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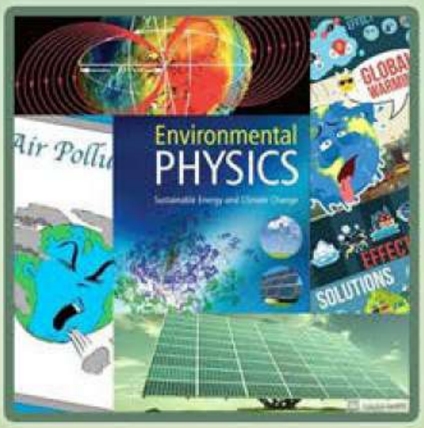
Zrenjanin, Republic of Serbia



III International Conference on
Physical Aspects of Environment
ICPAE 2024

PROCEEDINGS

Zrenjanin, Serbia, August 30-31, 2024.

University of Novi Sad
Technical Faculty
"Mihajlo Pupin"
Zrenjanin, Republic of Serbia

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Zrenjanin, 30 – 31th, August 2024.

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INTRODUCTION

III International Conference on Physical Aspects of Environment (ICPAE2024), held on August 30–31, 2024, was organised by the Technical Faculty “Mihajlo Pupin” in Zrenjanin. The Conference co-organiser was the Faculty of Sciences and Mathematics, University of Niš.

The members of Conference committees were distinguished professors and researchers from the University of Novi Sad, the University of Niš, the University of Pristina with temporary headquarters in Kosovska Mitrovica, the Institute of Physics in Zemun, the University of Maribor, the University of Josip Juraj Štrosmajer in Osijek, the University of Rijeka, the University of Montenegro, the “Ss. Cyril and Methodius” University in Skopje, the University of Banja Luka, the University of Sarajevo, the West University of Timișoara, Amirkabir University of Technology (Tehran, Iran), Donghua University (Shanghai, China), and Wuhan Textile University (Wuhan, China).

During the opening ceremony of the Conference, the audience, which included participants, members of Conference committees, and guests, was welcomed by Milan Nikolić, Ph.D, Professor - Dean of the Technical Faculty “Mihajlo Pupin”; Darko Radovančević, Ph.D, Assistant Professor - President of the Organizing Committee; Ljubiša Nešić, Ph.D, Professor - Vice President of the Scientific Program Committee, Advisory Committee and Organizing Committee; and Vasilije Petrović, Ph.D, Professor - President of the Scientific Program Committee.

As part of the event, an agreement on academic and research cooperation was signed between the Faculty of Arts and Design at the Western University of Timișoara and the Technical Faculty “Mihajlo Pupin” of the University of Novi Sad.

After the official opening, the paper presentations were moderated by Vasilije Petrović, Ph.D, Professor; Mila Kavalić, Ph.D, Assistant Professor; Darko Radovančević, Ph.D, Assistant Professor; Jasna Tolmač, Ph.D, Assistant Professor, and Ljubiša Nešić, Ph.D, Professor.

The Conference featured 44 submitted papers, including 7 invited presentations, while the rest were designated for brief oral sessions. Among the submissions, 14 papers had first authors from China, Iran, Pakistan, Romania, Bulgaria, North Macedonia, Montenegro, Bosnia and Herzegovina, Croatia, and Slovenia, while 30 papers had first authors from Serbia. Additionally, two papers included co-authors from the United Kingdom and Ethiopia.

Wang Hua, Ph.D, Professor at Donghua University (Shanghai, China) and a Visiting Professor at the University of Novi Sad Technical Faculty “Mihajlo Pupin” in Zrenjanin, was present at the event and actively participated in its activities.

During the Conference, the Faculty hosted an “Archaic Symbols in Contemporary Art” exhibition created by Daniele Liliana Brebeanu, a Ph.D student at the Western University of Timișoara. The exhibition was open to all interested attendees throughout the event.

The Conference gathered distinguished participants who presented their research, ideas, and accomplishments on a range of pressing topics, including geophysics, environmental modelling, air pollution, the greenhouse effect, global warming and climate change, radiation and the environment, energy efficiency and sustainable development, environmental physics and education, as well as industry and new materials.

President of the Organizing Committee

Darko Radovančević, Ph.D, Assistant Professor

Zrenjanin, 30 - 31th August 2024.

Conference participants are from the following countries:

United Kingdom

Bosnia and Herzegovina

Romania

North Macedonia

Serbia

Croatia

Iran

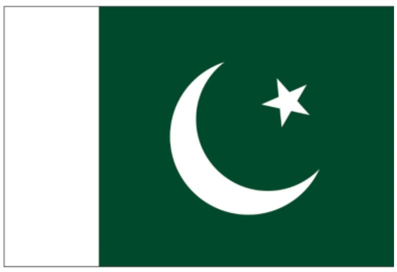
Bulgaria

Ethiopia

Montenegro

China

Slovenia



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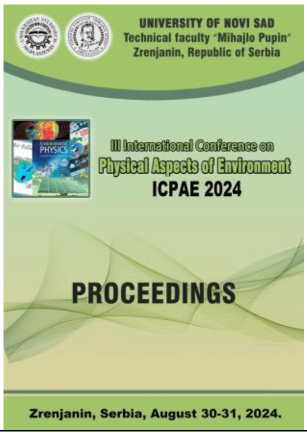

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INVITED LECTURES

Conference Proceedings
ICPAE 2024, August 30–31, Zrenjanin, Serbia
Technical Faculty "Mihajlo Pupin", Zrenjanin & Faculty of Sciences and Mathematics, Niš

The Practice of Chinese-Style Modernization in Xinjiang - Photovoltaic Desertification Control

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Abstract. This paper explores the practice of Chinese-style modernization in the Xinjiang region, with a specific focus on desertification control through the application of photovoltaic technologies in the Taklamakan Desert. By analyzing China's strategy for desertification control, the study examines how the implementation of photovoltaic systems can contribute to land preservation and mitigate the effects of desertification in this unique ecological context. The paper also investigates the ecological effects of desertification prevention and control measures employed by the photovoltaic industry in the desert and Gobi regions. Findings suggest that the use of photovoltaic technologies can significantly improve soil quality and stabilize ecosystems in areas affected by desertification, thereby providing sustainable solutions to one of the region's most critical ecological challenges.

Keywords: Chinese-style modernization, Xinjiang, Taklamakan Desert, ecological effects

ACHIEVEMENTS IN CHINA'S DESERT GOVERNANCE

The government work report released on March 5, 2023 pointed out that in the past five years, the Chinese government has "strengthened ecological and environmental protection and promoted green and low-carbon development", and "the area of soil erosion, desertification, and desertification has decreased by 106,000, 38,000, and 33,000 square kilometers, respectively".

TAKLAMAKAN DESERT, XINJIANG, CHINA

Located in the center of the Tarim Basin in southern Xinjiang, the Taklamakan Desert is the largest desert in China, the tenth largest desert in the world, and the second largest mobile desert in the world. The entire desert is about 1,000 kilometers long from east to west and 400 kilometers wide from north to south, covering an area of 330,000 square kilometers. The climate is a warm temperate continental arid climate, with an average annual precipitation of no more than 100 mm and an average evaporation of 2,500 to 3,400 mm.

Figure 1. Taklamakan Desert

The Taklamakan Desert, with a desert area of 330,000 square kilometers, is located in southern Xinjiang. The average annual precipitation does not exceed 100 millimeters, the lowest is only four or five millimeters, the extreme temperature of the desert can reach seventy or eighty degrees, and the sunshine resources are very abundant.

There are still many uncertainties and problems in the promotion of photovoltaic energy power stations in the Taklamakan Desert, and scientific researchers are also stepping up their demonstrations. If we can turn the "Sea of Death" into a vibrant oasis and energy base, then achieving carbon neutrality by 2060 will become a reality.

Design planning

Achieve the goal of "sand entering and people retreating" to "green entering and sand retreating". Desertification has always been the biggest obstacle to the development of western china, and xinjiang is the province with the largest area of desertified and desertified land in china, of which 1,068,600 square kilometers of desertified land is located.

If the Taklamakan Desert were covered with solar panels, would it provide all the electricity the Chinese need?

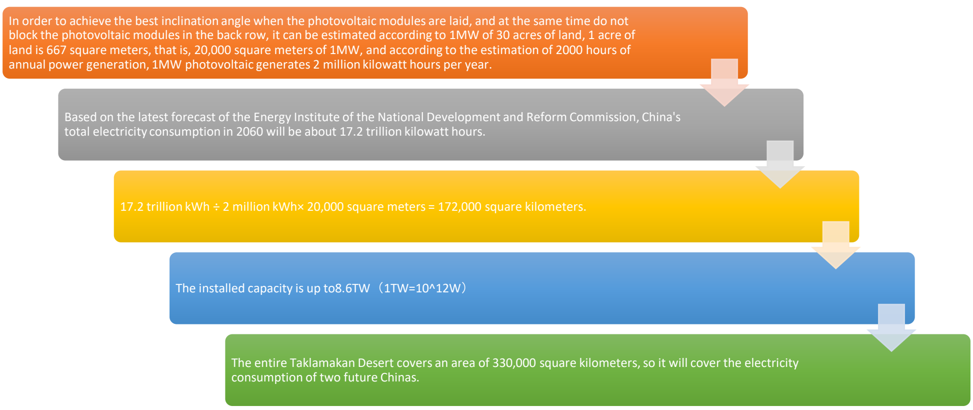

Figure2. Procedure of providing electricity by solar panels

What is photovoltaic desertification control?

Photovoltaic desertification control: It is a new type of engineering desertification control technology that combines photovoltaic technology with ecological protection technology.

Xinjiang has an arid climate, scarce precipitation, abundant sunshine, and more than 3,000 hours a year, so solar energy resources here are very abundant. However, on this basis, it has led to the intensification of soil desertification.

The role of photovoltaic desertification control

Solar cells convert sunlight into electricity, regulating the temperature in the desert and weakening the wind. Solar cells can also be used as wind and sand barriers for wind protection and sand fixation.

PHOTOVOLTAIC DESERTIFICATION CONTROL: CHINA'S PLAN FOR LAND DESERTIFICATION CONTROL

"On-board power generation, under-plate restoration, and inter-plate planting" maximize the ecological, social and economic benefits of the desert.

Why can photovoltaics control desertification? How does PV control desertification?

Step 1: Lay a sand barrier

Sand barriers (reed straw, etc.) are laid under the photovoltaic base slabs and between the slabs in the demonstration area to fully cover the sandy land to control sand activities, reduce the hazards of sand and fixation, and achieve the purpose of sand fixation.

Step 2: Planting under the slab

Make full use of the available land between and under the photovoltaic panels, plant high-quality pastures, shrubs and other vegetation or develop breeding. Because under the photovoltaic panels, direct sunlight is avoided, and the reed sand barrier is covered, which effectively reduces the surface evaporation, maintains the soil water content to the greatest extent, and is conducive to the growth and survival of vegetation, so as to achieve the effect of photovoltaic sand control.

The photovoltaic farm area organically combines sand control and sand use to achieve the purpose of comprehensive utilization of land. Low shrub plants are mainly planted under the photovoltaic panels and between the plates in the photovoltaic field area, and dwarf jujube trees, shuttle shuttles, caragana and so on, and Chinese herbal medicine plants should be selected licorice, meat indulgence, etc., with a plant row spacing of 2 meters ×3 meters, which not only achieves the effect of sand control and protection of the ecological environment, but also realizes the development of desert management and forestry and agricultural economy and industry.

Step 3: Perimeter protection

In the desert area on the periphery of the site, the carbon sequestration forest (windbreak belt) is planned and constructed by using the mixed sowing method of poplar, flower stick and sheep firewood, and in the carbon sequestration forest area, the method of aerial sowing of grass seeds is adopted to improve the vegetation coverage rate, prevent sand fixation, enhance the effect of sand fixation, and create a demonstration area of "photovoltaic + high-quality forage grass + carbon sequestration forest".

Photovoltaic desertification control: China's plan for land desertification control

With industrial alliance and rural revitalization as the starting point, with (government + platform company + cooperative + village collective + farmers and herdsmen + cooperative enterprise industrial union) as the combination point, through the (unified planning, centralized construction, intelligent operation) model, to create a beef cattle breeding industry chain integrating high-end beef cattle breeding, fattening, forage planting, feed processing, organic fertilizer processing, and sightseeing ranch experience functions, forming a pastoral complex combining breeding, raising, industry and tourism.

Sheep farming

Forage planting + breeding.

The adoption of the "forest-light complementation" and "animal husbandry and light complementation" models will leave sufficient space for planting cash crops such as sea buckthorn, wolfberry, jujube, and H. amondron by raising the height of the photovoltaic array and increasing the spacing of the array, so as to realize multiple ecological, social and economic benefits such as desertification control, photovoltaic power generation, ecological restoration, and rural revitalization.

THE ECOLOGICAL EFFECT OF DESERTIFICATION PREVENTION AND CONTROL IN THE DESERT AND GOBI PHOTOVOLTAIC INDUSTRY

The 2GWh photovoltaic desertification control base can control more than 100,000 acres of desert.

Power generation and emission reduction

2GWh generates 2.55 billion kilowatts of electricity annually, which is equivalent to saving about 440,000 tons of standard coal, reducing carbon dioxide emissions by about 1.161 million tons, sulfur dioxide by about 39,000 tons, nitrogen oxides by about 19,000 tons, and dust by about 347,000 tons.

China's photovoltaic desertification control technology

Photovoltaic desertification control technology refers to a technology that lays a large number of photovoltaic panels in deserts and other arid areas, and uses them to generate electricity while shading, improving the surface environment and promoting vegetation growth.

The implementation of this technology in China, especially in the Tarim oilfield area of the Taklamakan Desert, has shown remarkable results. The 3,300-acre photovoltaic power station not only generates 2.1 billion kWh of electricity annually, but also drives the ecological improvement of the surrounding environment.

INNOVATIONS IN THE STUDY OF ECOLOGICAL EFFECTS

1. Spanning the two disciplines of industry (solar energy development) and desert ecology, from the perspective of regulating the thermal balance of desert and Gobi, the contribution rate of photovoltaic panels and plant communities was compared and analyzed.
2. The equivalence relationship between solar energy converted by photovoltaic cells per unit area and the photosynthetic absorption and transpiration energy dissipation of desert plants was quantified through numerical conversion and calculation.

XINJIANG HAS INTRODUCED NINE MEASURES TO SUPPORT THE RESISTANCE ON THE EDGE OF THE TAKLAMAKAN DESERT

Figure 3. Nine measures to support the resistance on the edge of the taklamakan desert

THE IDEA OF DESERTIFICATION PREVENTION AND CONTROL OF SAND INDUSTRY CLUSTERS

12 comprehensive measures, such as artificial afforestation, sand closure and afforestation (grass), grass grid sand fixation, photovoltaic + sand control, have been adopted to ensure the high-quality completion of various tasks in the Taklamakan Desert edge resistance war.

Case: Shaya County planted 100,000 seedlings of H. ammodendron and adopted a new model of photovoltaic power generation for water intake and desertification control. Compared with power power water intake for desertification control, photovoltaic power generation water intake has the advantages of economic and environmental protection, green and low-carbon. Based on the calculation of 2,000 acres of irrigation per well, photovoltaic power generation can save 133,000 yuan in the first year and 160,000 yuan per year from the second year.

CONCLUSION

The integration of photovoltaic technologies into desertification control strategies in the Taklamakan Desert represents a significant advancement in China's efforts to combat environmental degradation. By leveraging the abundant solar resources in Xinjiang, photovoltaic systems not only generate clean energy but also contribute to soil stabilization and ecological restoration. The findings highlight that photovoltaic desertification control can enhance soil quality, reduce desertification, and support vegetation growth, creating a more sustainable and resilient ecosystem.

The success of these initiatives demonstrates the effectiveness of combining technology with ecological management practices. The reduction in decertified land and improvements in the surrounding environment underscore the potential for photovoltaic systems to address critical ecological challenges. Furthermore, the development of comprehensive models that incorporate solar energy, land reclamation, and agricultural practices illustrates a holistic approach to environmental stewardship.

Continued investment in and expansion of these technologies could further advance China's goals of carbon neutrality and sustainable development. The experiences and outcomes observed in the Taklamakan Desert may serve as valuable lessons for similar efforts in other arid and semi-arid regions globally.

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Conference Proceedings
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The Impact of the Textile Sector on the Environment

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Abstract. The paper points out that clothes in the concept of fast fashion are designed for single use. This encourages unnecessary and excessive consumption and thus creates large amounts of waste. In the existing design of textile products, most products cannot be recycled in a financially justified way. Worldwide, approximately 25 to 40% of all used textile products become waste. On the other hand, the technological process of textile production consumes huge amounts of water, land and raw materials. Also, the paper points out that several ways are generally proposed to reduce the negative impact of the textile industry on the environment. These are: New circular business models, new raw material recycling technologies and the design of new materials adapted to easier recycling. These innovations in the processing and production phase usually include reducing the consumption of chemicals, replacing them with enzymes, using color controllers and dyeing machines that require less water, and water recycling.

Keywords: textile, environment, product life cycle, recycling

INTRODUCTION

In the global economy, the textile sector is one of the most important sectors, with an annual turnover of 1.22 trillion dollars. However, this sector has a large impact on the environment. These are the negative effects that this industry has on ecosystems. That is why today the development of the industry, including the textile industry, is moving towards a greater share of the circular economy. In doing so, it is necessary to move from the old model based on extracting raw materials from the earth and producing things that will be used and then thrown away. Approaching the circular dimension of industry reduces the effects of environmental impact and mitigates market competition for scarce resources. Also, production expenses are reduced, which becomes cleaner and more competitive. All this, in addition to protecting the environment, has an economic justification as well as an ethical basis. Some predictions say that by switching to the circular principle of the economy, in all sectors, including industry, it is possible to create 700,000 new jobs across the EU by 2030, many of them in SMEs. [1]

The most obvious function of clothing is to protect the human body from cold, wind, rain or sun. Clothes often send a message about ourselves. However, the textile sector, which includes clothing, has the fourth highest negative impact on the environment and climate change. Ahead are only food, housing and transport. The textile sector has a huge potential for saving energy, water, land and other resources, reducing waste and pollution. Therefore, the vision of transformation into a circular economy is very present in the textile industry. Today, many countries are adopting concrete measures necessary for its implementation. These measures include changes in the textile and fashion industry from designers, through manufacturers and retailers to consumers. It works on finding sustainable ways to reduce waste and pollution associated with the textile sector and save energy, water and other natural resources used to produce clothing. [2]

The goal of creating a greener textile sector is major changes within the textile industry as well as among the consumers themselves. The new approach includes the entire life cycle of textile products, which implies the application of new measures related to the way of production and use of textile products. We are moving towards redesign, better quality textile products that will have a longer lifespan, which will be easy to maintain and most importantly, they will be suitable for recycling. This can only be achieved by paying more attention to the design of new textile products. This is because the design of new textile products is the key phase in which the mentioned characteristics are determined. Good results can always be achieved by mandatory addition of a certain amount of recycled materials in new products, as well as by better informing buyers of textile products. [3-7]

THE IMPORTANCE OF THE TEXTILE INDUSTRY

The negative impact of the textile industry on the environment is great. That trend will continue as apparel production has doubled in the last 15 years, and demand for textile fibers is estimated to grow from 62 million tons in 2017 to 102 million in 2030. It is estimated that 60 to 70 million people work in the textile industry globally today. So, for example, cotton is the most widespread non-food product in the world. The cotton sector provides livelihood for more than 250 million people and employs 7% of all workers in developing countries. The global textile market is valued at USD 1,837.27 billion in 2023 and is expected to grow at a compound annual growth rate (CAGR) of 7.4% from 2024-2030. year. This is because the growth of the market is ensured by the constant demand of the fashion industry for clothes and the astonishing growth of e-commerce platforms. However, the global textile recycling rate was only 14.7% in 2018, with 2.5 million tons of recycled textile materials. [2.8]

The textile industry has always made a significant contribution to the negative impact on the environment. The main problems caused by the textile industry are resource consumption, water pollution, air pollution and pollution from solid waste production. Thus, the data shows that in 2019, the textile industry globally was responsible for the consumption of 79 billion cubic meters of water and the creation of 91 million tons of waste. In addition, the textile industry uses 1,900 types of chemicals for dyeing and processing textiles. Of this number, 165 types of chemicals are considered harmful to health and the environment in the EU. The use of these substances accounts for 20% of global water pollution. That is enough for the needs of 110 million people throughout the year. According to some data, at the world level, about 5 trillion liters of water are used in the dyeing process. But the real problem with this resource arises when the production ends, because textile factories discharge millions of liters of untreated waste water into public sewers, i.e. into rivers and seas. Textile dyes are a big problem in wastewater because they are not easily biodegradable.

