristics of plants, so that it is possible to conduct express analysis in field conditions and diagnose the level of technogenic load based on atypical morphogenesis of plants.

In field diagnostics, the most multiple teratous manifestations in the plant *Taraxacum officinale (L.) Webb ex F.H.Wigg.* structure are fasciations of the flower arrow (inflorescence peduncle) - directly inflorescences of the first generation of flowering, 2-3 and multiple accretions and a visual tendency to flattening. A comparison of the norm and pathology of the structure during the fruiting period and the still incomplete flowering period (normally) is shown in Figure 8. At the same time, the morphological status of the basal rosette of leaves remains, and the generative part has significant differences in structure.

The diagnosed hypergenesis of the peduncle, apparently, is the cause of multiple atypifications of inflorescences, which is important in field rapid diagnosis. In the case of peduncle hypergenesis (Fig. 8), modifications at the flower level are manifested in dystopia and quantitative differences in parts of the corolla bend, stamens and parts of ovules: polymerization and oligomerization of the stamen series is also associated with modifications of synchocotylia and schichocotylia, which in practice was established by primary seedlings when analyzing seed material after a month-long period of stimulated rest.

In the recorded cases of fasciated intrusions of the peduncle and concomitant inflorescences, the opposite trend is observed: destruction and elimination of many parts of the flower: frequent cases of complete loss of androcea and monomerization of guinecea. at the same time, the quality of seed material sharply decreases to 5-12% of fruits capable of germination, which, of course, sharply reduces the reproductive potential of the species, however, given its cosmopolitanism and explerency, the possibility of full-fledged representation of seed material in the soil bank of the weed-ruderal fraction of the regional flora remains. A separate correlation analysis of the conjugacy of the identified structural anomalies revealed a dependence in the accumulation of some elements in the plant above the norm. The results are shown in Figure 8.

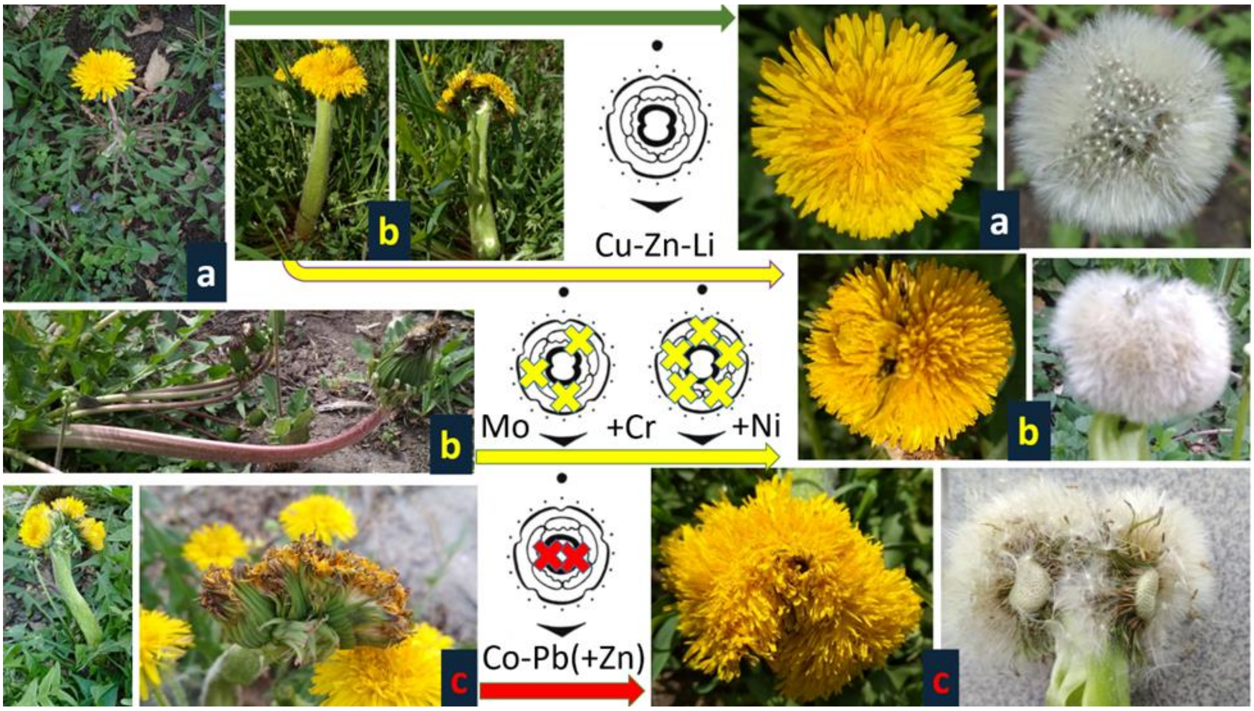

Figure 8. Trends in morphological plasticity of medicinal dandelion under conditions of geochemical contrast in Donbass: habitus structure of inflorescence and inflorescence axis during fruiting in normal (a) and multidirectional pathology (b, c) depending on the nature of contamination

The system of accounting for asymmetry in the structure of botanical objects is also of particular interest in teratology for the future use and more fractional identification of samples for toxicological phytomonitoring. The tasks of the following observations include checking the fluctuation nature of the manifestation of such effects when establishing the phenotypic nature of the recorded indicators of abnormality in the structure of plant samples.