It is estimated that around 105 tons of dyes are released into the environment every year through 200 billion liters of wastewater, which makes the recovery of this water one of the most debated issues at the moment. [8,9]

Figure 1. River polluted with water from textile dyeing [10]

LIFE CYCLE OF TEXTILE PRODUCTS

The life cycle of textile products can be observed according to the following phases: production phase, use phase and phase after the use of clothing, i.e. the phase of the end of the product's life. The industrial production of textile products begins with the procurement of raw materials. It then continues through the processes of spinning, weaving, knitting, confectioning and refining until the assembly of the final product. The production of textile products is a complex process and therefore it is difficult to make a comprehensive overview of the overall impact of that process on the environment.

The design of new textile products includes quality assurance throughout its entire life cycle. This includes all activities starting from design, projecting, production, distribution, use, maintenance, up to its recycling or disposal. Today, these activities are directed towards the development of new solutions for better recycling and management of waste material. For a typical textile product, there are seven life stages that it goes through: [8,9]

- stages of concept and design development: quality parameters of raw materials, parameters of use and maintenance of the end product, prediction and simulation of its possibilities, comfort and satisfaction of standards and legal provisions,
- engineering phases: include innovative tools for optimizing quality and ecology in production, distribution, application, use, service activities, recycling or disposal, and prototyping. This phase is based on the experiences of using existing products,
- production phases: include specification of materials in production, quality management, system management of errors / damage to materials, self-

optimization of production systems, on-line control of quality and environmental parameters,

- distribution and application phases: foresee improvement in product quality standardization and quality data management,
- phases of use and service activities (dry cleaning and washing): foresee the development of methods and processes for retaining and restoring the functional properties of textile materials, the durability of properties during the phase of use, the development of new products that affect the improvement of product quality during the phase of use and care, instructions and training for the correct global use and care of the product, analysis of problems arising during application and complaints, methods of more precise determination of possible errors, development of non-destructive methods for quality assessment, modeling / simulating the aging process in various conditions of use or care,
- phases of the second life cycle (reuse): envisage the development of new procedures by which existing textile products could be reused,
- end-of-cycle phases (recycling or disposal): foresee research in the last cycle that must focus on the development of new recycling procedures. [11]

Research development, in the textile sector, foresees in the future additional research on the life cycle of new, innovative products, taking into account new areas of their application (e.g. technical or medical textile products), models that would predict their life cycle and quality, methods of modeling properties in production and application (non-technological innovations) and providing guidelines for the maintenance and care of new products.

The concept of the life cycle of textile products and related to them also foresees integrated quality management that includes: testing, certification and monitoring of textile products, production control, simulations of production processes and textile properties, accreditation of methods for testing high-quality textile products, non-destructive product testing methods, monitoring care processes, etc.

Research development in the textile sector also includes the concept of recycling management, i.e. waste. This concept includes: the construction of materials that can be easily recycled (this is where the term recycling-friendly is introduced), the policy of integrated production, technological improvements of equipment for recycling textile products, water recycling, saving water, energy, chemicals, water purification, etc. [11]

IMPROVING THE CIRCULARITY OF THE SECTOR AND WASTE REDUCTION

Clothes in the concept of fast fashion are designed for single use. This encourages unnecessary and excessive consumption and thus creates large amounts of waste. In the existing design of textile products, most products cannot be recycled in a financially justified way. Worldwide, approximately 25 to 40% of all used textile products become waste. The practice of reuse and recycling in Europe is limited, so discarded clothes end up in landfills, mostly in Africa and Asia. Therefore, the EU aims to stop the overproduction and overconsumption of clothing. In this direction, new measures are being launched that aim to discourage the destruction of unsold textiles and limit the export of textile waste. [12]

Figure 2. Display of discarded clothing [12]

PROBLEMS WITH MICROPLATIC FROM TEXTILE

Microplastic is a small piece of plastic, usually much smaller than 5 mm. Increasing amounts of microplastics are found in the environment, including the sea and soil, as well as food and drinking water. Microplastics do not degrade and usually accumulate in the environment. Unless, in rare cases, it is not specifically designed for biodegradation in the open environment. Biodegradability is a complex phenomenon, especially in the marine environment. There is growing concern about the presence of microplastics in various parts of the environment, its impact on the environment and biodiversity, and potentially on human health. [2]

Therefore, to a large extent, there are initiatives to combat microplastic pollution, promote research and innovation, and ensure integrated monitoring of microplastics. Namely, every time clothes made of polyester, rayon and nylon are washed, small parts of microplastics go into the water. Clothes made of synthetic materials, which are washed in washing machines, are responsible for 35% of primary microplastics released into the environment. One wash of PES clothing can release 700,000 micropolyester fibers that can end up in the human food chain. These tiny plastic particles eventually end up in the sea where plankton eat them, then fish eat the plankton, and then the fish used for food end up in human bodies. Most microplastics from textiles are released during the first few washes, and fast fashion, due to its mass production, low prices and high volume sales, is responsible for many first washes. It is estimated that around half a million tons of microplastics come from synthetic clothing. This is the equivalent of about 50 billion plastic bottles.[12]

In the world, numerous researches are funded to solve the problem of microplastics. However, it is clear that microplastics released from textiles have a measurable impact on the environment. Therefore, we are moving towards solving this problem. Especially in cases of unintentional release of microplastics into the environment. [12]

CAN THE TEXTILE INDUSTRY BE SUSTAINABLE

In general, several ways are proposed to reduce the negative impact of the textile industry on the environment. They are:

- New circular business models,
- New technologies recycle raw materials and
- Designing new materials suitable for easier recycling. [2]

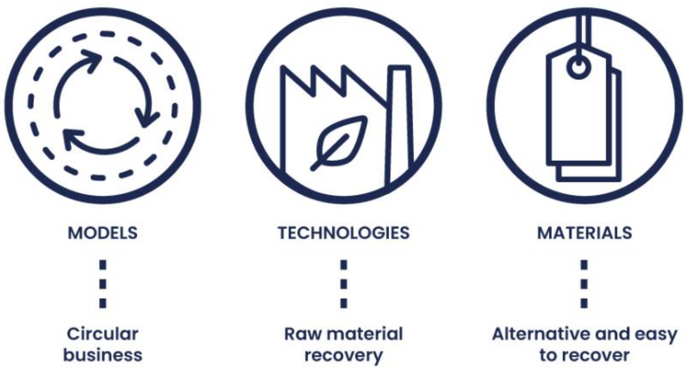

Figure 3. Solution areas for the textile industry [2]

NEW BUSINESS MODELS

The circular business model is a way that involves maximizing efficiency in the use of raw materials, energy resources and minimizing waste. Compared to the traditional linear model of consumption, it promotes the reduction, reuse, recycling and recovery of textile materials and products through different stages of the life cycle. In this sense, companies can integrate new, circular options for extending the life of garments, such as rental, resale of used products and their redesign, into their service system. [2,3]

NEW PRODUCTION TECHNOLOGIES AND RECYCLING

The textile industry is increasing its production to a large extent, and thus creating large amounts of waste that have a negative impact on the environment. To solve these problems, new ways are recommended to reduce the impact on the environment in the processing and production phase, including reducing the consumption of chemicals, replacing them with enzymes, using color controllers and dyeing machines that require less water, and water recycling. Integral knitting is also recommended, where the entire garment is produced in one piece without the need for cutting and sewing. [1,2]

In this sense, it is important to have a more responsible overview of the entire supply chain, including aspects such as the working and economic conditions of suppliers, health and safety at work, legality and transparency in procurement and the technologies used. The success of a company depends not only on the quality of its product / service, but also on its ability to establish positive relationships with customers, local communities, authorities and other stakeholders.

As far as reclaim water suppliers are concerned, keep in mind:

- choose suppliers that use 100% biological treatment, to avoid contamination with toxic chemicals
- choose suppliers for wastewater recovery that guarantee at least 95% - 98% recovery
- give preference to suppliers who explicitly list all sustainability certificates obtained from third parties. [2]

INVESTMENT IN SYSTEMS FOR EASIER RECYCLING OF MATERIALS

For sustainability, the influence of textile materials during the entire life cycle of the product is important. Applying life cycle assessment methodology, it is concluded that polyester, for example, requires less water and is easier to recycle than cotton. 6% of the world's pesticides and 16% of all insecticides that pollute the surrounding waterways are used to grow cotton. 2,700 liters of water are used for one T-shirt. What is aimed at is designing more durable textile materials, encouraging responsible consumption and the practice of reusing textile products. Also investing in research into new, more sustainable alternative textile materials. [1,2]

CONCLUSION

Clothes in the concept of fast fashion are designed for single use. This encourages unnecessary and excessive consumption and thus creates large amounts of waste. In the existing design of textile products, most products cannot be recycled in a financially justified way. Worldwide, approximately 25 to 40% of all used textile products become waste. On the other hand, the technological process of textile production consumes huge amounts of water, land and raw materials. Therefore, the textile sector is the third largest source of water degradation and land use in 2020. Today, less than 50% of used clothing is recycled or reused. Of that, only 1% is recycled (returned) into new clothes.

In general, several ways are proposed to reduce the negative impact of the textile industry on the environment. These are: New circular business models, new raw material recycling technologies and the design of new materials adapted to easier recycling. These innovations in the processing and production phase usually include reducing the consumption of chemicals, replacing them with enzymes, using color controllers and dyeing machines that require less water, and water recycling.

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The Textiles of the Future - Sustainable and Smart Materials in Fashion

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Abstract. The textiles of the future will combine sustainability with technological innovation to transform the fashion industry. Sustainable materials, made from renewable and recycled sources, will reduce environmental impact, while smart textiles will introduce new functionalities such as health monitoring or adaptation to external conditions. This evolution will enable the creation of durable, customizable, and efficient products, marking an important transition towards a more responsible and future-oriented fashion industry. The textile industry is undergoing a profound transformation driven by the demands for sustainability and innovation. As global trends continue to evolve, the companies that embrace these changes will be the ones that manage to adapt and thrive in an increasingly complex and demanding business environment. Sustainability is no longer just a niche concept but an essential requirement for the future of fashion.

Keywords: future textiles, sustainability, sustainable and smart materials

INTRODUCTION

Writing an article about the textiles of the future is an opportunity to contribute to essential discussions on innovation, sustainability, and the future of the fashion industry. You can influence perceptions, educate the public, and bring to the forefront solutions and trends that have the potential to shape the industry in the coming years. You can contribute to raising awareness and promoting more responsible practices in fashion. The textiles of the future in fashion represent a fascinating and innovative field, continuously developing, which will be characterized by a combination of sustainability, advanced technology, and customization, offering innovative and eco-friendly solutions for consumers' needs and desires.

Smart textiles are an interdisciplinary achievement resulting from the combination of knowledge from science and technology, including mathematics, chemistry, physics, IT, and textile, electrical, and mechanical technologies. Although not long ago these textiles were seen as mere fantasies of scientists, today, cyber fashion has become a tangible reality. Cyber fashion explores the intersection of fashion, technology, and design, offering new ways to experience clothing not just as an aesthetic element, but also as a functional and interactive tool.

The textiles of the future

The textiles of the future could include augmented reality elements that allow the modification of clothing designs through special applications or devices. These can offer interactive and customizable experiences for users.

Smart materials or "e-textiles" include fabrics that can monitor and respond to external conditions, such as temperature and humidity. For example, there are clothes that can adjust the temperature or monitor the wearer's vital signs. Materials with specific functions are being developed, such as water-resistant, antibacterial, or self-repairing fabrics. These textiles are designed to offer greater durability and convenience in use.

Sustainability

Sustainability refers to the ability to maintain or sustain a long-term balance between human activities and the natural environment. In the industrial context, sustainability involves the responsible use of natural resources so that they remain available for future generations, reducing the negative impact on the environment, and promoting an economic development model that is equitable and viable in the long term.

In fashion, sustainability involves adopting practices that minimize the impact on the environment and society throughout the entire life cycle of a garment – from raw material cultivation, production, and distribution, to the use and disposal of products.

Sustainability has become a central point in the strategies of many companies in the textile industry. With consumers becoming increasingly aware of the environmental impact of the clothes they buy, there is a growing demand for products that are not only of high quality but also produced in an ethical and sustainable manner. This shift in consumer behavior has prompted companies to reevaluate the entire life cycle of their products, from raw material sourcing to production, use, and recycling.

The textile industry is known as one of the most polluting industries globally, significantly contributing to carbon emissions, water consumption, and chemical pollution. In this context, recent trends focus on reducing these negative impacts. Many companies are investing in technologies that minimize resource consumption and reduce emissions. For example, the use of natural dyes, water recycling processes in production, and the adoption of organic farming practices for cotton and other natural fibers are becoming increasingly common.

In addition to sustainability, technological innovation plays a crucial role in transforming the textile industry. Smart materials that enhance the functionality and comfort of clothing have become increasingly popular. These materials can respond to external stimuli such as temperature, light, or movement, offering benefits such as thermoregulation, water repellency, or color change. Such innovations not only offer more attractive and useful products but can also extend the lifespan of clothing, thereby contributing to waste reduction.

Another important aspect of the transition to sustainability is the adoption of the circular economy model, in which materials are reused and recycled as much as possible. Instead of following the traditional "produce-consume-discard" model, the circular economy encourages the recycling of worn clothes and their reintegration into the production chain, thus reducing the need for new raw materials and the environmental impact.

Digital technologies play an increasingly important role in optimizing production and distribution processes. From computer-assisted design, which minimizes material waste, to ecommerce platforms that allow better inventory management and reduce surpluses, digitalization contributes to increasing efficiency and sustainability in the textile industry.

Sustainable materials

Sustainable materials used in fashion contribute to reducing the negative environmental impact and offer eco-friendly alternatives to traditional materials, which can be more expensive or less sustainable.

As demand for sustainable products grows, the fashion industry continues to explore new technologies and new materials that improve durability and meet the needs of a consumer increasingly aware of the importance of environmental protection. Embracing sustainability through the use of eco-friendly, recycled, or renewable materials provides solutions for reducing the ecological footprint.

What are the most popular sustainable materials?

Organic cotton, cultivated without the use of pesticides and chemical fertilizers, with soil fertilization done using organic fertilizers such as compost and manure, which reduces the negative impact on soil and water. It is biodegradable and much more environmentally friendly compared to conventional cotton. Conventional cotton is often grown with the widespread use of chemical pesticides and herbicides to control pests and invasive plants.

Organic cotton represents a more ecological and safer alternative from a health standpoint compared to conventional cotton, which is more widely available in large quantities and is extensively used in the fashion industry. Organic cotton is certified by a research institute that grants it the GOTS certification.

Figure 1. Cotton

Figure 2. GOTS certification (Global Organic Textile Standard)

Tencel (Lyocell) is a material produced from wood cellulose sourced from sustainably managed forests. The production process is environmentally friendly, using a non-toxic solvent that is almost entirely recycled. Tencel is biodegradable and very comfortable, with a soft and breathable texture.

Figure 3. Tencel fiber and Tencel material

Organic wool comes from sheep raised sustainably, without chemical treatments and with grazing practices that protect local ecosystems. Organic wool is durable, biodegradable, and natural.

Figure 4. Organic wool thread and organic wool sweater

Hemp, a very durable and resistant material, hemp grows quickly and requires few resources (water, pesticides). It is biodegradable and has a much smaller ecological footprint than other textile fibers.

Figure 5. Hemp-plant, thread, material

Bamboo is a fast-growing plant that does not require pesticides or fertilizers to grow. Bamboo fibers are used to create soft, antibacterial and biodegradable fabrics. However, the chemical process sometimes used to turn bamboo into textile fibers can be harmful to the environment, so it's important to use greener methods.

Figure 6. Bamboo, fiber

Recycled polyester, from recycled PET bottles or other plastic waste, recycled polyester reduces dependence on petroleum resources and minimizes waste. It is used in various garments, from sportswear to casual fashion.

Figure 7. The production process of recycled polyester fiber

Piñatex, a textile material obtained from the fibers of pineapple leaves, Piñatex is a sustainable alternative to traditional leather. It is biodegradable and provides an additional source of income for pineapple farming communities.

Figure 8. Pineapple leaves, fiber, fabric

Econyl, a type of regenerated nylon made from plastic waste recovered from the oceans, such as discarded fishing nets. Econyl can be recycled and reused endlessly without losing quality, being used in sportswear, swimwear and other textile products.

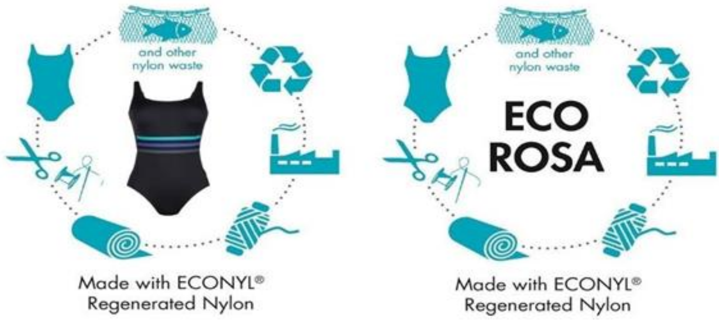

Figure 9. The production process

Vegan Silk, developed through biotechnology, mimics the properties of natural silk without involving the use of silkworms. It is a sustainable and ethical option for luxury clothing.

New materials

New materials represent a category of advanced materials that have been developed or improved to offer superior properties compared to traditional materials. These include innovative materials created through advanced engineering techniques and material sciences, such as nanotechnology, biotechnology, and advanced chemical processes.

In a constantly changing industrial world, the use of new materials can provide companies with a competitive advantage through innovation, creating more attractive and efficient products. Many are developed to be more environmentally friendly, either through the use of renewable resources or through efficient recycling and reuse.

In recent years, the textile industry has undergone significant changes driven by a series of global factors and increasingly stringent consumer demands. These changes are essential for adapting to new economic and ecological realities and for maintaining competitiveness in a market increasingly aware of its environmental impact.

In a circular economy model, durable and versatile materials are essential. Smart textiles, by their adaptive and resilient nature, fit perfectly into this model, as they allow for more efficient reuse and recycling of resources.