Adaptive mechanisms that allow the species to preserve its natural discrete characteristics (using the example of *Taraxacum officinale*) are manifested in a heteromorphic structure, which, by the nature of fluctuations in dimensional amplitudes and territorial confinement, is considered as an indicator property and allows using data in phyto-indication monitoring and environmental assessment in large areas, which is proved by the example of several districts of Donbass.

Further interest in the framework of phytocenosis observations of stable subpopulations of native plant species can be realized from the point of view of establishing anatomical and morphological effects and physiological processes that cause a wide ecological amplitude and high adaptive potential of plants in conditions of chronic factor of technogenesis and polemostress in the region. The task of establishing conjugate processes in the implementation of different types of survival strategies by plants and possible connections of this fundamental process with individual chemical elements or groups of elements in ecologically unfavorable conditions of life realization also deserves attention.

CONCLUSION

The conditions in which the ecological systems of Donbass develop can be considered critical at the present stage in terms of the level of technogenic load and the factor of human disturbance of the surface and landscape horizons of historically formed geosystems. In such critical conditions, geopathogenic zones arise, which need to be identified to correct the adverse impact of such formations on the adjacent systems and directly on human health.

Nine large technogenic objects were examined for geochemical composition and the state of indicator plant species on these coal mine dumps. Since the coal mining method in Donetsk is underground, the resulting dumps are large objects of accumulated harm that change the landscape and pollute the environment as a result of combustion and migration of active toxic elements in biogeochemical cycles.

The work as a whole combines methods of structural botany, ecological monitoring and analytical control thanks to the joint work of botanists, chemists and mathematicians - the result is a biogeochemical model as a pattern of the implementation of mutual adaptations and adaptation of plants to changing environmental conditions of high anthropogenic transformations.

Thanks to sadistic accounting and methods of mathematical interpretations, some additional patterns were identified in groups of joint receipt and accumulation of individual elements in the plant organism under the conditions of technogenesis factors in Donbass. The task was implemented in the difficult conditions of a military conflict and represents unique information about the environmental characteristics of Donbass in 2023-2024 and the prospects for study in 2025.

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Bioenergy trends in Serbia, Croatia, Hungary, and Bulgaria: a green economy perspective

Trendovi bioenergije u Srbiji, Hrvatskoj, Mađarskoj i Bugarskoj: perspektiva zelene ekonomije

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Abstract: Bioenergy, derived from biomass and organic waste conversion, represents a key component of sustainable energy systems and green economy development. This paper explores bioenergy trends in Serbia, Croatia, Hungary, and Bulgaria, focusing on integration into national energy mixes and alignment with European sustainability frameworks. Emphasis is placed on regional patterns, institutional context, and the role of bioenergy in supporting decarbonization and rural development. The study situates bioenergy within broader discussions on biomass valorization and advanced bioenergy production, highlighting its relevance for future directions in sustainable bioeconomy. Positioned within the European Green Deal and the Green Agenda for the Western Balkans, bioenergy is examined not only as a technological solution but also as a strategic pathway toward energy diversification and low-carbon transition in Southeast Europe.

Keywords: Bioenergy, Biomass valorization, Renewable Energy Sources (RE), Energy transition, Serbia, EU.

Sažetak: Bioenergija, dobijena iz biomase i konverzije organskog otpada, predstavlja ključnu komponentu održivih energetskih sistema i razvoja zelene ekonomije. Ovaj rad istražuje trendove bioenergije u Srbiji, Hrvatskoj, Mađarskoj i Bugarskoj, fokusirajući se na integraciju u nacionalne energetske miksove i usklađivanje sa evropskim okvirima održivosti. Naglasak je stavljen na regionalne obrasce, institucionalni kontekst i ulogu bioenergije u podršci dekarbonizaciji i ruralnom razvoju. Studija smešta bioenergiju u okvir širih diskusija o valorizaciji biomase i naprednoj proizvodnji bioenergije, ističući njen značaj za buduće pravce u održivoj bioekonomiji. Pozicionirana u okviru Evropskog zelenog plana i Zelene agende za Zapadni Balkan, bioenergija se ispituje ne samo kao tehnološko rešenje već i kao strateški put ka diverzifikaciji energije i tranziciji ka niskougljeničnoj energiji u jugoistočnoj Evropi.

Ključne reči: Bioenergija, Valorizacija biomase, Obnovljivi izvori energije (OIE), Energetska tranzicija, Srbija, EU.

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INTRODUCTION

Energy plays an increasingly vital role in contemporary society. As global population expands and economic activity intensifies, energy consumption continues to grow. Simultaneously, concerns over greenhouse gas emissions and environmental degradation are becoming more urgent. A key response to these challenges lies in the adoption of clean energy sources, with renewables emerging as a cornerstone of sustainable development. The transition to renewable energy is driven not only by environmental imperatives but also by the growing recognition of its economic advantages, which are becoming more evident as technologies evolve (Jovanović & Pavlović, 2025). Among renewable sources, bioenergy - defined as the use of biomass feedstocks for energy production - has gained increasing relevance across Europe (Wu & Phenniger, 2023). The world demand for energy has shifted from fossil fuel to the use of bioenergy due to the skyrocketing price of fossil fuels, environmental concerns, and depleting reserves. Consequently, countries around the world have put in efforts to advance the production of biofuels from cheap and readily available feedstocks (Oladoye et al., 2024). Beyond environmental benefits, bioenergy development carries socio-economic implications, particularly in rural regions. Feedstock such as organic waste and manure are perceived as an effective contributor to the energy transition and, therefore, have a higher public acceptance than energy crops and wood, which score lower on perceived effectiveness and, therefore, lower on public acceptance (Dijk et al., 2024).

In the Western Balkans, countries such as Bosnia and Herzegovina, Albania, and North Macedonia currently operate at relatively low levels of bioenergy utilization, while Montenegro has yet to activate this potential. Serbia stands out within the region for its active efforts to develop bioenergy infrastructure and policy. Serbia has a significant energy potential of most renewable energy sources. The potential for energy utilization of biomass is not dependent on weather conditions, time of day, or season, unlike other renewable energy sources such as wind and solar power (Mladenović et al., 2022). However, this potential is poorly utilized due to the dominance of outdated technologies, especially in the energy sector (Jovanović & Pavlović, 2024). In contrast, neighboring EU member states demonstrate more advanced implementation and measurable outcomes in this domain. Understanding the dynamics of bioenergy development requires a multidimensional perspective - one that encompasses production trends, legislative harmonization, institutional capacity, and market orientation. By comparing Serbia with selected EU neighbors, this study seeks to identify structural strengths and limitations, offering insights into how bioenergy can be more effectively integrated into national energy strategies and green economy frameworks.

Within the framework of the European Green Deal, bioenergy is recognized as a key component of the transition toward climate neutrality by 2050. This strategy promotes the use of sustainable energy sources, including biomass, while emphasizing safeguards for biodiversity, land use, and emissions. For Western Balkan countries, the Green Deal has been extended through the Green Agenda for the Western Balkans, adopted in 2020, which calls for decarbonization, sustainable mobility, circular economy development, and nature protection. Bioenergy is positioned within this agenda as part of broader efforts to diversify energy sources and support rural development. Additional EU-supported initiatives - such as the 2023 Growth Plan for the Western Balkans and the Western Balkans Investment Framework (WBIF) - include targeted support for renewable energy projects, including bioenergy, through mechanisms such as EFSD+ guarantees and technical assistance for institutional capacity building. These instruments provide a strategic foundation that, when complemented by coherent national policies, can accelerate bioenergy development across the region.

1. METHODOLOGY

The research adopts a descriptive, analytical, and comparative approach to examine bioenergy development across selected European countries. The analysis draws on data from the International Renewable Energy Agency (IRENA, 2025) and the International Energy Agency (IEA, 2025).

The first part of the research provides a structured overview of national energy mixes, with particular emphasis on the share of bioenergy within each system. The second part presents a comparative assessment between Serbia, Croatia, Hungary, and Bulgaria, alongside the EU-27 average, focusing on installed bioenergy capacity, net increase over the 2015-2024 period, and relative growth trends. In addition to absolute and annual growth indicators, the analysis incorporates percentage deviations from the EU benchmark, allowing for a more nuanced understanding of Serbia's position and development pace within the broader European energy transition.

2. RESEARCH AND DISCUSSION

This study examines bioenergy trends across four selected countries: Serbia (the focal country and EU candidate), alongside Croatia, Hungary, and Bulgaria (EU member states). The analysis includes a review of each country's energy mix, with a particular focus on the role and share of bioenergy. A structured synthesis and comparative assessment of bioenergy production were conducted to identify patterns, disparities, and development trajectories within the regional context.