What are smart materials?

Smart materials are textiles developed by combining advances in material science and technology. These are capable of sensing and responding to changes in the surrounding environment, adapting to provide increased comfort or to perform specific functions. In the era of advanced technology, the textile industry has begun to adopt a series of smart materials that not only enhance the wearer's comfort but also offer innovative functionalities. These materials can dynamically respond to external stimuli, such as temperature, light, or movement, thus adding value to modern clothing.

What benefits do smart materials bring to fashion?

By adapting to environmental conditions and user needs, smart materials ensure *superior comfort* compared to traditional textiles. For example, automatic thermoregulation allows the wearer to feel comfortable in various temperature conditions without needing to add or remove layers of clothing.

Smart materials can improve *performance in sports activities* by more efficiently managing perspiration or providing thermal support. Additionally, clothing that monitors health can offer valuable data to help optimize workouts or monitor health status.

Some smart materials, such as those that *regulate temperature or repel water*, can help reduce the need to buy multiple layers of clothing or to use harsh cleaning products. Thus, environmental impact can be reduced through more efficient use of resources.

Color-changing materials add an element of novelty and dynamism to fashion, allowing creations that transform and adapt according to the context. These not only bring a "wow" factor but also reflect a spirit of *innovation and creativity* in fashion design.

Smart materials represent the future of the textile industry, combining advanced functionality with comfort and sustainability. They not only enhance the wearer's experience but also open new horizons for creativity and innovation in fashion. In a world where technology increasingly intertwines with daily life, smart materials will play an essential role in defining the clothing of tomorrow.

One of the major advantages of these smart materials is their ability to reduce the need to purchase multiple layers of clothing or to use aggressive chemical products in the maintenance of garments.

Reducing the need for additional layers means thermoregulating materials that are designed to maintain an optimal body temperature, regardless of external conditions. They can retain heat in cold conditions or disperse excess heat in warm conditions.

Thanks to this thermal self-regulation capability, consumers no longer need to purchase multiple layers of clothing to adapt to various weather conditions. A single smart garment can replace several traditional clothing items, thus reducing the resource consumption needed for producing and transporting additional garments.

By reducing the demand for additional products, the carbon footprint associated with their production, packaging, and distribution is also diminished. Moreover, the amount of textile waste is reduced, contributing to a more sustainable fashion industry.

Water-repellent materials, which prevent water from penetrating the fabric, are hydrophobic materials. This keeps clothes dry and clean even in rainy or high humidity conditions. Due to their water and dirt-repellent properties, these materials require less cleaning and maintenance. For example, garments made from hydrophobic materials can be washed less frequently and with fewer cleaning chemicals. By reducing the frequency of washing and eliminating the need for special chemical treatments, the negative environmental impact is reduced.

Smart materials are generally more durable and resistant than traditional textiles. By extending the lifespan of clothing products, the need for frequent replacement is reduced, contributing to a more efficient use of resources.

Smart materials, such as those that regulate temperature and hydrophobic materials, offer much more than comfort and functionality; they are an integral part of the transition to more sustainable fashion. By reducing the need to buy multiple layers of clothing and to use cleaning chemicals, these materials contribute to environmental protection and the optimization of natural resources. As these technologies become more accessible and widely used, they have the potential to fundamentally change how we consume and maintain clothing, making the fashion industry more responsible and eco-friendly.

Fashion brands that have adopted smart materials

Several fashion brands have begun adopting smart materials in their collections, combining technology with design to create innovative and functional products.

Nike has developed Nike Dri-FIT technology, which is a special material designed to wick moisture away from the skin, keeping the wearer dry and comfortable. Nike also uses thermoregulating materials and integrated technologies in its sports shoes, such as Nike Adapt, which automatically adjusts the fit of the shoes through an electronically controlled lacing system.

Figure 10. Nike Dri-FIT Figure and Nike Men's Shoes Adapt BB 2.0Black BQ5397-001

Adidas uses materials such as Climacool and Climachill that regulate body temperature according to environmental conditions. The brand also collaborates with innovative companies to introduce smart fibers and recycled materials into their products, such as the Adidas Parley range, made from recycled ocean waste.

Figure 11. Climacool T-shirt and Adidas Parley

Under Armour, uses materials such as ColdGear and HeatGear to ensure optimal performance depending on the temperature. ColdGear Infrared is a material that captures body heat and stores it, providing thermal comfort in cold conditions.

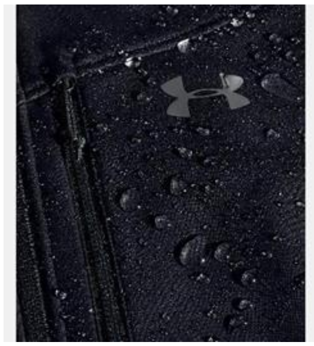

Figure 12. Men's ColdGear®

Figure 13. Under Armour - Infrared Shield Hooded Jacket

UA Base 2.0 is great for covering in cool to cold conditions. This type of Under Armour thermal underwear is ideal for outdoor fall or spring runs, or you can wear it under your outfit during outdoor football games to protect yourself from the cold air.

UA Base 3.0 These thermal underwear pieces are great for being active outdoors in colder conditions. You will stay protected from the wind and cold air while skiing, snowboarding, or just playing in the snow. The moisture-wicking technology in these base layers will keep you comfortable even if you sweat.

UA Base 4.0 is for superior warmth. These thermal underwear pieces are great to wear under your hunting clothes to stay warm in a tree stand or under your jacket while ice fishing. Being the warmest of Under Armour's base layers, UA Base 4.0 is what you want when staying out in cold weather for long periods.

Vollebak is an innovative brand that uses cutting-edge materials to create clothes with special functionalities. For example, the Solar Charged Jacket is a jacket that changes color in the dark after being exposed to light, and the Black Squid Jacket changes color depending on the angle it is viewed from, mimicking squid skin.

Figure 14. Solar Charged Jacket and Black Squid Jacket

CONCLUSION

In conclusion, the textiles of the future - sustainable and smart materials in fashion - highlight the rapid evolution of the textile industry, which is increasingly focused on sustainability and the integration of advanced technologies. The future of fashion is being shaped by the development of eco-friendly and renewable materials, the creation of smart textiles capable of responding to external stimuli, and the adoption of practices that support the circular economy. These innovations not only reduce environmental impact but also open new horizons in the design and functionality of clothing, offering consumers durable, customizable solutions that are adaptable to modern lifestyles.

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Correlation between Geology and Radon in Soil Gas as well as GRP in Croatia

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Abstract. Radon (^{222}Rn) is an inert radioactive noble gas, originating from the decay of radium (^{226}Ra) both members of the uranium (^{238}U) decay chain. Influenced by uranium and radium concentrations, the mineral type and grain size, radon releases from rocks and soils. Although, mudstones exhibit higher uranium concentrations, the high porosity and permeability of karst and limestone formations facilitate enhanced radon transport to the surface. Radon activity concentrations in soil gas and soil permeability were measured at over 400 locations, and the geogenic radon potential (GRP) was subsequently calculated for each site. The Kolmogorov-Smirnov normality tests indicated that the measured data did not follow a normal distribution. The statistical analysis confirms significant positive correlations between radon activity concentrations in soil gas / geogenic radon potential (GRP) and geological formations in Panonnian basin as well as Adriatic/Dinnaric zones in Croatia. Additionally, Mann-Whitney tests revealed statistically significant differences in the measured soil gas radon activity concentrations ($p = 0.00001169$) and GRP ($p = 7.77 \cdot 10^{-16}$), in dependence on geological substrates. These findings underscore the necessity of region-specific radon risk assessments, especially as an additional/auxiliary tool in the process of defining and identification of radon prone/priority areas according to the national Radon Action Plan in Croatia.

Keywords: radon, soil gas, geogenic radon potential, geological formations

INTRODUCTION

Radon (^{222}Rn) is a naturally occurring, inert, radioactive, noble gas with a half-life of 3.8235 days. It is produced in the uranium ^{238}U decay chain through the radioactive alpha decay of radium (^{226}Ra). These radionuclides occur naturally in varying concentrations across all rock types, including sedimentary, metamorphic, and igneous formations. Typically, igneous rocks have the highest uranium concentrations, while sedimentary rocks have the lowest. However, deviations from this rule are common, with uranium impregnations in sedimentary rocks and vein-type deposits observed in metamorphic and igneous rocks. Due to its gaseous state, radon exhibits significantly greater mobility than its parent elements, uranium and radium, which remain confined within mineral structures. The rate of the newly formed radon atoms in rocks and soils mostly depends on uranium and radium concentrations, the type of the mineral and grain size [1]. However, the kinetic energy of radon obtained in nuclear reaction determines whether radon will come out of the mineral or not. Given that radon is a gas with a relatively short half-life, its probability of escaping a mineral matrix is significantly higher if it is produced at the mineral's margins or points of openness and imperfections within the crystal lattice. Mudstones have higher uranium concentrations (8-35 ppm) compared to limestones (2-10 ppm) [2]. However, due to their waterlogged nature, mudstones contribute significantly less to soil gas radon levels. Conversely, karst and limestone formations, despite their lower uranium content, provide an excellent medium for radon transport to the surface due to their high porosity. In soils, 20-40% of generated radon atoms, and up to 70% in clays, are released into soil pores, where they mix with soil gases and water. Radon is then transported from these pore spaces through diffusion, driven by radon concentration gradients and/or advection, driven by pressure differences. Among these mechanisms, advection is markedly more efficient in radon transport from deeper layers to the surface where it enters closed spaces: dwellings and other buildings of socially important purpose and high occupancy (schools, kindergartens, hospitals) [3]. Radon is the predominant contributor to the total radiation dose received by the general population from natural background radiation [4]. It poses a significant health risk due to its association with lung cancer, ranking as the second leading cause of the disease after smoking [5]. Investigating the correlation between radon concentrations in soil gas and geological formations is crucial for assessing potential exposure risks, especially in regions like Croatia where various geological formations and features are present.

MATERIALS AND METHODS

During targeted measurements of indoor radon activity concentrations in kindergartens, schools and dwellings, the Laboratory for Low-level Radioactivity also conducted measurements of radon activity concentrations in soil gas as well as soil permeability at over 400 locations in the vicinity of these buildings. These efforts aimed not only to enhance the evaluation of radiological risks but also to conduct a thorough investigation of radon dynamics within the ecosystem and potentially develop an auxiliary tool for the identification of the radon priority areas.

Croatia's geological landscape is diverse, encompassing various formations from different geological periods. The country can be divided into several geologically distinct regions [6]:

1. Pannonian Basin: Characterized by primarily clays, silts, sands, alluvial deposits and sedimentary rocks.
2. Dinaric Alps: Predominantly composed of carbonate rocks, including limestone and dolomite.
3. Adriatic Coastal Region: Features a mix of karst landscapes with significant limestone formations and sporadic alluvial plains.

This geological diversity influences the distribution and concentration of uranium and its decay products, including radon. For this analysis, the measured data have been divided into two groups based on the locations of our targeted measurements: the Pannonian Basin and the Adriatic-Dinaric zone. These groups are geologically and geomorphologically distinct, representing two very different areas.

Radon concentrations in soil gas were measured using the RM-2 measuring system [7]. Soil gas samples were extracted from a depth of 80 cm, with a sampling geometry of 5 cm, using a soil probe and a 150 ml syringe. The samples were then introduced into ionization chambers, and measurements were performed twice: 15 minutes and three hours after the sampling to exclude thoron (^{220}Rn), the radon isotope with a much shorter half-life of 55.6 seconds, thereby ensuring that the results predominantly reflected the activity concentration of radon. Soil gas sampling was generally conducted immediately after measuring soil permeability with the Radon-JOK device, also manufactured by Radon v.o.s., Czech Republic [8]. Soil permeability was calculated based on Darcy's law, measuring the time required to withdraw a specific volume of soil air under negative pressure established by the Radon-JOK setup. For sites with extremely high or low permeability, withdrawal times could be too short (less than 6 seconds) or too long (more than an hour). In these cases, soil permeability values were determined as two extreme values of $1.8 \cdot 10^{-11}$ m^2 and $5.2 \cdot 10^{-14}$ m^2, as recommended by the manufacturer.

Radon concentrations in soil gas and soil permeability have been integrated to define the geogenic radon potential (GRP), a widely used metric to assess the geogenic hazard of radon emissions from the Earth without the anthropogenic influence of any kind [9-12]. GRP refers to the likelihood or potential for radon to be present in an area based on geological and soil characteristics. The most important variables determining GRP are uranium content in rocks, soil permeability and the presence of faults or fractures. The literature presents several definitions and interpretations of GRP [13-17]. In this study, we employed the Czech approach, specifically the parameter known as "Neznal's" GRP, which is derived from the radon index (RI) of building sites [18]:

$$GRP = \frac{c}{-log_{10}k - 10} \qquad (1)$$

RESULTS AND DISCUSSION

Based on the described geological division of the territory of the Republic of Croatia, all measured results were divided into two groups according to the measuring locations: Pannonian Basin and Adriatic–Dinaric zone. This was done in order to verify correlation between geology on one side and radon in soil gas and GRP on the other side. In other words, to verify the null hypothesis that geology has no influence on measured radon activity concentration in soil gas or GRP.

In each of the geological unit's normality tests were performed, on both measured activity concentration of radon in soil gas as well as calculated GRP values, in order to apply appropriate statistical tests. Considering the number of samples (which is greater than 50 in each set) Kolmogorov-Smirnov tests were applied. For Pannonian Basin data obtained p-values when the measured radon activity concentration in soil gas was tested was significantly lower than α ($0.00001323 < 0.05$), and similar for GRP values ($3.299 \cdot 10^{-10} < 0.05$). From these results it was concluded that both sets of data do not follow normal distribution. For data obtained in Adriatic-Dinaric zone p-values were lower than α as well: $3.886 \cdot 10^{-15}$ for the radon activity concentration in soil gas and 0 for the GRP values, respectively. From these results it is obvious that these data do not follow a normal distribution either. Although this may not have been expected at first, due to the choice of measurement locations that were not random, but deliberately chosen near schools and kindergartens during the targeted measurement campaigns in Croatia. Figure 1. shows the two geological groups on the x axis vs. the measured mean values of radon activity concentrations in soil gas with the corresponding standard error on the y axis.

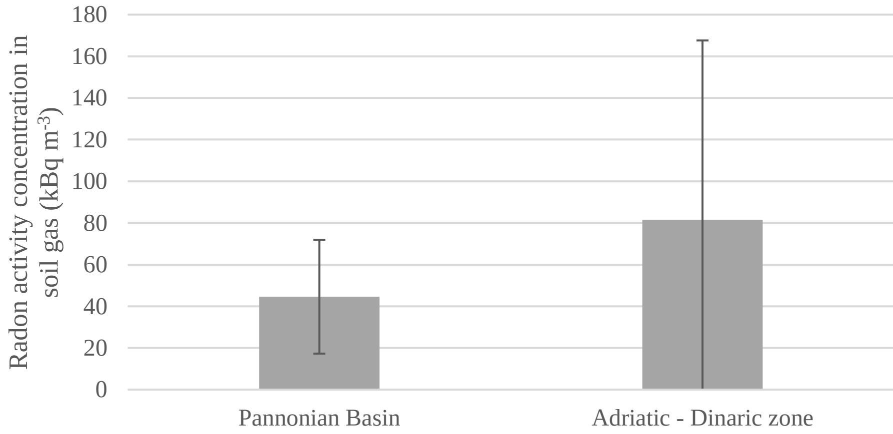

Figure 1. Mean radon activity concentration in soil gas, with standard errors, for the two geological groups.

A similar analysis was performed for the calculated GRP on every location as well. Results can be seen in Figure 2.

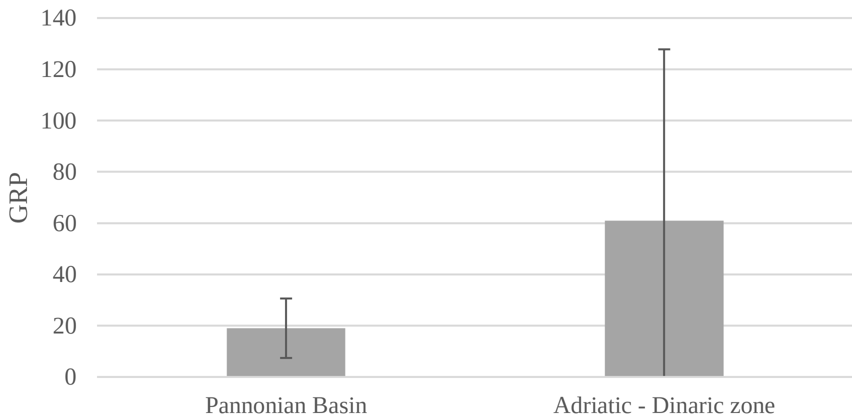

Figure 2. Mean GRPs calculated for every measuring location shown with standard errors, for the two geological groups.

When looking at both figures, it can be concluded that the measuring locations in the Adriatic-Dinaric zone shows higher radon activity concentration in soil gas as well as higher calculated GRP values when compared to the locations in Pannonian Basin. In order to verify these statements suitable statistical Mann-Whitney tests were applied.

The null hypothesis (H_0) and alternative hypothesis (H_1) for the Mann-Whitney test applied on the two sets of the radon activity concentration in soil gas sampled on the two different geological units can be expressed as follows:

H_0: $\mu_1 = \mu_2$ ("the two-population means are equal" i.e., there is no correlation between geology and the measured radon activity concentrations in soil gas and the mean values of two data sets are equal)

H_1: $\mu_1 \neq \mu_2$ ("the two-population means are not equal" i.e., there is a correlation between geology and the measured radon activity concentrations in soil gas and the mean values of two data sets are different). In the performed test a usual p-value significance threshold of 0.05 was taken.

The performed test gave a p-value of 0.00006716 which is significantly smaller than 0.05 (the smaller the p-value it supports H_1 more). This means that there is a significant difference between the two sets of data: one group- measured radon activity concentration in soil gas in Pannonian Basin and the other group measured in Adriatic – Dinaric zone. Therefore, we can reject the null hypothesis and accept the alternative hypothesis and claim that there is a correlation between geology and measured activity concentrations of radon in soil gas and this correlation is statistically significant.

When the same test was conducted on the two sets of GRP values calculated for the different geological units, a standard significance threshold of 0.05 was used for the p-value as well. The performed test gave a p-value of $6.661 \cdot 10^{-16}$ which is significantly smaller than 0.05 and even smaller than the previous test result (the smaller the p-value it supports H_1 more). This means that there is a significant difference between two sets of data: one group of GRP values calculated for the locations in the Pannonian Basin and the other group was determined for the locations in the Adriatic–Dinaric zone. Therefore, we can reject the null hypothesis and accept alternative hypothesis and claim that there is a correlation between geology and calculated GRP values and this correlation is statistically significant.

It is important to mention that other quantitative analyses of the data gathered in the ecosystem of two different geological units (Pannonian vs. Adriatic-Dinaric) were performed [19]. The Spearman correlation coefficients are calculated to measure the degree of association between two variables based on their ranks. We wanted to analyse correlations between several measured variables in each geological unit. Spearman's rank correlation coefficient can be used to investigate the relationship between radon concentrations in soil gas and GRP across different geological units. Thus, we have performed Spearman correlation coefficient calculation for the two sets of values measured at the locations in the Pannonian Basin and obtained $r_s = 0.726$ and for the Adriatic-Dinaric zone $r_s = 0.935$, respectively. Results of the Spearman correlation coefficients indicate that there is a significant large positive relationship between radon activity concentration in soil gas and GRP in both geological units. The linear regression model illustrating the relationship between these two variables is depicted in Figures 3 and 4, for the two respective geological units.