2.1. Comparative energy mix profiles and bioenergy integration

Table 1 – Energy Mix Profiles and Bioenergy Share in 2023 (TJ)

Country	Coal and coal products	Natural gas	Hydro-power	Solar, wind and other RES	Oil and oil products	Biofuels and waste	Nuclear	Bioenergy share (%)
Serbia	281893	94364	44084	4073	172007	70899	-	9.62
Croatia	14702	95826	29377	12094	142502	61347		16.77
Hungary	30881	297204	831	47068	308788	108023	175801	8.52
Bulgaria	155559	90948	11088	21321	188592	67954	176843	9.58

Source: Author's systematization and calculation based on IEA, 2025

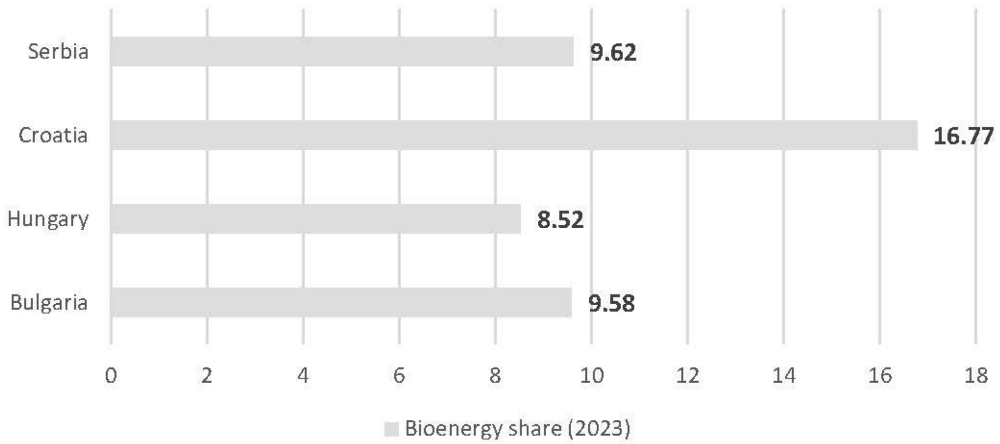

Figure 1 – Bioenergy share in selected countries (2023) in %
Source: Author's figure

The energy mix profiles presented in Table 1 reveal distinct structural patterns across the four observed countries. Serbia's energy supply is dominated by coal and oil products, with biofuels and waste accounting for 70,899 TJ, or 9.62% of the total mix. Croatia, despite its smaller overall energy volume, demonstrates the highest relative share of bioenergy at 16.77%, indicating a more balanced integration of renewable sources, particularly biomass and biogenic waste.

Hungary exhibits the highest absolute bioenergy use (108,023 TJ), yet its relative share remains the lowest (8.52%) due to the substantial presence of natural gas, oil, and nuclear energy. Bulgaria's energy structure is characterized by a strong reliance on coal, oil, and nuclear, with bioenergy contributing 9.58% of the total supply. Hydropower and solar/ wind sources remain secondary across all countries, with notable variation in their distribution - Croatia and Bulgaria show higher solar and wind integration compared to Serbia and Hungary.

The presence or absence of nuclear energy further differentiates the profiles: Hungary and Bulgaria include significant nuclear components, while Serbia and Croatia do not report nuclear use. In discussions on future energy diversification, nuclear power remains a contested yet increasingly considered option. While small modular reactors (SMRs) are gaining attention as part of long-term decarbonization strategies, concerns regarding safety and public perception persist. As noted by Čučulović et al. (2024), nuclear power plants have been constructed to meet global energy demands and, under normal operating conditions, contribute minimally to population-level radiation exposure. This influences the overall share of renewables and the relative weight of bioenergy within the non-fossil segment. The comparative share of biofuels and waste suggests varying degrees of institutional prioritization and resource mobilization, which can be further explored through policy and infrastructure analysis.

2.2. Bioenergy capacity and growth in selected countries

The following section provides a comparative overview of bioenergy capacity and its growth dynamics across selected European countries over the period 2015-2024, highlighting both absolute developments and relative performance indicators.

Table 2 – Annual Bioenergy Capacity in Selected European Countries (2015-2024) (MW)

Year / Country	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Serbia	6	11	15	19	28	31	36	39	55	55
Croatia	53	63	87	115	127	135	154	161	151	153
Hungary	519	427	491	513	504	509	551	533	522	622
Bulgaria	54	57	52	69	57	48	47	79	79	79
EU 27 average	991	1019	1058	1101	1129	1142	1138	1166	1148	1196

Source: Author's systematization and calculation based on IEA 2025 database

Table 3 – Bioenergy Capacity Growth and Net Increase 2015-2024 in selected countries, with trend (%)

Country	Net Increase (MW)	Average Annual Growth (MW)	Growth Trend (%)
Serbia	+49	+5.4	816.7
Croatia	+100	+11.1	188.7
Hungary	+103	+11.4	19.8
Bulgaria	+25	+2.8	46.3

Source: Author's research

Tables 2 and 3 provide a complementary overview of bioenergy capacity development in Serbia, Croatia, Hungary, and Bulgaria over the period 2015-2024. Table 2 presents annual installed capacity values, while Table 3 summarizes net growth, average annual increase, and relative expansion trends.

Serbia demonstrates a pronounced upward trajectory, with bioenergy capacity increasing from 6 MW in 2015 to 55 MW in 2024. This represents a net gain of 49 MW and a remarkable growth rate of 816.7%, reflecting the country's transition from marginal deployment toward more structured integration of bioenergy technologies. Croatia shows consistent expansion, with a net increase of 100 MW and a growth rate of 188.7%, indicating stable policy support and gradual scaling of biomass-based systems.

Hungary, despite having the highest absolute capacity throughout the period, exhibits modest relative growth (19.8%), suggesting a more mature and saturated bioenergy sector. Bulgaria's development is characterized by early stagnation followed by a sudden increase in 2022, resulting in a net gain of 25 MW and a growth rate of 46.3%.

The comparison with the EU-27 average, which increased from 991 MW to 1,196 MW between 2015 and 2024, offers a broader contextual benchmark for assessing national performance. Serbia and Croatia exhibit notable expansion relative to their initial capacities, indicating a proactive shift toward bioenergy integration. In contrast, Hungary and Bulgaria display more restrained or irregular development, shaped by differing institutional priorities and energy strategies. This variation illustrates the heterogeneous nature of bioenergy deployment across the region and reveals distinct levels of convergence with EU renewable energy objectives.

2.3. Key differences in bioenergy capacity: Serbia vs. EU-27 average (2015-2024)

A comparative overview of bioenergy capacity indicators between Serbia and the EU-27 average over the period 2015-2024 provides insight into Serbia's relative position and development pace within the broader European context. The analysis includes absolute capacity values, net increase, average annual growth, and percentage differences, enabling a structured assessment of convergence trends, investment dynamics, and institutional performance in the field of bioenergy.

The development of bioenergy in EU countries is impacted by the differences in biomass resource locations between EU member states (Proskurina & Mendoza-Martinez, 2023). The comparative indicators presented in the table highlight substantial differences between Serbia and the EU-27 average in terms of bioenergy capacity over the 2015-2024 period. Serbia's absolute values remain significantly below the EU benchmark, while its relative growth rate is markedly higher due to a low starting point. The deviation percentages reflect both the scale of disparity and the intensity of Serbia's expansion efforts, offering a quantitative basis for assessing national progress in relation to broader European trends.

Table 4 – Serbia's Bioenergy Capacity in Relation to EU-27 Trends (2015-2024)

Indicator	Serbia	EU-27 average	Deviation from EU-27 average (%)
Installed Capacity in 2015 (MW)	6	991	-99.39%
Installed Capacity in 2024 (MW)	55	1196	-95.40%
Net Increase (2015-2024) (MW)	+49	+205	-76.10%
Average Annual Growth (MW)	+5.4	+22.8	-76.32%
Total Growth Rate (%)	816.7%	20.7%	+786%
Share of EU-27 Capacity in 2024	4.6%	100%	-95.4%

Source: Author's research

CONCLUSION

Bioenergy plays a growing role in shaping sustainable energy systems and advancing green economy objectives across Southeast Europe. The comparative analysis of Serbia, Croatia, Hungary, and Bulgaria reveals distinct national approaches to bioenergy development, shaped by institutional priorities, policy continuity, and energy mix structures.

Serbia has moved from marginal deployment toward more structured integration, reflecting a shift in strategic orientation despite limited absolute capacity. Croatia demonstrates steady and consistent progress, supported by favorable policy frameworks and a balanced share of bioenergy within its energy mix. Hungary maintains the highest overall capacity, yet its development reflects a mature and saturated sector with limited relative expansion. Bulgaria's pathway has been marked by early stagnation and later recovery, resulting in uneven growth and constrained advancement.

These differences underscore the heterogeneous nature of bioenergy deployment in the region and highlight the importance of aligning national strategies with broader European frameworks. As part of the European Green Deal and the Green Agenda for the Western Balkans, bioenergy offers not only technological potential but also a pathway toward decarbonization, rural revitalization, and institutional convergence with EU sustainability goals.

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Digital Marketing Innovations: From Brand Awareness to Digital Brand Equity

Inovacije u digitalnom marketingu: od prepoznatljivosti brenda do digitalne vrednosti brenda

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Abstract: This paper presents a comprehensive synthesis of current academic and professional literature that examines the impact of digital marketing innovations on building brand awareness and related constructs in the digital age. In today's highly competitive digital ecosystem, understanding and implementing new technologies becomes key to achieving brand recognition. The goal of the work is to synthesize knowledge about the most significant trends, including issues from the domain of artificial intelligence (AI), augmented reality (AR), influencer marketing and data-driven content marketing, through the prism of the broader concept of Digital Brand Equity (DigBE) and the grounded model of Consumer-Based Brand Equity (CBBE).