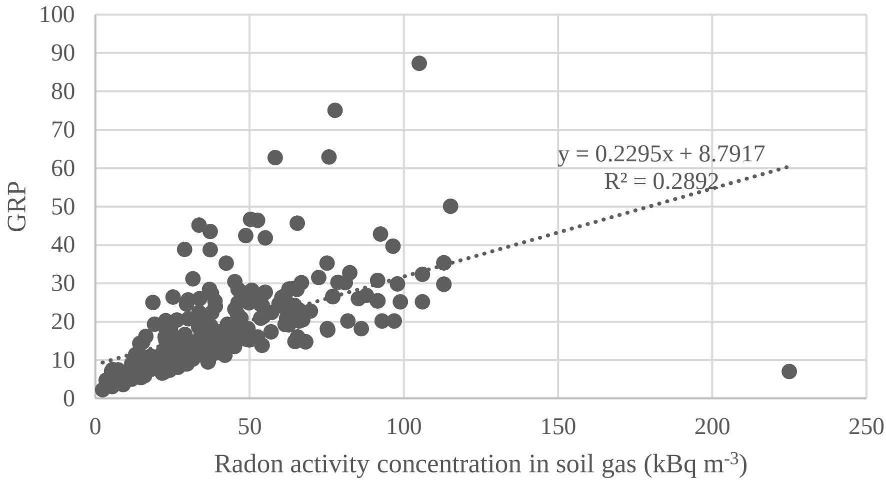

Figure 3. Relationship between radon activity concentration in soil gas and GRP at the measuring locations in the Pannonian Basin.

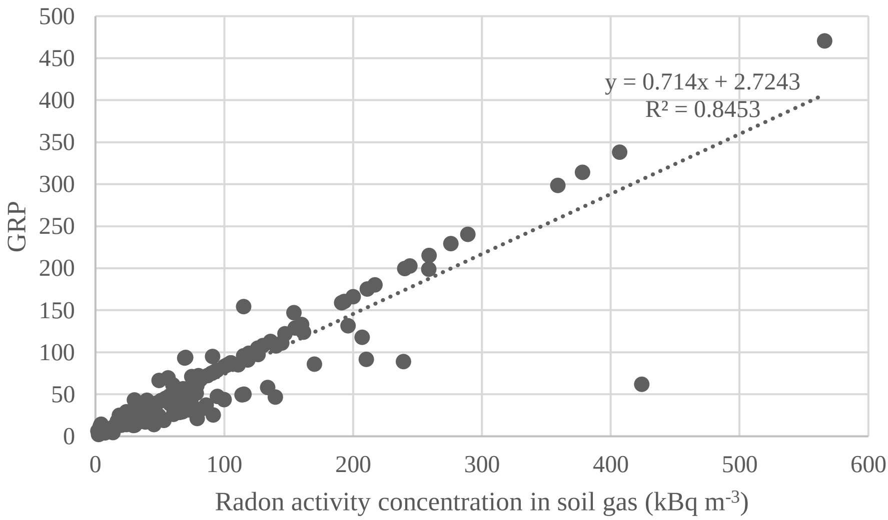

Figure 4. Relationship between radon activity concentration in soil gas and GRP at the measuring locations in the Adriatic-Dinaric zone.

When taking a closer look and comparing Figure 3. and Figure 4. it can be seen that the coefficient of determination R^2 of linear regression equals 0.2892 for the data obtained in the Pannonian Basin while the same value for the data obtained in the Adriatic – Dinaric zone is 0.8453. This suggests a weaker linear relationship between the radon activity concentration in soil gas and GRP in the Pannonian Basin locations. This can indicate that other factors not included in the model might influence the dependent variable (pronounced inhomogeneity of the soil, meteorological influence, etc.). However, in the Adriatic-Dinaric area fewer external factors disrupt the linear relationship.

CONCLUSION

This work demonstrates a significant correlation between geological formations and radon activity concentrations in soil gas, as well as geogenic radon potential (GRP) in Croatia. The analysis of over 400 locations across two distinct geological regions, the Pannonian Basin and the Adriatic-Dinaric zone, reveals that both radon concentrations and GRP are strongly influenced by the underlying geology.

The Mann-Whitney tests confirm statistically significant differences in radon activity concentrations and GRP between these two geological units, with the Adriatic-Dinaric zone exhibiting higher values compared to the Pannonian Basin. Additionally, Spearman's rank correlation coefficients indicate a strong positive relationship between radon concentrations in soil gas and GRP within each geological unit, with a notably stronger linear relationship observed in the Adriatic-Dinaric zone. As such it can be a valuable tool for understanding the relationship between radon levels in soil gas and the underlying geological formations.

These findings underscore the importance of geology in determining radon priority areas and suggest that regional-specific radon assessments are essential for accurately identifying radon-prone zones. This research contributes valuable data that could enhance the implementation of the national Radon Action Plan in Croatia, ultimately aiding in the identification and prioritization of areas requiring targeted indoor radon measurement programs and consequently radon mitigation efforts.

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Gamification as Support in Teaching Physics and Mathematics for Developing Digital and Sustainable Competences

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Abstract. In today's rapidly evolving digital world and increasing focus on sustainability, it is crucial to cultivate digital and sustainability competences among students. This paper investigates the role of gamification in physics education, specifically within the thematic unit of Mechanics, to enhance digital competences, science literacy, and student engagement. Gamification, which incorporates game design elements into educational contexts, has shown the potential in making learning more interactive and motivating. Theoretical foundations of gamification and its connections with digital competences are explored, followed by an analysis of current uses of gamification in physics education. By examining examples such as the game "Angry Birds," we demonstrate how physics concepts can be effectively taught through gamified learning experiences. This approach not only improves engagement but also fosters authentic problem-solving and sustainable learning. The findings suggest that integrating gamification contributes to developing essential competences while making learning more enjoyable and impactful.

Keywords: gamification, physics, digital competences, sustainability competences, science literacy

INTRODUCTION

The widespread use of information and communication technology (ICT) in everyday life significantly impacts how we work and learn. Therefore, it is crucial to develop students' digital competences through diverse teaching methods. For more than fifty years, educators worldwide have integrated ICT into education, focusing on four main areas: computer-assisted instruction (CAI) and intelligent tutoring systems (ITS), computer science and programming, cognitive development and problem-solving skills, and the use of the internet for information gathering and problem-solving. Among these areas, using ICT tools in traditional teaching methods has shown significant promise for educational enhancement. Despite the potential educational benefits of ICT, it is still predominantly used for entertainment, especially through computer games. Nowadays, students are often immersed in a media-rich, constantly connected environment, frequently engaging in computer games. Researchers have identified three key elements—challenge, fantasy, and curiosity—that contribute to the appeal of these games and are essential for effective learning. The challenge keeps students motivated, fantasy helps them visualize concepts, and curiosity fuels their desire to explore and discover. This paper explores how gamification, which integrates game elements into learning, enhances the acquisition of science literacy and digital competences among students. In addition to fostering digital competences, gamification also impacts sustainability education. Sustainable competences involve the skills and understanding required to live and work in a way that is mindful of the planet's resources. Together with science literacy, which involves understanding and applying scientific concepts, these competences are essential for a comprehensive education. Integrating these skills into the curriculum through innovative approaches like gamification ensures that students are well-prepared for the challenges of the future.

THEORETICAL BACKGROUND

Gamification and Digital Competences

Gamification is increasingly establishing itself as an effective approach to education worldwide, encouraging greater student engagement and improving learning outcomes. In many countries, particularly in the USA, the UK, and Finland, gamification is used in various educational contexts, from primary schools to universities (Deterding, Dixon, Khaled, & Nacke, 2011). Educators utilize various digital platforms and applications, such as Kahoot!, Duolingo, and Classcraft, to enrich lessons and motivate students (Hamari, Koivisto, & Sarsa, 2014). Research shows that gamification promotes active participation, improves knowledge retention, and enables more personalized learning (Domínguez et al., 2013).

In Slovenia, gamification is also gradually gaining traction in education. Some schools and teachers are already using gamified teaching methods, primarily within projects funded by the European Union, such as Erasmus+ and various national digital education initiatives (European Commission, 2020). Slovenian schools are experimenting with using games and interactive platforms to teach mathematics, science, and foreign languages (Sajinčič et al., 2022). However, the use of gamification is still in its early stages, and there is considerable room for expanding and deepening this practice within the educational system (Sajinčič et al., 2022; Marolt, 2019).

It is crucial for teachers to continually explore new methods for incorporating games into the classroom, both informally and through structured teaching practices. While game-based learning is a relatively new concept in the Slovenian education system, it has long-standing informal roots. Game-based learning encompasses two main areas: educational games and gamification.

Educational games are specifically designed for teaching and contain characteristics included in curricula based on the level of students' understanding. The key difference between educational games and classic computer games is that the latter are primarily designed for entertainment, which increases their popularity (Prensky, 2001). For example, a computer game might require players to solve math problems to navigate through a maze. These are often referred to as didactic games. Despite the potential benefits of educational games, there remains a preference among students for traditional, entertainment-focused games. This preference stems from the superior design, graphics, and playability of commercial games (Mayo, 2009).

The concept of gamification, first mentioned in 2008 in a blog post by Brett Terrill, involves the use of game elements in non-game contexts (Deterding et al., 2011). Gamification refers to the use of game design elements in non-game contexts to motivate and increase user activity and engagement. In education, it involves incorporating aspects such as point scoring, leaderboards, and challenges into the learning process. The application of gamification in education has gained traction due to its potential to make learning more engaging and effective. Gamification aims to enhance engagement and motivation by incorporating aspects such as point scoring, leaderboards, and challenges into various activities. Within the national project Na-Ma Poti (2021): Scientific and mathematical literacy: the development of critical thinking and problem-solving one of the main goals was to “equip and support teachers to implement critical thinking and interdisciplinary solving of complex authentic problems by using ICT, gamification and programming through cross-curricular cooperation”. There are several elements of gamification (Bezjak et al., 2022), including choice, time limits, badges, leaderboards, points, collections, goods, challenges, collaborations, competitions, role-play, avatars, and rewards. Within the project it was suggested to implement gamification-based learning in five steps: (1) understanding the participants and the context, (2) designing the objectives, (3) structuring the delivery, (4) choosing the means of delivery, (5) and finalizing the elements of gamification.

Gamification can be a valuable approach to enhance motivation and engagement in various learning environments. However, to increase the intrinsic motivation of the participants in the process, understanding the participants is important. Gamification theory is linked with the psychological theory of personality developed by Richard Bartle (1985). Bartle introduced four types of gamers: the killer, the achiever, the socialiser, and the explorer. The killer enjoys competing with other (real) players (Ratliff, 2015) and wants to reach the top of the leaderboard. The achiever is the type of player who prefers to gain points, conquer levels, and other concrete measures of success in the game. The socialiser chooses to play games for the social aspect and enjoys the game by interacting with other players or computer-controlled characters (Luton, 2013). The explorer is particularly excited to discover new stories and uncharted territories and is often annoyed by time-limited missions (Palmer and Petroski, 2016).

Through sensible utilization of gamification for authentic problem-solving students can develop science literacy, as well as digital competences. Digital competences refer to the skills required to effectively and critically navigate and utilize digital technologies. These competences include not only technical skills but also the ability to use digital tools for communication, collaboration, content creation, and problem-solving. As education increasingly integrates digital technologies, fostering these competences has become crucial. The European Digital Competence Framework (Vuorikari, Kluzer, & Punie, 2022) provides a comprehensive reference for identifying and developing the digital competences needed by citizens to thrive in a digital society. DigComp 2.2 outlines five key areas: (1) Information and Data Literacy: The ability to locate, retrieve, evaluate, and use digital information effectively and ethically; (2) Communication and Collaboration: Skills for interacting, sharing, and collaborating through digital technologies, understanding netiquette, and managing digital identity; (3) Digital Content Creation: Competence in creating, editing, and managing digital content, understanding copyright and licenses, and programming; (4) Safety: Skills for protecting devices, personal data, privacy, and health in digital environments, and understanding the environmental impact of digital technologies; (5) Problem-Solving: The ability to identify digital needs, solve problems through digital means, and creatively use digital tools for innovation.

Gamification helps develop digital competences across all five areas of the DigComp Framework, with the following activities:

1. effective search, evaluation, and management of information through interactive game scenarios;
2. multiplayer games and collaborative challenges;
3. game design and content creation activities to produce and manipulate digital content;
4. awareness of safety and protection of devices and personal data;
5. problem-solving tasks, solving digital issues.

Gamification has been applied in various educational contexts, including physics. Physics, often perceived as challenging, can benefit from gamification by making abstract concepts more tangible and accessible. Current applications range from simple quizzes and interactive simulations to complex games that model physical phenomena.

At both primary and secondary education levels, the thematic unit of Mechanics can be taught using gamified methods. These methods should be tailored to the cognitive and developmental stages of the students. For primary students, this might involve simple interactive games that illustrate basic principles of motion and force. For secondary students, more complex simulations and problem-solving challenges can be introduced.

Games and gamification in physics and mathematics education

In education, Physics and Mathematics are often referred to as difficult, abstract subjects, that are not favourites among others. By introducing innovative teaching methods, we can support students' engagement, motivation, and consequently their understanding (Bokal, Klemencic, & Repnik, 2022). As discussed in the previous chapter, introducing games and gamification can enhance the learning experience as well as support the development of digital competences and sustainable knowledge.

The curricula analysis of digital competences in physics-related courses in the Slovenian education system (Klemencic, Mencinger & Repnik, 2024) shows an emphasis on ICT across all educational levels. Animation and simulations are featured in more than half of the examined curricula; however, gamification is not explicitly introduced. On the other hand, the study by Repnik, Kaucic & Krasna (2012) pointed out that e-study materials for primary school include gamified interactive quizzes. In secondary school, the use of PhET simulations (2024) among teachers is more common. PhET simulations integrate gamification elements such as interactivity, immediate feedback, challenges, progression, and visualizations to enhance learning experiences. These simulations offer different levels of engagement. Students can play with changing parameters and observe how they affect the dynamics of a system in real-time. Moreover, many PhET simulations also offer a so-called playground where students can test and evaluate their knowledge. These simulations appeal to a variety of learners, particularly explorers who enjoy manipulating variables and experimenting with virtual environments.

There are other opportunities to include games and gamification in physics education. For example, **simulation environment such as Algodoo** (2024) **and Physion** (2024) allows students to create their simulations. Algodoo focuses on creating interactive scenes where users can experiment with physics concepts playfully. It is used mainly to teach concepts of mechanics, optics, and thermodynamics. It also features an education edition with specific tools and tutorials designed for classroom use. Physion is physics simulation software that allows users to create interactive simulations and hands-on experimentation. It also provides educational simulations that demonstrate physics concepts of Newton's law, Hooke's law, kinematics, energy conservation, electricity, and oscillations.

Research on the use of games and gamification in physics education highlights several benefits of these approaches in improving learning outcomes and student engagement. One significant study conducted by Hariyono et al. (2022) explored the impact of a physics-based game on student engagement and motivation. The results indicated that students who participated in this game-based environment demonstrated higher levels of engagement and motivation compared to those who used traditional teaching methods. The interactive and immersive nature of the game made complex physics concepts more accessible and appealing. Another study by Zacharia (2005) examined the effects of interactive simulations and games on students' understanding of physics concepts. The results showed that students using these gamified learning tools had a better grasp of concepts such as force, motion, and energy conservation. The ability to visualize and manipulate variables through interactive tools led to a deeper understanding of physical principles. Liu & Chen (2013) focused on how game-based learning impacts problem-solving skills in physics. Their research revealed that students engaging with physics games and simulations developed stronger problem-solving abilities. The games presented real-world physics problems, encouraging students to apply theoretical knowledge and enhance their critical thinking. Although Hake (1998) did not focus exclusively on games, it investigated the impact of interactive teaching methods, including games and simulations, and revealed significant long-term benefits for physics education. The study emphasized that students exposed to these interactive methods retained information better and performed well on subsequent assessments, indicating a lasting impact of such approaches on learning outcomes. Rose et al. (2016) examined how different student groups respond to gamified physics education. Their study showed that all student groups benefited from gamified elements, but those with a lower initial understanding of physics experienced more pronounced improvements in engagement and learning outcomes. The gamified approach helped bridge gaps in understanding and provided a more inclusive learning environment. Rieber's (1996) research investigated the role of educational games in developing practical skills and a conceptual understanding of physics. The study demonstrated that games allowing students to experiment with physical phenomena in a virtual environment significantly improved their practical skills and understanding of physical topics.

Together, these studies indicate that integrating games and gamification into physics education can lead to increased student engagement, better understanding of complex concepts, improved problem-solving skills, and long-term learning benefits. However, these tools must be carefully designed and integrated into the curriculum to align with educational goals and meet the diverse needs of students.

In mathematics education, the most common tool is GeoGebra (2024), which allows students to explore geometry, algebra, calculus, and other areas of mathematics through dynamic constructions and simulations. It is important to point out that GeoGebra lacks gamified elements and game-like aspects. However, some other gamified digital tools and environments could be introduced to mathematics classrooms. For example, **DragonBox Algebra** (2022) **is a** series of educational games that teach algebraic concepts through engaging puzzles and challenges. It's designed to gradually introduce abstract algebraic thinking and is suitable for students of age 9 and more. Other math-based role-playing games include Prodigy (2024), which adapts to student's skill levels for a personalized learning experience, and MathBreaker (2024), which combines mathematics with exploration and adventure gaming. Students manipulate numbers and shapes to solve puzzles and overcome obstacles, reinforcing fundamental math skills. Research on the use of games and gamification in mathematics education has demonstrated numerous positive effects of these approaches on learning and student engagement. Studies reveal that mathematical games significantly increase students' motivation and engagement. Kim's et al. (2020) study showed that students who used mathematical games exhibited greater interest in tasks and a higher willingness to tackle more challenging problems compared to those learning through traditional methods. The results indicated that games, which provided immediate feedback and rewarded progress, contributed to increased interest and readiness to solve complex problems. Understanding of mathematical concepts is also improved through the use of interactive simulations. Höffler and Leutner (2007) found that students using interactive simulations, such as those provided by GeoGebra, had a better grasp of mathematical concepts and solved problems more effectively compared to students who only used text-based problems. The results revealed that students engaged with interactive simulations achieved higher test scores measuring their understanding of mathematical concepts and demonstrated enhanced problem-solving abilities. Moreover, Cleveland-Innes and Campbell (2012) found that students using gamified platforms, such as DragonBox and Prodigy, achieved better test results and improved problem-solving skills. The study indicated that students who incorporated gamified elements into their learning attained higher scores on knowledge tests and developed better critical thinking and problem-solving strategies. The effects of gamification are especially noticeable in younger students. Hirsh-Pasek et al. (2015) demonstrated that educational games featuring mathematical puzzles and challenges positively impacted the development of fundamental mathematical skills and concepts in children aged 5 to 8 years. The results showed that students participating in these games developed improved basic numerical skills and enhanced understanding of mathematical concepts, contributing to a better grasp of foundational mathematics. The long-term effects of using mathematical games are also significant. Pehlivan and Arabacioglu (2023) found that students who regularly used gamified applications and games showed lasting improvements in mathematical achievements and a greater interest in furthering their math education. The study revealed that students who consistently engaged with these applications maintained improved mathematical performance even after the games ended, indicating the lasting impact of gamification on academic success. Different groups of students respond differently to gamification. Kulik and Kulik (1991) found in their meta-analysis that students with initial difficulties in mathematics often showed more significant improvement with gamified methods, while students with higher initial knowledge demonstrated greater engagement and enjoyment in learning. The results indicated that students with foundational difficulties in math experienced more substantial progress through gamified methods, whereas students with stronger initial skills showed increased motivation and pleasure in learning. These studies indicate that games and gamification can significantly enhance mathematics education.