Keywords: Digital marketing, brand awareness, Digital brand equity, AI, AR, influencer marketing, branding strategy.

Sažetak: Ovaj rad predstavlja sveobuhvatnu sintezu aktuelne akademske i stručne literature koja ispituje uticaj inovacija digitalnog marketinga na izgradnju prepoznatljivosti brenda i srodnih konstrukata u digitalnom dobu. U današnjem visoko konkurentnom digitalnom ekosistemu, razumevanje i implementacija novih tehnologija postaje ključno za postizanje prepoznatljivosti brenda. Cilj rada je da se sintetiše znanje o najznačajnijim trendovima, uključujući pitanja iz oblasti veštačke inteligencije (VI), proširene stvarnosti (PR), marketinga uticajnih ljudi i marketinga sadržaja zasnovanog na podacima, kroz prizmu šireg koncepta digitalne vrednosti brenda (DigBE) i utemeljenog modela vrednosti brenda zasnovane na potrošačima (CBBE).

Ključne reči: Digitalni marketing, prepoznatljivost brenda, digitalna vrednost brenda, VI, PR, marketing uticajnih ljudi, strategija brendiranja..

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INTRODUCTION

Building brand awareness is the starting point in the process of successfully positioning the company in the minds of consumers. In addition, it is the basis for building loyalty and future financial success. Due to the fragmentation of a large number of media and the saturation of information on the consumers` side, traditional approaches to building brand awareness are facing increasing challenges in the modern age. For the survival of the company in the market and the growth of the brand value, it is imperative to carry out constant adaptation and acceptance of digital marketing innovations. According to the author Górska-Wrasewicz (2024), DigBE (Digital Brand Equity) represents a set of assets and liabilities associated with a brand, its name and symbol, which adds or subtracts value to a product or service in a digital environment. On the other hand, Keller's CBBE (Customer-Based Brand Equity) model consists of four basic components: brand awareness, brand associations, perceived quality, and brand loyalty. This broader concept includes not only recognition but also quality perception, loyalty, associations and other dimensions that together constitute brand strength on digital platforms.

As Wimalasena and Jayasinghe (2025) point out, digital marketing enables dynamic interaction that goes beyond traditional, passive forms of communication, which builds brand awareness into deep engagement that leads to loyalty. Nevertheless, the goal of the digital marketing strategy should be to encourage brand advocacy, voluntary and devoted promotion of the brand by consumers through recommendations, defence against criticism, sharing of positive experiences and the like (Bappi et al., 2025). While brand awareness focuses on recognition and engagement on active involvement, brand advocacy represents the highest form of loyalty where consumers become unpaid brand ambassadors.

In the era of Industry 4.0, characterized by the relationship of digital-physical systems and high digital connectivity (Tahar et al., 2022), traditional marketing approaches are becoming less and less effective. As stated by Aman et al. (2024), this paradigm shift forces companies to adopt sophisticated digital marketing strategies in order to build and maintain brand awareness. In addition to artificial intelligence (AI) emerging as a powerful tool, another key trend is influencer marketing. It relies on the human factor and individual recognition to build trust and brand awareness. As Xu (2023) points out, influencer marketing uses influential individuals on social networks to rapidly build and communicate brand value. Social media platforms, such as Instagram, have become central to this type of marketing, allowing brands to reach highly engaged audiences through authentic content (Challa & Anute, 2021). At the same time, augmented reality (AR) is emerging as a particularly promising technology that is reshaping the user experience by creating unique and interactive brand encounters. As Phan, Hoang & Nguyen (2025) point out, AR marketing allows brands to combine the physical and digital worlds, providing consumers with additional values that directly contribute to strengthening emotional connection and brand recognition. This paper aims to systematize and synthesize current academic knowledge about the impact of the most significant digital marketing innovations on brand awareness and the broader concept of DigBE and CBBE, taking into account contextual factors that moderate their effectiveness.

1. METHODOLOGY AND LITERATURE REVIEW

This review was conducted through a systematic approach of identification, evaluation and synthesis of relevant academic literature. The goal was to include the latest studies that explore the relationship between digital marketing innovation and building brand awareness and DigBE. The search is limited to works published in English, with a primary focus on the period from 2020 to 2024, in order to include the most current trends in the literature.

The criteria used to include scientific papers in the literature review include: peer-reviewed scientific articles, conference papers, books and chapters dealing with the impact of digital marketing technologies (AI, social media, AR, VR, influencer marketing) on brand awareness, brand recognition, CBBE, digital brand equity or consumer engagement. The criteria for exclusion from further analysis were: non-reviewed papers, blog posts, newspaper articles, papers dealing exclusively with traditional marketing aspects. After the initial search, titles and abstracts were screened to identify potentially relevant papers. The full texts of the selected papers were analysed in detail. Thematic synthesis was used to identify recurring concepts, patterns and central trends. The analysis involved categorizing the literature according to major innovations (e.g. AI, influencer marketing, AR) and their impact on the components of the CBBE model, in order to form a coherent overview. The analysis includes papers on AI marketing for social enterprises (Shaily & Emma, 2021), digital brand building in dermatology (Kream

& Jerdan, 2023), human-computer interaction (Pizzi et al., 2021), Chatbot communication strategies (Kull et al., 2021), digital brand equity (France et al., 2025), influencer marketing (Xu, 2023), Instagram marketing (Challa & Anute, 2021), the impact of SMM on CBBE (Almestarihi et al., 2021), as well as empirical studies that test basic digital tactics in specific contexts (Karen & Zai, 2022). These papers provide specific case studies and quantitative evidence that illustrate the broader principles of digital brand building and their contextual limitations. Jacob and Johnson (2021) offer a systematized approach to understanding the mechanisms through which digital content marketing (DCM) drives engagement. They identify six key characteristics of DCM communication that serve as motivators for consumer interaction: value, relevance, reliability, consistency, interactivity, and fun.

One of the most transformative innovations in digital marketing is undoubtedly artificial intelligence. Shaily and Emma (2021) define AI marketing as the use of artificial intelligence-related technologies that make programmed decisions based on the collection, analysis and interpretation of target consumer behaviour and economic trends. This definition emphasizes AI's ability to make fast, data-driven decisions that directly impact the effectiveness of marketing campaigns. According to the same survey, elements of AI marketing include machine learning, big data analytics and AI platforms. These tools allow brands to gain deeper insight into target audiences, personalize messages and automatically deliver content at the optimal moment, thereby achieving higher levels of efficiency and engagement without the constant intervention of human staff. AI marketing techniques first contribute to increasing consumer awareness of the existence of the brand, and then lead to better recognition. This finding supports the theoretical framework that considers brand recognition as a component of the broader brand awareness construct and emphasizes the importance of a gradual approach in brand building. According to Surikova, Siroda, and Bhattarai (2022), brand voice is a set of marketing, linguistic, and stylistic parameters that influence brand communication, and AI develops it through big data analysis, machine learning, and text-to-speech technology (TTS). For example, Amazon Alexa uses deep learning and neural networks to recognize humour in user queries and generate a voice that reflects the brand's humorous tone. This ability of AI to analyse, predict and standardize tonality enables brands to maintain a consistent identity across all digital touchpoints, thus directly strengthening brand recognition and trustworthiness, and thus brand associations. A systematic literature review by Jelonek, Kumar and Paweloszek (2024) confirms the transformative role of AI and machine learning in brand management. The authors point out that AI technologies enable more precise consumer segmentation, behaviour prediction and personalized communication, which directly contributes to strengthening brand awareness and engagement. The application of AI in the analysis of social networks is particularly significant, where tools for sentiment analysis and content classification help brands monitor perceptions and react to changes in real time, thereby protecting and improving perceived quality and brand loyalty. These personalized experiences that enable AI not only raise awareness but also build trust (brand trust), which has been identified as a key component in maintaining long-term relationships with consumers in the digital environment (Górska-Wrasewicz, 2024; Ozbal et al., 2020), which is directly related to brand loyalty.

While artificial intelligence focuses on automation and personalization, influencer marketing relies on the human factor and individual recognition to build trust and brand recognition. As Kream and Jerdan (2023) point out in the context of dermatology, social media has enabled healthcare professionals to directly educate the public, build relationships with patients and colleagues, and build a strong digital brand. This phenomenon transcends the boundaries of medicine and is applicable to all industries. Effective influencer marketing requires a strategic approach. Influencer interactivity positively correlates with perceived authenticity and emotional attachment to the influencer's brand. Furthermore, authenticity has been identified as a mediator of the relationship between interactivity and emotional attachment, which then directly increases brand trust and thus loyalty. This emphasizes that the success of influencer marketing does not depend only on the number of followers. It is based on the ability to build a sense of believability and emotional connection through interaction, which directly affects brand associations and brand loyalty.

The design of AI tools is not only a matter of functionality, but also of the psychology of interaction. Marketing professionals must carefully balance the desire for efficiency (automatic activation) with the need to preserve consumers' perception of control. Research (Pizzi et al., 2021) emphasizes that an increase in satisfaction can result even from an initial negative reaction (resistance), if it is channelled through a mechanism that encourages cognitive engagement and decision certainty. This expands the perception of AI marketing from a mere efficiency tool to a means of shaping the entire customer experience, which directly affects perceived quality and brand loyalty. Consistent with these findings, recent research by Kull, Romero, and Monahan (2021) further deepens understanding of the mechanisms behind successful Chatbot-User interactions. The authors emphasize that the tone of the Chabot's initial message – perceived as warm (friendly, emotional) versus competent (professional, efficient) – has a direct impact on consumer engagement with the brand. Through three studies, it has been shown that a warm tone of the initial message leads to a decrease in the psychological distance between the consumer and the brand (brand-self distance), which indirectly increases engagement for the brand. This reduction in distance is explained by the fact that warm signals encourage a sense of connection and personal relevance, which is especially pronounced among consumers who already have an affinity for the brand. These results indicate that the strategy of warm introductory communication via chatbots is particularly effective in the stage of attracting attention and creating a first impression, which is crucial for building brand awareness and positive brand associations in the digital environment.