For the successful implementation of games and gamification in classrooms, future teachers must acquire sufficient skills and knowledge in the sensible use of ICT during their studies. They should also develop positive attitudes towards innovative teaching methods and continuously enhance their digital competences. A previous study by Svetec et al. (2019) reviewed the integration of educational technology in the Subject Teacher study program at the University of Maribor, Slovenia, which trains future natural science and mathematics teachers. The study showed that students have several mandatory subjects with ICT content and learn about various opportunities for the pedagogical use of ICT in class. Furthermore, a recent state-of-the-art analysis (Klemencic et al., 2024) confirmed that graduates of the Subject Teacher study program evaluate their digital competences as sufficient for market needs.

INTEGRATION OF COMPUTER GAME IN PHYSICS CLASSROOM

Studies show that playing computer games can enhance cognitive functions such as attention allocation, spatial resolution, and mental rotation abilities (Gee, 2007). Games can also improve problem-solving skills, creativity, motivation, and emotional regulation. These benefits, combined with the social interactions fostered by multiplayer games, highlight the potential of computer games as educational tools (Shaffer, 2006).

Angry Birds

"Angry Birds" is a popular computer game that involves launching birds at structures, requiring players to consider angles, force, and trajectories. By integrating such games into the curriculum, teachers can make learning physics more engaging and relatable. The study by Repnik, Robič, and Pesek (2015) chose "Angry Birds" due to its popularity among students and its use of realistic physical principles such as projectile motion and gravitational acceleration. The methodology of the study involved two main tools: LoiLo Game Recorder to capture gameplay sessions and Tracker (2024), a video analysis and modelling software, to obtain quantitative data from these recordings. Multiple gameplay sessions were recorded to capture various scenarios and trajectories of the birds. These recordings were then imported into Tracker (Figure 1), where key frames of the birds' flight paths were marked for tracking. Tracker's tools were used to measure horizontal and vertical displacement over time, from which the initial velocity, launch angle, and effects of gravitational acceleration on the birds' motion were calculated. Quantitative analysis using Tracker software verified game physics accuracy, showing consistent horizontal speed and gravity's uniform vertical acceleration.

Figure 1. Using Tracker software to analyse video of the computer game Angry Birds and obtain necessary data for further exploration

Teaching physics with angry birds

Introducing the computer game Angry Birds in the physics classroom can be an effective and engaging way to achieve the curriculum objectives outlined in the Slovenian primary school physics curriculum (Verovnik et al., 2011). In the following, we provide some suggestions on how each objective can be addressed using the game:

- Define the difference between motion and rest of an observed body to its surroundings: By observing the birds at rest before launch and in motion during flight, students can discuss and define the concepts of motion and rest concerning the slingshot and the ground.
- Describe linear and curved motions: Students can observe the trajectory of the birds, identifying portions of the flight path that are linear (initial launch) and curved (parabolic trajectory due to gravity).
- Master the conversion between speed units m/s to km/h and vice versa: After calculating speed in m/s from the game, students can practice converting these values to km/h, reinforcing their understanding of unit conversion.
- Describe uniform and non-uniform motion: By analysing the bird's flight, students can identify when the motion is uniform (horizontal component) and non-uniform (vertical component affected by gravity).
- Draw a graph showing the dependence of the distance (and speed) on time, read the data from it, explain it, and understand what type of motion it represents: Using data from the game, students can plot distance-time and speed-time graphs, interpreting the types of motion (uniform and non-uniform) depicted.
- Use the equations to calculate the path in uniform and uniformly accelerated motion: Students can use kinematic equations to predict and calculate the bird's flight path, comparing their calculations to the game's results.
- Analyse how velocity changes with time in uniformly accelerated motion: By observing the vertical motion of the bird, students can analyse how gravity causes a uniform acceleration, changing the bird's velocity over time.

- Learn the concepts of initial, final, average velocity, and instantaneous velocity: By focusing on specific moments in the bird's flight, students can determine velocity at various points using the game's data from Tracker.
- Learn that acceleration is the quotient of the change in velocity and time: Using Tracker, students can calculate the bird's acceleration during flight measuring changes in the bird's velocity and the corresponding time intervals.
- Recognise that the path is directly proportional to the area of the graph $v(t)$ Students can plot velocity-time graphs for the bird's flight and calculate the area under the curve to determine the distance travelled, linking this to the path.
- Understand that a body is accelerating if the sum of the external forces acting on it is different from zero: By discussing the forces acting on the bird (gravity and initial launch force), students can understand the conditions under which the bird accelerates.
- Investigate the acceleration of free fall and interpret it: Students can measure the bird's vertical acceleration, comparing it to the standard acceleration due to gravity (9.8 m/s²) and interpreting the results.

To sum up, a teacher can guide students to observe the motion in a horizontal direction, which shows that the horizontal component of the speed remained approximately constant throughout the flight. Using Tracker and focusing on the horizontal motion (Figure 2a), students can obtain the horizontal distance the bird has travelled, the time dependency of the displacement, and calculate the initial speed in the horizontal direction:

$$v_{0,x} = \frac{x(t) - x(0)}{t}, \tag{1}$$

where *t* is the time of the motion. In addition, a teacher can guide students to qualitatively explore vertical motion, which shows uniform acceleration. Students can discuss gravitational acceleration, its direction and magnitude, and its effect on motion.

In the high school physics curriculum in Slovenia, the computer game "Angry Birds" can be explored within the topic of Linear and Curved Motion. In addition to activities in primary school, students can use and verify known kinematic equations based on the data from Tracker. Based on the time dependency of vertical displacement (Figure 2b) they can calculate the initial y-component of the velocity v_{0y} by using the equation:

$$y_{max} = y_0 + v_{0,y}t - \frac{1}{2}g\,t^2, \tag{2}$$

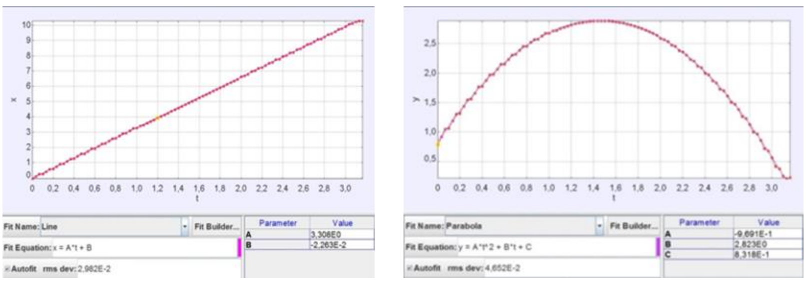
where y_{max} and y_0 are maximum and initial height respectively, g is gravitational acceleration and t is the time needed for the bird to move from y_0 to y_{max}. Students can also plot graphs showing the dependence of distance (and speed) on time, read data from these graphs, and explain the type of motion represented. The quantitative analysis can include calculating the initial speed v_o and launch angle:

$$v_o = \sqrt{{v_{0,x}}^2 + {v_{0,y}}^2}, \tag{3}$$

$$\theta = \arctan\left(\frac{v_{0,y}}{v_{0,x}}\right). \tag{4}$$

Students can also analyse how the birds' velocity changes with time, particularly in uniformly accelerated motion, and learn the concepts of initial, final, average, and instantaneous velocity using scenarios from the game. In addition, they can discuss how the motion would change in the presence of air resistance.

Furthermore, students can compare the birds' trajectories with real experiments and discuss the realism of the game's physical model, which enhances their problem-solving and critical thinking skills. By using games and related software tools for experiments and data analysis, they are developing digital competences and science literacy.



(a) (b)

Figure 2. Tracker Software analysis for a) horizontal and b) vertical motion.

In the master thesis, Robič (2017) developed a structured lesson plan and tested it in the classroom involving 500 students aged 10 to 16 years. Students reported high engagement and motivation, finding the game-based approach enjoyable and educational. Results indicated a significant improvement in students' understanding of physics concepts post-intervention. The average score on the post-test was 20% higher than the pre-test score, with statistically significant improvements in areas such as projectile motion and force calculations. A paired t-test confirmed that the improvement in test scores was statistically significant ($p < 0.05$). Teachers noted that "Angry Birds" helped to visualize abstract physics concepts, making them more accessible to students. However, they also identified challenges such as the need for adequate technological resources and the importance of aligning game content with curriculum standards.

By using "Angry Birds" in the classroom, students can achieve a hands-on understanding of complex physics concepts engagingly and interactively. This approach aligns well with the curriculum's goals to make learning more dynamic and contextually relevant.

Teaching mathematics with angry birds

Incorporating Angry Birds in the classroom can make abstract mathematical concepts more tangible and interactive. Students can apply their mathematical knowledge to solve real-world-like problems presented by the game's mechanics.

Based on the primary school curriculum for mathematics (Zakelj et al., 2011), students can address the following objectives:

- Define the linear function $y = kx + n$ (graph, the meaning of coefficients *k* and *n*, the position of a point relative to the line): In Angry Birds, the horizontal component of the bird's motion can be modelled as a linear function when considering the initial straight-line trajectory. Students can plot this motion on a graph, identifying *k* as the slope (related to the bird's horizontal speed) and *n* as the *y*-intercept (initial height). They can analyse how changes in the launch angle and velocity affect these coefficients.
- Graphically and algebraically determine if a given point lies on a line:
- Students can select specific points from the bird's trajectory and use the linear equation derived to check if these points satisfy the equation, reinforcing their understanding of point-line relationships. Determine the intersections of the line with both coordinate axes: By setting $y = 0$ and solving for *x*, students can find the *x*-intercept (where the bird hits the ground if we ignore the parabolic motion for simplicity). Similarly, by setting $x = 0$, they can find the *y*-intercept, which is the initial height of the bird when launched.
- Recognize a linear equation and solve it by transforming it into equivalent equations: Students can analyse the bird's horizontal motion to recognize the linear equation that represents its path.

To sum up, by analysing the initial trajectory of the bird, which is often straight, or by focusing only on horizontal motion (Figure 2a), students can identify and model the relationship between the launch angle and initial velocity as a linear function. They can create equations to represent this relationship and use them to predict the bird’s path.

In high school, students can apply their knowledge of quadratic functions, trigonometry, and calculus to analyze and optimize the bird's movement in the game Angry Birds. The game provides a practical context where the bird's trajectory, influenced by gravity, forms a parabolic curve (see Figure 2b). By modeling this trajectory with a quadratic function, students can derive the quadratic equation representing the bird’s path and use it to predict key features such as the vertex (maximum height) and the roots (points where the bird hits the ground). Additionally, students can use trigonometric functions to resolve the bird's initial velocity into horizontal and vertical components and apply calculus to optimize parameters such as the launch angle for achieving maximum distance or height. This approach allows students to practically apply mathematical concepts to solve real-world-like problems.

In addition, students can use trigonometric functions to calculate and optimize the launch angle for achieving specific distances or hitting targets. For example, they can use sine and cosine functions to resolve the bird's initial velocity into horizontal and vertical components (see equations 3, and 4). By using the data from the game, students can derive the equations for velocity and acceleration. They can differentiate the position function concerning time to find the velocity function and differentiate the velocity function to find the acceleration function. Furthermore, students can use derivatives to solve optimization problems, such as finding the angle that maximizes the distance travelled by the bird or the maximum height reached.

CONCLUSION

In an increasingly digital world, integrating gamification into physics and maths lessons is proving to be a transformative approach that not only encourages student engagement but also cultivates essential digital and sustainability competences. Through the use of interactive and gamified learning experiences, such as those exemplified by the game "Angry Birds"," students can better understand complex physical and abstract mathematical concepts while developing their digital competences.

Research emphasises the potential of gamification to make learning more interactive and motivating, promoting authentic problem-solving and sustainable knowledge acquisition. By incorporating game design elements into the educational context, educators can create a more stimulating learning environment that appeals to students' natural inclinations for challenge, curiosity, and imagination. This approach not only supports the development of digital competences as outlined in the European Digital Competence Framework (DigComp 2.2) but is also in line with the goals of sustainable education by promoting skills and understanding necessary for mindful living and working. Furthermore, the integration of gamification into education recognises the need for innovative teaching methods that prepare students for future challenges. When students engage with gamified learning methods, they improve their ability to effectively navigate and utilise digital technologies, collaborate with peers, create digital content and solve problems creatively and critically. These competences are crucial for their future success in a digital society and for their contribution to sustainable development. Our research findings in the field of physics have shown that using the game "Angry Birds" significantly improves the understanding of basic physical principles such as gravity, force, and motion. In mathematics, gamified tasks and games led to greater student engagement and enhanced their ability to solve complex mathematical problems. Students demonstrated higher motivation for learning and improved their grades compared to traditional teaching methods.

In conclusion, the application of gamification in physics and mathematics education not only makes learning more enjoyable and impactful but also ensures that students are equipped with the digital and sustainability competences essential for thriving in the 21st century. This innovative approach represents a significant step towards a more engaging, effective, and future-oriented educational paradigm.

ACKNOWLEDGEMENTS

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Environmental Physics as a Teaching Subject in Serbia

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Abstract. In recent decades, there has been a growing number of courses designed to encompass a wide range of phenomena relevant to the environment. Considering that life occurs in the biosphere, which includes components of the lithosphere, hydrosphere, and atmosphere, not only biology but also chemistry and physics are actively engaged in studying the environment from their respective perspectives. This has led to the development of scientific fields such as environmental chemistry and environmental physics. More broadly, environmental science is discussed as a unique synergy of environmental physics, chemistry, and biology. This paper presents some details related to courses in the field of environmental physics that are accredited in the study programs of faculties and colleges of applied studies in Serbia.

Keywords: environmental physics, environmental education

INTRODUCTION

Students commonly perceive physics as an abstract science focused on studying the characteristics of physical models, such as a material point, ideal gas, rigid body, black body, ideal fluid, etc. However, the real systems they encounter often deviate from these models. This perception changes when students realize that these studied models, along with standard physical concepts like velocity, force, pressure, mass, temperature, and energy, are fundamentally important for explaining everyday phenomena.

The connection between physics and the environment can also be emphasized during physics lessons, which teachers often do to motivate students. Another approach is to offer, alongside the traditional physics course, a separate course dedicated to the application of physics in studying environmental characteristics and processes. Courses in environmental physics have existed at universities around the world for some time, while in Serbia, they have been present for the past twenty years.

Initial Ideas and Main Sources

A group of high school physics teachers, researchers from the Institute of Physics in Belgrade, and professors from the Faculties of Sciences and Mathematics in Niš and Novi Sad initiated a teacher training program called *EcoPhysics* in 2003 [https://mail.ipb.ac.rs/~markusev/EkoWeb/Osnovni%20podaci%20Eko%20Fizika.htm]. Through this program, several hundred teachers working in elementary and high schools have been introduced to various environmental issues. One of the authors of this paper (Lj. Nešić) participated in the creation and implementation of the training, during which it became clear that there was a need for a subject of this type at the university level. The introduction of the subject was facilitated by the accreditation of new study programs, in which a course titled *Environmental Physics* was introduced as an elective in the second year of biology and physics studies. In designing the program, the experiences of other study programs (Dželalija, Belić) were largely taken into account.

Development of the Environmental Physics Program at the Faculty of Sciences and Mathematics in Niš

When developing the *Environmental Physics* course program, two potential approaches were considered. One was the ecological aspect, where the impacts of human activities on pollution and environmental degradation would be analyzed. Specifically, the scientific and technological revolution has caused numerous changes in the environment, so within this approach, human influence on physical processes in the atmosphere, hydrosphere, and lithosphere, i.e., the biosphere located at their intersection, is examined. The authors, in addition to environmental degradation, also focus on the application of modern physics achievements in solving global ecological problems and the sustainable use of natural resources.

The global ecological situation (GES) can be represented as a system of interconnected elements, as illustrated in Figure 1, where the term *anthroposphere* refers to the part of the biosphere influenced by human activity.

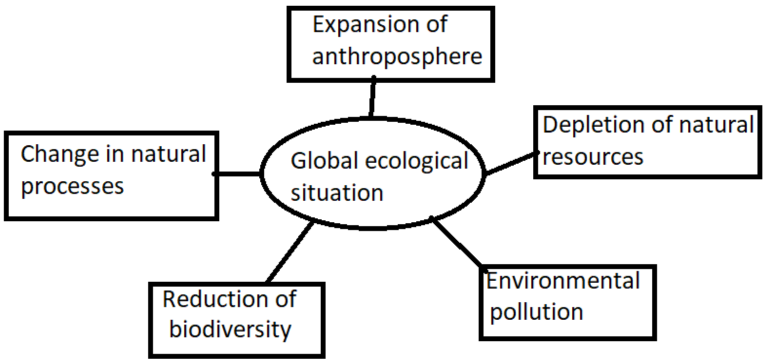
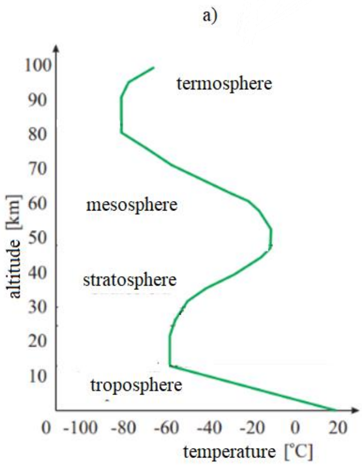


Figure 1. Global ecological situation

The second approach involves describing the environment using physics, i.e., applying physics to everything we observe around us. Considering that study programs in physics and some technical sciences already include courses titled *Physical Sources of Harm*, it was more natural to choose this approach. In this way, it also answers one of the questions that students, especially those studying biology or geography, often ask themselves when encountering physics: *Why am I even learning this, and what relevance does it have for understanding the environment I live in?*

The *Environmental Physics* course program at the Faculty of Sciences and Mathematics in Niš consists of seven areas: atmospheric structure, radiation, hydrosphere, wind, soil physics, energy and the environment, sound and noise. After the program was accredited, a textbook was also written, which fully follows the course syllabus.



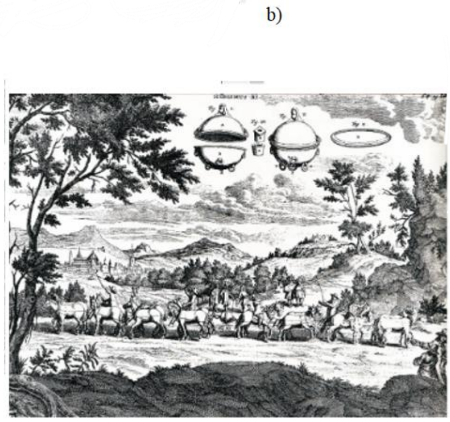


Figure 2. a) Change in temperature with altitude. b) The famous experiment by Otto von Guericke, which demonstrates the existence of atmospheric pressure. [5].