Authors France, Davcik and Kazandjian (2025) introduce a broader conceptual framework – digital brand equity – to explain how the measurement of brand equity must adapt to the digital reality. The authors emphasize that a key challenge is integrating digital metrics with traditional measurements to get a more comprehensive picture of brand performance. It is important to point out that the effectiveness of digital innovations is not universal, but is deeply context dependent. It can vary depending on the demographic, cultural and technological characteristics of the target audience. Success requires adjusting the intensity and method of application of each component. Before implementing sophisticated strategies, it is necessary to diagnose the local digital ecosystem.

2. DISCUSSION

The analysis of the literature so far enables a synthesis that goes beyond a simple enumeration of trends. It is clear that artificial intelligence, influencer marketing, carefully designed human-machine interactions, augmented reality and measuring digital brand value are interconnected elements of a successful digital strategy for building brand awareness and wider CBBE and DigBE. Findings on the power of AI platforms and big data analytics, combined with authenticity principles and psychological insights into Chatbot interactions, point the way to a synergistic approach. For example, data collected through AI tools can be used to identify the right micro-influencers whose style and values match the brand. Then, user-initiated chatbots with a warm tone can serve as the first point of contact, building trust and reducing resistance, while educational content shared by influencers and the brand itself increases awareness and enriches associations. Such an integrated approach creates a coherent and multi-layered experience that solidifies the presence of the brand in the consumer's mind and builds all components of CBBE. The work of France et al. (2025) clearly indicates that digital brand equity cannot be measured solely through digital metrics; it is necessary to combine it with the human dimension of the brand.

Augmented reality contributes to a synergistic approach with its ability to create concrete, tangible experiences that stick in the memory. AR can be considered a bridge between the digital 'brain' (AI data) and the physical 'heart' (authentic interaction), as it uses data for personalization (e.g. recommending products for a virtual product trial) while creating a strong emotional response through entertainment and aesthetics. In this way, AR not only increases engagement but also serves as a direct generator of brand awareness through shareable experiences (e.g. sharing AR filters on social networks). While an integrated approach is key, it is important to note that the effectiveness of individual tactics varies by industry within the service sector. As the authors Bari et al. (2024) noted, while interactive content is universally useful, the specific strategies and platforms that best raise brand equity can differ significantly between sectors, banking, aviation and tourism.

CONCLUSION

Digital innovations, including AI, chatbots, influencer marketing, augmented reality and advanced digital brand value metrics, have revolutionized the approach to building brand awareness. The key conclusion is the need for an integrated approach that combines human warmth and authenticity with advanced technologies and measurements. This work has shown that the goal is far broader than just raising awareness; it is about the systematic construction of Customer Based Brand Equity (CBBE) through the coordinated application of "Brain" (AI), "Heart" (authenticity), "Voice" (content) and "Experience Bridge" (AR), the success of which is constantly monitored in the "Mirror" of digital brand value. The rapid development of technology, especially generative AI, promises to further transform the way brands interact with consumers. However, as the literature shows, technological efficiency must be balanced with emotional connection and ethical responsibility. Brands that successfully integrate technological innovation with authentic human interaction will have the best chance of building lasting awareness, engagement, strong CBBE and, ultimately, passionate advocacy in the digital age.

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ECOLOGICA

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Под покровитељством
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ИНТЕРДИСЦИПЛИНАРНИ ПРИСТУП ЗЕЛЕНОМ РАЗВОЈУ: ИНОВАЦИЈЕ И ЗАШТИТА ЖИВОТНЕ СРЕДИНЕ

INTERDISCIPLINARY APPROACH TO GREEN DEVELOPMENT: INNOVATIONS AND ENVIRONMENTAL PROTECTION

У Београду, 22-24. априла 2026. године

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- Зелене перспективе: изазови у управљању ресурсима
- Иновације за одрживост: од критичних сировина до зелене економије
- Зелени хоризонти: иновације, економија и одрживи ресурси
- Еколошки изазови и иновативне праксе у савременој економији
- Иновације и одрживо управљање ресурсима
- Екодинамика: нови токови зелене будућности
- Критичне сировине за одржив свет
- Зелени код: дешифровање будућности одрживог развоја
- Иновације које покрећу зелени развој

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