Radiation is the next topic, covering the electromagnetic radiation spectrum, introducing Planck's law (along with Stefan-Boltzmann's and Wien's laws), and discussing the types of possible spectra we can observe (continuous, emission, and absorption). Atomic and molecular spectra are also analyzed to help students understand the radiation spectrum that reaches Earth's surface from the Sun. By the end of this section, students are equipped to understand the greenhouse effect and perform a comparative analysis of this effect on Earth, Venus, and Mars

At the end of the section, Milanković cycles, which explain long-term climate changes on a large scale, are also covered (Figure 3).

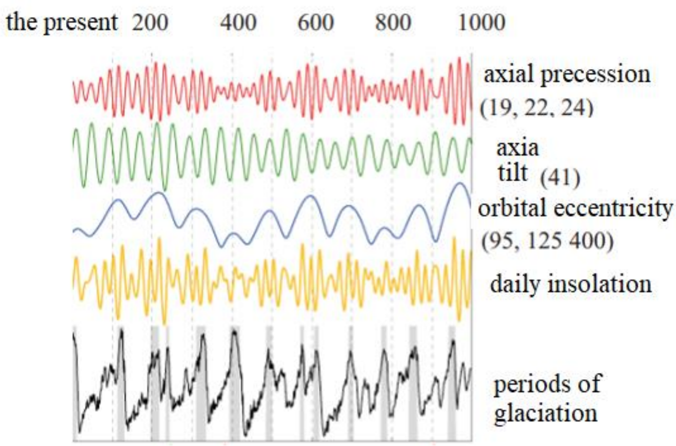


Figure 3. Milankovic cycles in the last 1,000,000 years. The numbers in the picture are in thousands of years

In this section, it is emphasized that water vapor is also a greenhouse gas, and the next section covers the hydrosphere, primarily from the perspective of the distribution of water in all three states of matter on Earth, as well as from a thermodynamic standpoint. Various methods for determining the moisture content in the atmosphere are also discussed.

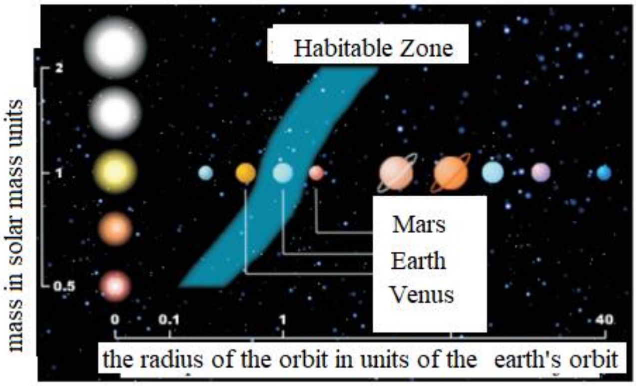


Figure 4. Habitable zone [5]

The concept of the habitable zone in a planetary system (Figure 4) is closely related to the existence of the kind of hydrosphere found on our planet.

The formation of wind is a phenomenon that highlights the significance of Newton's second law and the force as the cause of changes in the state of motion of an object (in this case, parts of the atmosphere). In this section, it is important to emphasize that during the formation of wind, the fact becomes evident that it is observed from a reference frame tied to the Earth, which is essentially non-inertial. Non-inertial reference frames, introduced in physics courses, can appear confusing and unnecessary to students. However, in both sections, students realize that the formation of wind cannot be explained without taking into account the Coriolis force and centrifugal force, two inertial forces observed in the reference frame tied to the Earth, whose basic cause is the Earth's rotation around its axis. As a result of the Coriolis force, which acts on objects moving relative to the Earth, the three large circulation cells have the shape shown in Figure 5.

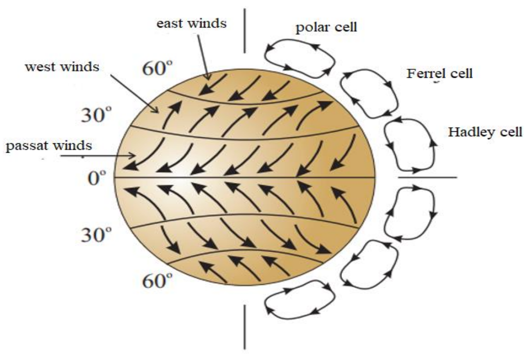


Figure 5. Vertical structure of circulation loops [5]

In the topic *Soil Physics*, the structure of the Earth is studied first (based on the propagation of seismic waves), as well as the structure of the soil itself, since it is part of the biosphere. Since soil consists of substances in solid, liquid, and gaseous states, we return once again to the hydrosphere, specifically the existence of water in soil pores. If the soil pores are completely filled with water, the soil is saturated. The movement of such water is primarily governed by gravitational force, this is known as gravitational water. If not all soil pores are filled with water, the soil is unsaturated. The pores form a capillary system, so the water is called capillary water. Hygroscopic water is adhered to soil particles by adhesive forces, and such soil is considered dry (Figure 6). Plants can utilize gravitational and capillary water through their root systems, while hygroscopic water is inaccessible to them.

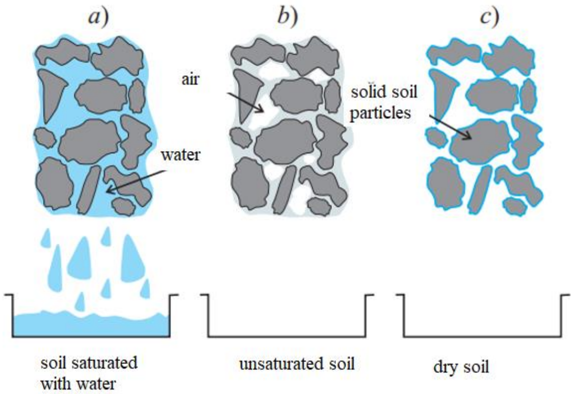


Figure 6. Types of water in soil: a) gravitational, b) capillary, and c) hygroscopic. [5]

The section *Energy and the Environment* deals with the forms of energy that students are already familiar with from physics and chemistry. When it comes to energy sources, attention is given to two major groups: renewable and non-renewable energy sources, with an emphasis on the physical principles of converting energy from the environment into electrical energy.

The final section of the program is *Sound and Noise*, where, after recapping the basic physical concepts that describe sound as a mechanical wave, the concept of noise is introduced, along with its measurement and noise reduction.

CONCLUSION

Simultaneously with the development of the Environmental Physics program at the Faculty of Sciences and Mathematics in Niš, a similar program, along with supporting materials, was developed at the Faculty of Sciences and Mathematics in Novi Sad [M. Terzić]. Building on these programs and the experience gained from their implementation, the same course was introduced at the Academy of Applied Technical and Preschool Studies, at both the Vranje and Niš departments. During the previous seven-year accreditation period, the course was included in the curricula for the study programs in Mechanical Engineering and Environmental Protection, as an elective and a compulsory course, respectively. In the new accreditation period, beginning in the 2024/25 academic year, and with a slightly revised syllabus, the course has become compulsory in the Ecology and Environmental Protection study program.

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From Planck's Quantum Hypothesis to the Planck Temperature of Planets

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Abstract. This paper begins by examining the properties of radiation emitted by an ideal black body, highlighting the limitations of classical theories explaining them. It then explores Planck's quantum hypothesis, which introduced the concept of energy quantization for oscillators, providing a successful explanation for the principles governing black body radiation. Starting from the assumption that the Sun and planets can be treated as objects for which the laws of black body radiation apply, the solar constant and Planck temperature of planets will be determined. The basic characteristics of the greenhouse effect will then be discussed. In the paper's final section, an expression for the planet's temperature will be derived using Arrhenius' model of a single-layer atmosphere, which takes the greenhouse effect into account.

Keywords: blackbody radiation, Planck's quantum hypothesis, Planck temperature of planets, greenhouse effect

INTRODUCTION

At the end of the 19th century, it was widely believed that physics was a well-established science capable of explaining all natural phenomena using essentially two theories: Newtonian mechanics and Maxwell's electrodynamics. The prevailing view within scientific circles was that theoretical physics had reached its pinnacle, leaving only the task of performing more precise measurements. William Thomson (1824–1907), a British mathematician, mathematical physicist, and engineer better known as Lord Kelvin, delivered a lecture in April 1900 in London, later published in the Philosophical Magazine under the title "Nineteenth Century Clouds Over the Dynamical Theory of Heat and Light." In this work, Kelvin identified two pressing issues or "clouds" that loomed over the physics of his time. The first concerned the concept of ether and the negative result of the Michelson-Morley experiment, while the second dealt with the breakdown of the equipartition theorem of classical mechanics in statistical thermodynamics. Addressing these "clouds" ultimately led to advancements far beyond initially anticipated. Specifically, it paved the way for the developing of two groundbreaking physical theories of the 20th century: the theory of relativity (special and general) and quantum mechanics. These revolutionary theories profoundly transformed the classical understanding of space, time, and the structure of matter.

In the subsequent section, we will explore the concept of the black body model and the unique properties of its radiation. As it turns out, classical physics could not adequately explain the behaviour of radiation emitted by this model. Moving beyond classical theories, a renowned German physicist, Max Planck (1858–1947), successfully accounted for black body radiation laws by introducing the so-called quantum (or Planck's) hypothesis. This groundbreaking hypothesis disrupted the classical equipartition theorem, which had been presumed applicable to the black body model. Planck's revolutionary work resolved the black body radiation problem and marked the inception of quantum mechanics as an entirely new field of physics.

Building on the potential application of the black body model to the Sun and planets, this paper will present the derivation of an expression for the so-called Planck temperature of a planet based on its surface absorption of solar radiation. The discussion will then shift to the greenhouse effect, exploring how this phenomenon raises a planet's average temperature above its Planck temperature. Finally, an expression for the planet's temperature will be derived using Arrhenius' single-layer atmospheric model.

RADIATION OF A BLACK BODY AND PLANCK'S HYPOTHESIS

One of the physics models that gained significant attention in the early 20th century is the black body model. This thermodynamic model represents a cavity filled with electromagnetic radiation generated by charged particles moving inside the walls of a substance. The walls absorb all the energy of this radiation, which then re-emit, that is radiate it. By establishing an energy balance between the emission and absorption of radiation, the black body achieves a state of thermodynamic equilibrium.

Experimentally, it has been determined that, at various thermodynamic temperatures, the distribution of radiation energy per unit volume, averaged over time, $w(\omega, T)$, as a function of the angular frequency of radiation, ω, follows the pattern shown in Figure 1.

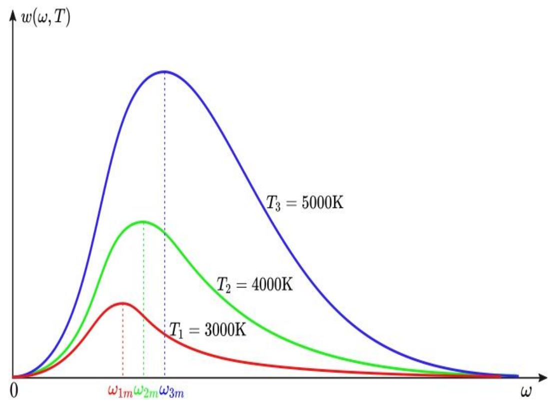

Figure 1. Distribution of black body radiation energy density at different thermodynamic temperatures [1]

Two fundamental physical laws were derived from this distribution and experimental findings. Jožef Štefan (1835–1893), a Slovenian mathematician and physicist, and Ludwig

Boltzmann (1844–1906), an Austrian physicist, independently concluded that the radiative power per unit area of a black body is directly proportional to the fourth power of its temperature

$$M = \sigma T^4, \tag{1}$$

where $\sigma = 5.67 \times 10^{-8}\ \frac{\mathrm{W}}{\mathrm{m^2K^4}}$ is Stefan-Boltzmann constant. The previous expression represents the so-called Stefan-Boltzmann law.

Wilhelm Wien (1864–1928), a German physicist, established that the product of the wavelength of the radiation λ_m corresponding to the maximum of the curve $w(\omega, T)$ and the temperature T of an absolute black body is constant, i.e., that

$$\lambda_m T = b, \tag{2}$$

where $b = 2.898 \times 10^{-3}$ m · K is the Wien constant. This formulates Wien's displacement law.

The attempt to explain the distributions shown in Figure 1, along with the Stefan-Boltzmann law and Wien's law, was initially approached, as expected, from the perspective of classical statistical physics. Within this classical framework, each harmonic oscillator in the walls of an black body, in thermodynamic equilibrium at temperature T, according to the equipartition theorem, corresponds to the energy of $k_B T$ (where $k_B = 1.381 \times 10^{-23}\ \frac{\mathrm{J}}{\mathrm{K}}$ is the Boltzmann constant). This led to a functional relationship between the radiation energy density and its frequency for a black body, which matched the experimental curves in Figure 1 at low frequencies (Rayleigh-Jeans law). However, as the frequency of radiation increased, the discrepancies became more pronounced, resulting in what was termed the "ultraviolet catastrophe".

In 1900, Max Planck proposed that, for this model in a state of thermodynamic equilibrium, oscillators could only possess discrete energy values

$$E_n = nh\nu, \tag{3}$$

where $n = 0,1,2 \ldots$ and $h = 6.626 \times 10^{-34}$ J · s is Planck's constant. According to Planck, oscillators in the walls of a substance that forms an absolutely black body, in a state of thermodynamic equilibrium, can only have energy values that are integer multiples of a single quantum of energy $h\nu$ (where $\nu = \frac{\omega}{2\pi}$ is the ordinary frequency of radiation). This assumption is known as Planck's quantum hypothesis.

Starting from this assumption, Planck derived the expression:

$$w(\omega, T) = \frac{8\pi h\nu^3}{c^3} \frac{1}{e^{\frac{h\nu}{k_B T}} - 1}, \tag{4}$$

This expression accurately reproduces the curves shown in Figure 1, commonly referred to as Planck's radiation curves for an ideal black body. The expression (4) is known as Planck's radiation law. The Stefan-Boltzmann law and Wien's law can be derived from it.

In this way, Planck's hypothesis provided a comprehensive explanation for the radiation behaviour of the black body model.

PLANCK TEMPERATURE OF PLANETS

Radiation energy measurements from celestial bodies have revealed that their energy density distributions across frequencies/wavelengths closely match the Planck's curves (Figure 2).

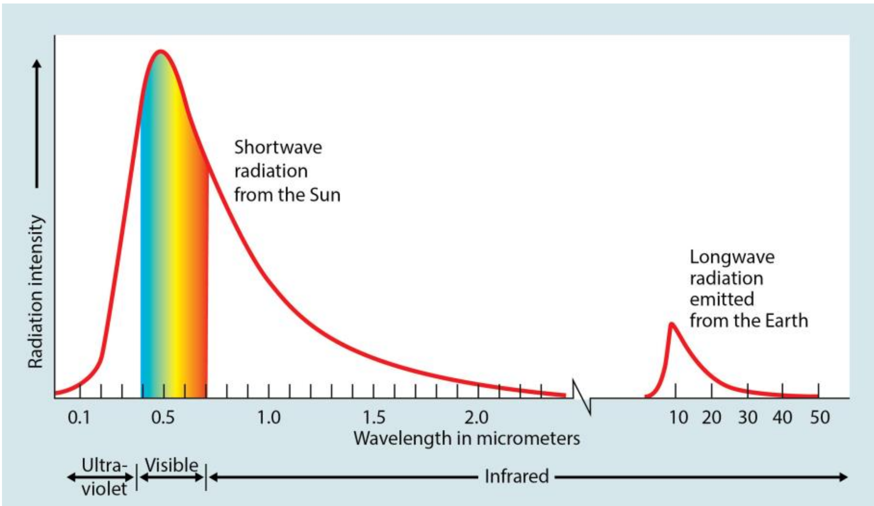

Figure 2. Spectral energy densities of Sun (left) and Earth (right) radiation[https://ugc.berkeley.edu/background-content/re-radiation-of-heat/]

It should be noted here that all heated bodies, to varying extents, "conform" to Planck's radiation law. Based on this, the Planck's curve for the Sun obtained through measurements allows us to determine the wavelength λ_m corresponding to its maximum. Using the known value for λ_m, and applying Wien's displacement law (2), the temperature of the photosphere of the Sun can be calculated, which is $T_S = 5772$ K. Substituting this temperature into equation (1) gives the radiative power per unit area of the Sun, $M_S = 6.29 \times 10^7\ \frac{\mathrm{W}}{\mathrm{m}^2}$. Given the radius of the Sun $R_S = 6.957 \times 10^8$ m, its total radiative power (luminosity) is

$$L_S = 4\pi R_S^2 M_S \approx 3.83 \times 10^{26}\ \mathrm{W}. \qquad (5)$$

It should be noted that this is the radiative power of our star within any sphere described around it and, therefore, also within the sphere encompassing orbit of the Earth at an average distance of $r = 1.496 \times 10^{11}$ m. Keeping this in mind, the surface power density of the radiation reaching Earth from the Sun will be

$$M_{SK} = \frac{L_S}{4\pi r^2} \approx 1362\ \frac{\mathrm{W}}{\mathrm{m}^2}, \qquad (6)$$

which has been confirmed by measurements. This value is referred to as the solar constant for Earth. In this way, the value of the solar constant can be determined for any planet or celestial body, i.e., at any distance from the Sun.

Let us consider a Solar System planet with radius of the planet R, solar constant M_{SK}, and albedo (the ratio of the energy the planet reflects to the total solar energy that reaches it) a. In this case, the solar radiation energy the planet receives per unit of time can be expressed as $(1-a)\pi R^2 M_{SK}$.

Assuming that the planet re-emits this absorbed energy as an black body at temperature T, in a state of thermodynamic equilibrium, we have:

$$(1-a)\pi R^2 M_{SK} = 4\pi R^2 \sigma T^4. \tag{7}$$

Then, the temperature of the planet, known as the Planck temperature, will be:

$$T = \left(\frac{(1-a)M_{SK}}{4\sigma}\right)^{\frac{1}{4}}. \tag{8}$$

For Earth, substituting the solar constant value from equation (6) and the albedo of the planet of 0.37, the calculated Planck temperature is approximately -25 ℃. This is 40 degrees lower than Earth's average temperature of 15 ℃, which highlights the impact of the greenhouse effect that is not accounted for in this calculation.

GREENHOUSE EFFECT AND TEMPERATURE OF PLANETS

The greenhouse effect refers to the process by which heat is retained near a planet's surface due to the presence of greenhouse gases. In Earth's atmosphere, the primary greenhouse gases are water vapour (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and ozone (O_3), which together make up around $0{,}1\%$ of the atmosphere. The dominant gases – nitrogen (N_2), which accounts for 78%, oxygen (O_2) 21%, and argon (Ar) $0{,}9\%$ – do not contribute to the greenhouse effect. This is due to the specific structure of their molecular energy levels, which can be electronic, vibrational, or rotational. Thermal radiation is primarily absorbed by molecules that possess rotational energy levels.

For a Planck temperature of -25 ℃ for Earth, Wien's law predicts that the wavelength corresponding to the peak of the spectral energy density of radiation re-emitted by Earth is 11.6 μm. This wavelength corresponds to long-wave infrared radiation, which, as previously mentioned, is absorbed by molecules with rotational energy levels. These levels are found in polar molecules, which is characteristic of the greenhouse gases mentioned above.

In 1859, an Irish physicist and chemist, John Tyndall (1820–1893), became the first to demonstrate that water vapour and carbon dioxide can absorb and emit heat via infrared radiation. Several years earlier, an American scientist and inventor, Eunice Newton Foote (1819–1888), had carried out the first such experiments. However, at the time, she did not distinguish between the energy transferred by sunlight across the entire spectrum and infrared radiation, nor could she explain the phenomenon. In 1820, French mathematician and physicist Jean Baptiste Joseph Fourier (1768–1830) coined the term "greenhouse effect".

For an arbitrary planet with an atmosphere, the impact of the atmosphere on the planet's temperature will be calculated using the one-layer model in the framework of Arrhenius' approximation, assuming that both the planet's surface and atmosphere behave as black bodies. Considering the planet's rotation, the energy from short-wavelength solar radiation that reaches one square meter of the atmosphere's surface per unit of time is given by $M_0 = \frac{1}{4}(1-a)M_{SK}$, where M_{SK} is the solar constant for the planet in question. The transmission coefficients of the atmosphere for short-wavelength and long-wavelength radiation are represented by t_k and t_d, respectively. The energy that reaches the planet's surface per unit time per square meter is therefore $t_k M_0$. This energy is absorbed by the planet's surface, which heats up to temperature T_p and re-emits energy per unit time per unit area according to the Stefan-Boltzmann law, $M_p = \sigma T_p^4$. A portion of this re-emitted energy $t_d M_p$ passes through the atmosphere, while the remainder is absorbed, heating the atmosphere to a temperature T_a. The heated atmosphere then emits energy per unit time per unit area, $M_a = \sigma T_a^4$ (Figure 3).

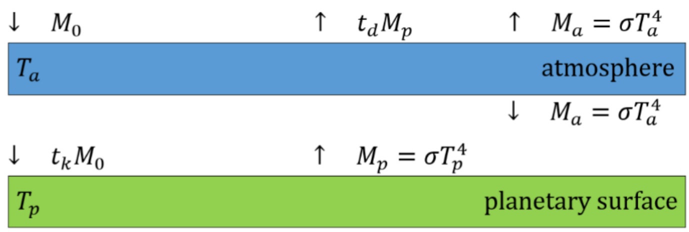

Figure 3. Arrhenius' model of a single-layer atmosphere

From the previous figure, we can see that in thermodynamic equilibrium for the atmosphere, the relation $M_0 = M_a + t_d M_p$ holds, and $M_p = M_a + t_k M_0$ for the planet's surface. From these equations, one gets $M_p = M_0 \frac{1+t_k}{1+t_d}$, which, when combined with $M_p = \sigma T_p^4$ gives the following expression for the planet's temperature within this model:

$$T_p = \left(\frac{M_0(1+t_k)}{\sigma(1+t_d)}\right)^{1/4}. \tag{9}$$

It should be noted that in the absence of an atmosphere (the so-called zero model), where $t_k = t_d = 1$, (9), expectedly, one gets (8), that is, the expression for the Planck temperature. Given that for Earth's atmosphere $t_k = 0.9$ and $t_d = 0.1$ and considering equation (6) for the solar constant, substituting these values into equation (9) gives a surface temperature of 285 K, or 12 °C, in the context of Arrhenius' one-layer model. Therefore, Earth's temperature is significantly higher than the corresponding Planck temperature thanks to the atmosphere and the greenhouse effect. This is also true for other planets in the Solar System with greenhouse gases atmospheres.

On the other hand, this implies that an increase in the concentration of greenhouse gases in the atmosphere results in a rise in the planet's average temperature, leading to climate change. In 1896, Svante August Arrhenius (1859–1927), a Swedish physicist and chemist, calculated how the Earth's temperature would change if the concentration of carbon dioxide in its atmosphere doubled. Later, in 1938, Guy Stewart Callendar (1898–1964), an English engineer and inventor, highlighted that human activities could contribute to the rising CO_2 levels in the atmosphere. In 2021, the Nobel Prize in Physics was awarded to Syukuro Manabe and Klaus Hasselmann "for the physical modelling of Earth's climate, quantifying variability, and reliably predicting global warming" and to Giorgio Parisi "for the discovery of the interplay of disorder and fluctuations in physical systems from atomic to planetary scales".

CONCLUSION

In an effort to explain the radiation laws of a black body, Max Planck proposed (correctly, as it later turned out) that oscillators can only possess discrete energy levels, which are integer multiples of the corresponding energy quanta. This assumption stood in contrast to the classical view, where energy was considered a continuous quantity. The distinction introduced by Planck's quantum hypothesis was, therefore, a groundbreaking shift in science, leading, as we know, to the development of quantum mechanics – the physics of the microscopic world. Planck successfully explained the radiation characteristics of black bodies by assuming discrete energy values. This was especially significant because the radiation emitted by all heated bodies, to varying degrees, shares these characteristics. Naturally, this applies to the Sun's radiation and also to that of planets and other celestial bodies.

When the black body model was applied to the Sun and to arbitrary planet without an atmosphere, whose surface is heated by absorbed solar radiation, the planet's Planck temperature was determined in the so-called zero approximation. It was found that for Earth, this temperature is forty degrees lower than the measured value, a difference attributed to the greenhouse effect. Due to the rising concentrations of greenhouse gases in the atmosphere due to human activities, this effect is primarily linked to global warming and its adverse impacts on the climate. On the other hand, the greenhouse effect makes planets with atmospheres containing these gases warmer than they would otherwise be, raising their temperature above the Planck temperature. This is particularly important in the case of Earth, as the greenhouse effect clearly makes it a more hospitable place for life.

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Circular Economy in The Textile Industry by Blockchain Technology

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Abstract. The textile industry, as one of the leading industries in the world, faces rapid development that negatively impacts environmental protection. For this reason, alongside numerous AI technologies, blockchain technology is highlighted as it enables sustainability, transparency, security, and data integrity. One of the leading problems is the amount of textile waste that ends up in landfills or incineration plants. To reduce the amount of waste, this technology provides additional information that allows, through circular economy principles and ESG standards, waste to be transformed into new (recycled / repaired) products.

Keywords: blockchain, technology, circular economy, textile industry, tree Rs

INTRODUCTION

In recent years, sustainable fashion in the textile industry has undergone significant innovations, especially regarding the integration of smart intelligence. Among numerous leading technologies, blockchain technology stands out in the realm of smart intelligence.

Blockchain technology has become a key tool in many industries, including fashion and textiles, due to its ability to provide sustainability, transparency, security, and data integrity. The fashion industry pays very little attention to material recycling as it currently adheres to what is easiest, which is the model of "take – make - dispose." With the emergence of new technology, the industry is given the opportunity to use blockchain not only for “taking” and “giving” but also for tracking “disposing,” or waste that is intended to end up in a landfill or incineration plant. Thus, brands would have the chance to monitor waste and adopt a circular model (repair and return to sale).

ABOUT BLOCKCHAIN TECHNOLOGY

Blockchain is a record-keeping technology designed to make it impossible to hack the system or forge the data stored on the blockchain, thereby making it secure and immutable. It's a type of distributed ledger technology (DLT), a digital record keeping system for recording transactions and related data in multiple places at the same time. [1].

The principle of this technology is that information is stored in blocks rather than in conventional computer systems as files, tables, or columns, which means that data storage is much more secure. Information stored in blocks and interconnected through cryptographic hashes is protected such that if someone tries to manipulate or modify a block, it would require changing every subsequent block, making manipulation computationally infeasible.

What is very typical of this technology model is its transparency. It allows for the tracking of materials and products throughout the entire supply chain, from suppliers to consumers. With this model, consumers can use QR code scanning on labels to ensure that materials come from sustainable sources, as well as to verify the authenticity of the garment, the origin of the materials, the ethics of the producer, and compliance with standards.

Blockchain technology is crucial in the circular economy because, through interconnected information, manufacturers and fashion designers can monitor the quantity of raw materials, the number of products, distribution, sales, and the quantity of waste that typically ends up in landfills or incineration plants. To reduce waste, this technology provides additional information that allows waste to be transformed into new (recycled / repaired) products through circular economy principles and standards.

ESG STANDARD (ENVIRONMENTAL, SOCIAL, GOVERNANCE)

Digital tools for environmental management, as techniques for generating, analyzing, and using financial and non-financial information, improve environmental and economic performance for businesses. Digital environmental monitoring and management aim to provide physical information about material and energy usage, as well as monetary information about environmental costs, revenues, and savings.

In light of these changes, the application of ESG (Environmental, Social, Governance) standards is gaining increasing importance in the textile industry. These standards help the textile industry address ecological issues such as the use of natural resources and the production of hazardous waste. To have appropriate ESG reports and sustainability reports, businesses in the textile industry must first establish relevant ESG practices and circular economy models [3].

Figure 1. ESG Standard [4]

Addressing the waste challenges arising from the linear economy in the textile industry, the circular economy model aims to create a sustainable and resilient system for resource management. [5].

CONNECTION OF BLOCKCHAIN TECHNOLOGY WITH CIRCULAR ECONOMY

The concept of Circular Economy attempts to integrate economic activities with environmental welfare in a sustainable manner [6]. The circular economy aims to depart from the practice of 'make, use, dispose' and encourages the cyclical implementation of processes and use of processes. It aims to restrict the depletion of natural resources and waste, through its cyclical use and embodies cleaner production through the three Rs 'reduce, reuse and recycle' [6], both in the manufacturing and service economy. Circular economy defines a new approach to addressing sustainability and social responsibility issues; paying particular attention to the social aspects of sustainability.

The importance of 3R is emphasized in many global agendas and action plans. Agenda 21 highlights to change consumption and production patterns for sustainable development. The Johannesburg Plan of Implementation (JPOI) adopted at the 2002 World Summit on Sustainable Development stipulated that all countries should promote sustainable consumption and production to facilitate global sustainable development [7].

It embraces a loop system of economy-environment collaborations creating a closed-loop economy [8]. Within the loop, the circular economy aims to keep materials, products and outputs in circulation for the longest time, by preserving their value [9].

Figure 2. Circular economy, 3R (Reduce - Reuse - Recycle) [10].

The connection between blockchain technology and the circular economy lies in the fact that blockchain technology contributes to the circular economy through applications by enhancing various aspects of this economic model. It provides transparency, traceability, and efficiency, while the circular economy emphasizes sustainable resource use, waste minimization, and value creation through the continuous use of products and materials.

CONCLUSION

The paper presents the connection between blockchain technology and the circular economy with the aim of environmental preservation, as well as the technology's contribution to the sustainability of the fashion industry. Given that currently only 1% of textiles are recycled, while a large portion of waste is either incinerated or ends up in landfills, it is crucial to raise awareness among designers, companies, and consumers about the potential for waste i.e., discarded products to be "repaired" and returned to the market. Additionally, using AI technology, they can gain accurate and precise information about the product's condition by scanning the QR code on the label.

For blockchain technology to fully realize its potential, it is important to discuss its capabilities extensively. Companies need to gain insights into waste circulation flows to focus more on the "Tree Rs" model, which aims to reduce waste, increase recycling, and strive towards sustainable business models.

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Sustainable Fashion - the Best Environmentally Friendly Materials for Clothing

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Abstract. Fashion industry is one of the largest sources of pollution on the planet. This is why it is becoming increasingly important to make conscious choices and prefer environmentally friendly fabrics in order to protect our planet. Paper describes six particularly eco-friendly fabrics that are the most environmentally friendly for sustainable fashion and should therefore be more widely used and researched. The listed materials are: hemp, linen, organic cotton, TENCEL, wool and vegetable leather. The paper highlights why the mentioned fabrics can make such a difference in our clothes and in the environment. Paper also emphasizes how important it is to invest in environmentally friendly fabrics and wardrobes.

Keywords: sustainable fashion, ecological materials, fabrics, sustainable wardrobes, recycling

INTRODUCTION

One of the most important manufacturing industries in the world is the textile industry, which creates a significant share in the economy at the global level. However, it is also an industry that in the coming period should focus on policies, strategies, innovative development and production concepts and processes that will contribute to positive changes related to sustainable production and consumption and the reduction of negative impacts on the environment because it is precisely one of the biggest polluters of the environment. Globalization processes, which led to a significant increase in the production of textile and fashion products at competitive prices, and the focus on the development of technologies that contribute to efficiency, led to a significant increase in the consumption of textile and fashion products on a global level. As a result, extremely large amounts of textile waste are generated, energy consumption is very high, and the environment is significantly threatened. The problem of proper disposal and recycling of textile waste is only one of the current and very important issues in the transition to sustainable textile management.

Current scientific research in the field of textile technologies is focused on the search for new methods and processes, as well as raw materials, materials and different types of processing in the development of advanced multifunctional textile and fashion products that could contribute to the gradual transformation of the entire field of textile technology towards a sustainable system aimed at development innovative value-added products that are safe for the health of the end user and can be recycled at the end of their life. [3]

THE BEST ENVIRONMENTALLY FRIENDLY MATERIALS FOR CLOTHING

Choosing to recycle unwanted fabrics will help reduce this global problem. The truth about the damage that the fashion world is causing to the environment is starting to surface more and more, which is leading to positive changes within the industry and through consumers who are becoming more aware and therefore more environmentally conscious.

Green or eco-friendly fabrics are creating big changes in the fashion industry. These unique fabrics and design concepts are changing the way designers think and feel about the products they create. They also offer a trendy alternative that helps protect the environment among these changes is the use of fabrics that are described as "sustainable" which will be discussed later in the paper. What is also important to note is that changes start from each of us if we choose a sustainable lifestyle and you can contribute to sustainable fashion and make conscious choices for your appearance by choosing the best environmentally friendly materials. [4]


Figure 1. Selection of sustainable clothing


Figure 2. Nature - preserved environment

There are six particularly environmentally friendly fabrics - materials whose use can greatly contribute to the improvement of the environment, namely: hemp, linen, organic cotton, TENCEL, wool and vegetable leather. In the upcoming chapters of this paper, we will describe and explore these six eco-friendly fabrics in more detail and discover why they can make a difference to our environment and the sustainable clothes we wear.

Figure 3. Ecologically acceptable fabrics - materials

Hemp

Hemp is the first choice of environmentally friendly fibers and fabrics. They are an excellent alternative to traditional cotton. Among the eco-friendly fibers, hemp has become a favorite for sustainable fashion fabrics because it is strong, versatile and durable, perfect for the production of textiles, paper, cosmetics and even food. Speaking of fashion, hemp is extremely useful. Light, soft and breathable fabrics are just some of the characteristics that make hemp ideal for summer wear. Moreover, thanks to its durability, hemp clothes last a long time, are resistant to wear and tear and retain their shape for a long time.

Hemp is an environmentally friendly alternative to traditional cotton because it requires 50% less water to produce the same amount of fabric, and also less pesticides. Choosing hemp clothing means making a smart choice for the environment and the health of the people involved in its cultivation. In addition, its durability makes it perfect for your sustainable wardrobe, offering durable, quality clothing. [5]

Figure 4. Hemp plant and fiber

Linen

When we want to combine quality, excellence and comfort, then linen is a real gem in the world of sustainable fashion. This natural fiber, produced from the flax plant, grows abundantly in Europe and Asia and requires less water and pesticides than cotton. Not only is linen strong and durable, it lasts up to three times longer than cotton according to a study by Cotton Incorporated. But it doesn't end there. Linen is a breathable fabric that absorbs moisture and dries quickly, making it perfect for hot summer days. And not only is it easy to wash, but it's also antibacterial, which also makes it ideal for bedding and underwear. Choosing linen bedding for your sustainable use or sustainable clothing means making the right choice for the environment, its preservation and for yourself. [6]

Figure 5. Flax plant and fiber

Figure 6. Linen fabric

Pure Egyptian cotton Mako

The highest quality fabrics are made from pure Egyptian Mako cotton. Egyptian Mako cotton is an excellent choice among sustainable fashion materials. This type of cotton is known for its softness, durability and strength, and is sustainably grown in the Nile Valley regions. Egyptian mako cotton is considered one of the finest cotton materials in the world because of its long fibers, which make it a stronger and more durable fabric than other types of cotton. In addition, Egyptian mako cotton is known for its softness, making it ideal for clothing, underwear and bedding. But it's not just the quality of cotton that makes it a great choice for sustainable fashion. The cultivation of Egyptian mako cotton is very environmentally friendly, with limited use of chemicals and the practice of efficient irrigation methods. Furthermore, the production of Egyptian mako cotton supports the local economy, creating jobs and supporting farming communities. This cotton is grown mostly by small farmers on small areas of land and about 70% use traditional cultivation techniques and do not use pesticides or chemical fertilizers. Its durability makes it a "long-life" fiber, which reduces the need to frequently buy new clothes. Its eco-friendly production supports the health of our planet, making Egyptian mako cotton an eco-friendly choice that will make you feel good inside and out. [5]

Figure 7. Mako Egyptian cotton

TENCEL - natural cellulose fibers

We can say that TENCEL fabric is a sustainable fabric that comes from the forest. This cellulose fabric is made from eucalyptus wood fibers sourced from sustainable forests and grown without the use of pesticides or chemical fertilizers. TENCEL's manufacturing process uses a closed loop that drastically reduces the use of water and chemicals, with 99% of the water used in the manufacturing process being recycled. This makes it one of the most environmentally sustainable materials on the market. TENCEL stands out from other fabrics for its softness, lightness and breathability. The fabric is very resistant to creasing and bending, keeps its shape and lasts longer than other materials. Choosing TENCEL for your wardrobe means making a sustainable and conscious choice. Not only is it produced in an environmentally friendly way, but its durability means it will last a long time, reducing the frequency of buying new garments. TENCEL is completely biodegradable and compostable. [7]

Figure 8. TENCEL – natural cellulose fiber

Vegetable leather

This type of leather is made using natural materials that replace the chemicals used in traditional leather tanning processes. Vegetable leather can be produced using different fabrics, such as pineapple fibers, cork, which come from sustainable and renewable sources. The plant-based leather production process uses less water and energy than traditional leather, reducing the impact on the environment. The softness, flexibility and durability of leather make it the perfect choice for bags, shoes and accessories. In addition, vegetable leather garments are stain and water resistant, making them suitable for everyday use. [2]

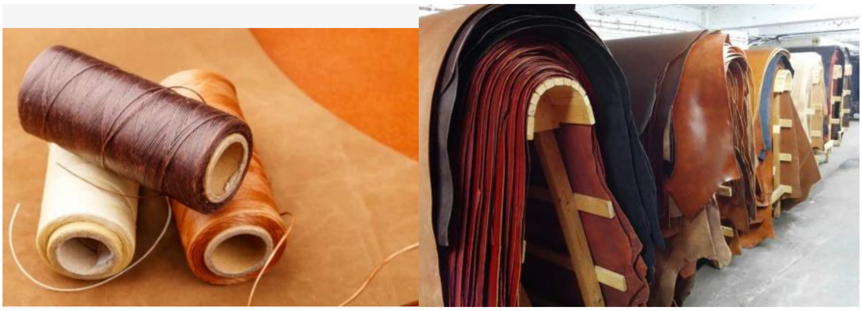

Figure 9. Vegetable leather

Merino wool and silk

A combination of Merino wool and silk, these two fibers are a great combination as they complement each other perfectly creating a fabric that is light and breathable, yet warm and durable. Merino wool is known for its ability to regulate body temperature, keeping the body warm in winter and cool in summer. In addition, Merino wool is also resistant to wrinkles and stains, ensuring a long life of the garment. Silk, on the other hand, creates a luxurious fabric that is soft to the touch. Thanks to its natural breathability, silk can regulate the body's moisture, keeping the skin cool and dry. Silk is also resistant to pigments and has a natural sheen that adds elegance to any garment. The combination of Merino wool and silk therefore creates a high-quality, sustainable material that offers numerous benefits. The ability to regulate body temperature, resistance to creases and stains, and the natural luster of silk make these fibers a winning pair for those looking for a sustainable, high-quality fabric. [1]

Figure 10. Merino wool and silk

CONCLUSION

Sustainable fashion is about innovation, responsibility and making decisions that are good for both people and the planet. When consumers, brands and designers embrace these principles more, the fashion industry will undergo a major transformation.

The paper describes high-quality environmentally friendly materials, by using which we can have clothing that respects the environment to a greater extent than before. From organic fabrics such as TENCEL to hemp and organic cotton, the choice of sustainable materials is wide and varied and not only are these materials free of harmful chemicals, they are also produced using environmentally friendly processes and are often 100% recyclable. The advantages of green dressing are not only limited to your style of clothing and the planet, but wearing clothes made of environmentally friendly fabrics contributes to protecting the health of consumers and the health of people working in the textile chain. In fact, many traditional materials contain toxic chemicals that can have harmful effects on human health. We can conclude from everything that investing in environmentally friendly fabrics brings benefits in many different fields, so let's make the world a more beautiful and healthier place to live. Together, with our decisions and choices, we can transform the fashion industry and create a more sustainable world.

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Enhancing Textile Design Education with AI: A Case Study on Time Efficiency and Student Engagement

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Abstract. This study explores the transformative potential of artificial intelligence (AI) in textile design education, focusing on time efficiency and student engagement. By integrating AI tools into textile design courses, educators can offer more dynamic and personalized learning experiences. The research examines the current state of textile design education, identifies challenges, and proposes AI-driven solutions to enhance educational outcomes. Data from undergraduate courses were analyzed to compare traditional and AI-assisted methods, revealing significant improvements in efficiency and quality. The study underscores the need for AI integration in curricula to better prepare students for the evolving demands of the textile industry.

Keywords: artificial intelligence (AI), textile design education, time efficiency, student engagement, curriculum innovation

INTRODUCTION

The textile design industry is characterised by rapid innovation and a continuous need for creativity and technical proficiency. As a significant contributor to the global economy, the industry requires designers who are skilled in both traditional methods and modern technologies. The integration of artificial intelligence (AI) in textile design education presents an opportunity to meet these demands by enhancing learning outcomes and better preparing students for the evolving market [1-3].

Current textile design education typically involves a combination of theoretical instruction and hands-on practice, encompassing a comprehensive process from conception to execution. This process includes several stages: conception and inspiration, research and exploration, sketching and visualisation, digital design and CAD software usage, colour selection and palette creation, prototyping and sampling, and execution and production [4-7]. Despite the thorough nature of these stages, traditional teaching methods often fail to keep pace with rapid technological advancements in the industry. This leads to a gap between academic training and industry requirements, exacerbated by slow curriculum updates and limited access to advanced design tools.

The application of AI in textile design education remains underexplored, with most institutions relying heavily on traditional methods [8-10]. This gap highlights the need for innovative solutions to align educational practices with industry standards. Integrating AI tools can potentially streamline the design process, enhance creativity, and improve efficiency and student engagement [11-13]. Addressing this gap is crucial for several reasons: ensuring that graduates possess the necessary skills and knowledge to thrive in a technology-driven industry; leveraging AI to personalise and improve the educational experience, leading to better student engagement and performance; and streamlining the design process to allow students to focus more on creativity and innovation rather than repetitive tasks.

The purpose of this study is to examine the current state of textile design education and explore how AI technologies can be integrated to enhance learning outcomes. This research aims to identify the challenges faced by traditional educational methods, assess the potential benefits of AI integration, and propose a comprehensive AI-driven framework for textile design education. By integrating AI tools into textile design courses, educators can offer more dynamic and personalised learning experiences, better preparing students for the future demands of the textile industry. This study will analyse data from undergraduate courses to compare traditional and AI-assisted methods, revealing significant improvements in efficiency and quality. The findings will underscore the need for AI integration in curricula to bridge the gap between academic training and industry requirements, ultimately enhancing the preparedness of students for the evolving demands of the textile industry.

METHODOLOGY

Research Design

This research utilised a combination of experimental and quasi-experimental designs, allowing for a comprehensive analysis of the impact of AI on textile design education. The study involved both within-subjects and between-subjects comparisons to assess the differences in learning outcomes and efficiency.

Data Collection

Data were collected from three undergraduate textile design courses, each consisting of 64 hours per semester: Textile Design 1 (Fundamentals), Textile Design 2 (Thematic Project), and Textile Design 3 (Creative Design). The study initially involved 401 students, including 35 male and 366 female students from the second, third, and fourth years of their programs. Surveys were distributed to all 401 students, resulting in a response rate of 91.8%, with 368 responses received.

After thorough data cleaning and validation, 350 of the 368 responses were deemed valid and complete, while 18 responses were excluded due to incomplete or inconsistent information. This left a final sample of 350 students for the analysis.

Courses Analysed

The analysis focused on three key courses within the textile design curriculum, reflecting different stages of student development. The distribution of the 350 students across these courses is summarized in Table 1. The numbers provided in this table reflect the validated responses after data cleaning.

Table 1. Student distribution by course and year

Year	Course	Total Students	Male Students	Female Students
Second	Textile Design 1	136	10	126
Third	Textile Design 2	114	14	100
Fourth	Textile Design 3	100	11	89

The student distribution data across the three courses reveals a consistent trend of higher female enrollment, reflecting the overall gender ratio in textile design education. Textile Design 1, as a foundational course, has the highest enrollment, indicating its critical role in establishing essential skills for subsequent courses. Textile Design 2, focused on thematic projects, shows a slight decrease in enrollment, potentially due to the increased complexity and specialization required. Textile Design 3 maintains strong enrollment, highlighting student interest in creative design projects and the effectiveness of AI tools in enhancing engagement and creativity. This distribution underscores the importance of foundational skills, thematic specialization, and creative exploration in the textile design curriculum, supported by AI technologies.

Comparative Methods

The study employed a combination of methods to rigorously analyse the impact of AI on textile design education. The mixed-methods sequential explanatory design was used, initially collecting quantitative data, which was then followed by qualitative data to elaborate on the quantitative results. For example, after measuring time efficiency and quality scores, follow-up interviews were conducted to gain deeper insights into the student experience with AI tools. Randomised controlled trials (RCTs) were also utilised, where a subset of students was randomly assigned to either a control group (traditional methods) or an experimental group (AI-assisted methods) to compare outcomes more rigorously. Additionally, a longitudinal study was implemented, tracking the same cohort of students over multiple semesters to observe the long-term effects of AI integration on learning outcomes and skill development. To control for confounding variables, propensity score matching (PSM) was employed, ensuring that the comparison between AI-assisted and traditional methods was fair and unbiased. This multifaceted approach provided a comprehensive and robust analysis of the impact of AI on textile design education.

RESULTS AND ANALYSIS

The following section presents the results and analysis of the study, focusing on student demographics and engagement, the comparison of design processes with and without AI, efficiency improvement, and statistical analysis.

Student Demographics and Engagement

The demographic distribution of students and their engagement levels across different courses are examined.

Quantitative Data

The analysis of student demographics revealed a significant gender imbalance, with 8.7% of students being male and 91.3% female. This gender ratio indicates a predominance of female students in textile design courses. The academic year distribution showed that 34.7% of students were in their second year, 32.4% in their third year, and 32.9% in their fourth year. Class sizes ranged from 130 to 139 students per course, reflecting a relatively consistent cohort size across different academic years.

Engagement Levels by Course

The engagement levels varied across different courses as shown in Table 2:

Table 2. Student engagement levels by course

Course	Engagement Level	Female (%)	Male (%)	Total Students
Textile Design 1	High	92.8%	7.2%	139
Textile Design 2	Moderate	89.2%	10.8%	130
Textile Design 3	High	91.7%	8.3%	132

In Textile Design 1, engagement was high, with 92.8% of female students and 7.2% of male students actively participating, totaling 139 students, suggesting AI tools are particularly effective in foundational courses. Textile Design 2 showed moderate engagement, with 89.2% of female and 10.8% of male students, totaling 130 students, possibly due to the thematic project's complexity requiring deeper understanding of AI tools. In Textile Design 3, engagement was again high, with 91.7% of female students and 8.3% of male students actively participating, totaling 132 students, indicating that AI tools enhance involvement in creative courses by providing new ways to experiment and visualize ideas. These engagement levels suggest that AI tools positively impact student engagement, especially in foundational and creative design courses, making the learning process more interactive and enjoyable.

Comparison of Design Process with and without AI

To evaluate the impact of AI on the textile design process, the study compared the time and efficiency of various design stages under traditional and AI-assisted methods.

Traditional Design Process

The traditional design process involved several stages, each requiring significant time investment. The initial stage, Conception: Seeds of Inspiration, took approximately 12 hours, during which students gathered and refined their ideas. Research and Exploration required 18 hours, as students delved into historical references, contemporary trends, and cultural symbols. The Sketching and Visualisation stage was particularly time-intensive, taking 25 hours to develop detailed drawings and concepts. Following this, Digital Design and CAD Software demanded 10 hours, allowing for precise detailing and pattern creation. The stage of Colour Selection and Palette Creation consumed 15 hours, with students selecting and finalizing their color schemes. Prototyping and Sampling involved 12 hours of creating initial fabric samples and prototypes. Finally, the Execution and Production phase, the most time-consuming, required 90 hours to complete the final textile products. In total, the traditional design process took 182 hours.

AI-Assisted Design Process

The integration of AI tools significantly reduced the time required for each design stage. The Conception: Seeds of Inspiration stage was reduced to 8 hours, a 33% reduction, as AI tools helped streamline idea generation. Research and Exploration took 12 hours, a 33% reduction, due to AI's ability to quickly analyze and compile relevant information. The Sketching and Visualisation stage was shortened to 14 hours, a 44% reduction, with AI assisting in creating and refining sketches more efficiently. The use of Digital Design and CAD Software was cut down to 5 hours, a 50% reduction, as AI tools facilitated faster design iterations and modifications. Colour Selection and Palette Creation was reduced to 8 hours, a 47% reduction, as AI tools provided optimized color palette suggestions. The Prototyping and Sampling stage was reduced to 7 hours, a 42% reduction, with AI enabling quicker prototype development. The Execution and Production stage saw a significant reduction to 50 hours, a 44% reduction, as AI tools enhanced the efficiency of production processes. Overall, the AI-assisted design process took 104 hours, a 43% reduction compared to the traditional method.

Efficiency Improvement

To quantify the efficiency gains from AI integration in textile design education, efficiency improvement percentages were calculated. The formula used for this calculation is as follows:

$$\text{Efficiency Improvement (\%)} = \frac{T_{\text{traditional}} - T_{\text{AI}}}{T_{\text{traditional}}} \times 100 \tag{1}$$

The table 3 below illustrates the substantial efficiency improvements achieved through the integration of AI tools in various design stages. Each stage experienced significant time reductions, highlighting the effectiveness of AI in streamlining the design process and enhancing overall productivity.

Table 3. Efficiency improvements in textile design stages using AI tools

Design Stage	Traditional Time (hours)	AI-Assisted Time (hours)	Efficiency Improvement (%)
Conception & Inspiration	12	8	33.33%
Research & Exploration	18	12	33.33%
Sketching & Visualisation	25	14	44.00%

Digital Design & CAD Software	10	5	50.00%
Colour Selection & Palette Creation	15	8	46.67%
Prototyping & Sampling	12	7	41.67%
Execution & Production	90	50	44.44%
Total Time	182	104	42.86%

Note: The percentages are approximations and reflect rounded values for better readability.

Statistical Analysis

To rigorously assess the impact of AI integration on student engagement and performance, both hypothesis testing and regression analysis were employed.

Hypothesis Testing

To determine the impact of AI on student engagement, a hypothesis test was conducted with the null hypothesis (H_0) positing no difference in engagement levels between AI-driven and traditional methods, and the alternative hypothesis (H_1) positing a difference in engagement levels.

$$H_0: \mu_{\text{traditional}} = \mu_{\text{AI-driven}} \tag{2}$$

$$H_1: \mu_{\text{traditional}} \neq \mu_{\text{AI-driven}} \tag{3}$$

Using a two-sample t-test, the p-value was found to be 0.02, indicating a statistically significant difference in engagement levels at the 5% significance level. This suggests that AI-driven methods significantly improve student engagement compared to traditional methods.

Regression Analysis

A regression analysis was conducted to explore the relationship between AI integration and student performance, with the model:

$$\text{Performance} = \beta_0 + \beta_1(\text{AI Integration}) + \epsilon \tag{4}$$

Where:

- Performance is the dependent variable, measured by project quality and job placement rates.

- AI Integration is the independent variable, measured by the extent of AI tools used in the curriculum.

The regression results indicated a positive and significant effect of AI integration on student performance (β_1=0.35, p<0.01). This suggests that greater use of AI tools in the curriculum is associated with higher student performance, as measured by project quality and job placement rates.

DISCUSSION

The integration of AI technology in textile design education has significantly improved efficiency, quality, and student engagement. Our data shows that AI-assisted design reduces the time required for sketching, digital design, and execution stages by 44%, 50%, and 44%, respectively, highlighting AI's effectiveness in automating and streamlining these phases. In addition to time efficiency, the quality of student work improved. Quality assessments using a rubric developed with industry professionals showed an average improvement of approximately 15% in AI-assisted projects. This suggests that AI tools help students complete their work faster and enhance their creative output with more accurate and detailed design capabilities. Survey results indicated a 20% increase in student engagement with AI-assisted methods compared to traditional methods, likely due to the interactive and innovative nature of AI tools.

Despite these positive outcomes, several challenges and limitations need addressing. One major limitation is the initial learning curve associated with new AI tools, requiring time for both students and educators to become proficient. Additionally, concerns about the accessibility and cost of advanced AI tools may limit availability to all educational institutions, particularly those with limited resources. There may also be resistance from both students and educators who prefer traditional methods.

Future research should focus on expanding and validating these findings. Longitudinal studies tracking the same cohort of students over multiple semesters would provide valuable insights into the sustained benefits and potential drawbacks of AI in the curriculum. Expanding AI technology applications to other design fields, such as fashion design, graphic design, and industrial design, could further validate AI's broader implications in design education. Another important area for future research is the development of AI-driven curriculum modules. Educational institutions could benefit from detailed guidelines and best practices for incorporating AI tools into their existing programs. These resources would help standardize the use of AI in design education and ensure that all students benefit from these technological advancements.

Implementing pilot programs in diverse educational contexts can provide practical insights and help identify potential issues and solutions. Moreover, research should explore methods to make AI tools more accessible to institutions with limited resources, ensuring that all students can benefit from these advancements. Ensuring that both educators and students receive proper training and support in using AI tools will be critical for maximizing the benefits of these technologies in educational settings. By addressing these challenges and expanding the research focus, the integration of AI in design education can be further optimized, providing significant benefits in terms of efficiency, quality, and engagement for all students.

CONCLUSION

This research highlights the potential of integrating AI technology into textile design education to address educational gaps and enhance learning outcomes. Our findings show that AI-assisted design significantly improves efficiency, quality, and student engagement. The most notable time reductions occurred in sketching, digital design, and execution stages, with decreases of 44%, 50%, and 44%, respectively. Quality assessments revealed a 15% improvement in AI-assisted projects, while student engagement increased by 20% due to the interactive and innovative nature of AI tools. Challenges include the initial learning curve and the accessibility and cost of advanced AI tools. Ensuring equitable access and training is crucial for all educational institutions. Future research should focus on the long-term impacts of AI integration, expanding its application to other design fields, and developing guidelines for AI-driven curriculum modules. Further research and pilot programs are essential to refine and implement this framework effectively.

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The Textile Industry and New Materials: A Comprehensive Analysis

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Abstract. Textiles have long been a fundamental aspect of human life, and their significance continues to rise with increasing demand. The global textile industry, a cornerstone of economic growth for centuries, has consistently adapted to technological advancements and shifting market needs. This research article offers a comprehensive analysis of the current state of the textile industry worldwide, examining its environmental impacts, country-specific dynamics, and the development of new materials. It also investigates future trends, environmental challenges, and the advantages and disadvantages of innovative materials with respect to pollution and cost-effectiveness. Emphasizing the urgent need for sustainable practices, the article focuses on environmentally friendly materials and the industry's path towards sustainability shown.

Keywords: textile industry, new materials, global industry, comprehensive analysis

INTRODUCTION

The textile industry is a critical component of global commerce, producing a wide range of essential products, from clothing to industrial fabrics. The rise of globalization has significantly expanded the industry's reach, leading to increased production and consumption worldwide. However, this growth has also introduced significant environmental challenges, necessitating the adoption of sustainable practices and the development of new materials that minimize the industry's ecological impact.

GLOBAL TEXTILE INDUSTRY: AN OVERVIEW

Historical Context

The origins of the textile industry can be traced back to ancient civilizations, with notable advancements occurring during the Industrial Revolution. Innovations such as the spinning jenny, power loom, and cotton gin transformed textile production, paving the way for large-scale manufacturing and global trade.

Current Scenario

Today, the global textile industry is valued at over $1 trillion, with major players including China, India, the United States, and the European Union. The industry encompasses various segments, such as fiber production, yarn manufacturing, fabric production, and garment manufacturing, each contributing to the sector's overall economic significance.

Environmental aspects of the textile industry

The textile industry is one of the most environmentally challenging sectors, contributing to water pollution, air pollution, and waste generation.

Water Pollution

The manufacturing processes in the textile industry, particularly dyeing and finishing, require substantial water usage. The discharge of toxic chemicals into water bodies during these processes poses severe risks to aquatic ecosystems and human health.

Air Pollution

Textile production also contributes to air pollution through the emission of volatile organic compounds (VOCs) and greenhouse gases (GHGs). These emissions exacerbate global warming and lead to respiratory health issues.

Waste Generation

The industry generates significant waste, including off-cuts, defective products, and post-consumer waste. Much of this waste ends up in landfills, where it contributes to soil and water pollution.

Country-specific reports

China

As the largest textile producer globally, China accounts for over 50% of the world's textile production. The country has made significant strides in technological advancements and sustainability practices. However, it continues to face challenges related to environmental pollution and labor conditions.

India

India is a major exporter of textiles, particularly known for its cotton. The sector is labor-intensive, providing employment to millions. However, India faces challenges such as water scarcity, environmental pollution, and the need for modernization of manufacturing processes.

United States

The U.S. textile industry has transitioned from traditional manufacturing to high-tech production, with a strong focus on innovation and sustainability. The industry, however, faces challenges from competition with low-cost producers and stringent environmental regulations.

European Union

The textile industry in the European Union is characterized by high-quality production and a strong emphasis on sustainability. European countries have implemented strict environmental regulations, drove the adoption of eco-friendly practices and positioning the EU as a leader in sustainable textiles.

Pakistan

Overview of Pakistan's Textile Sector.

Pakistan's textile industry is a cornerstone of its economy, accounting for approximately 60% of total exports and employing around 40% of the industrial workforce. The sector is diverse, encompassing activities from cotton growing and ginning to yarn, fabric, and garment production.

Strengths and shortcomings

Strengths:

Cotton Production: Pakistan is the fourth-largest cotton producer globally, providing a robust raw material base for its textile industry.

Skilled Workforce: The country boasts a large pool of skilled labor, which is crucial for maintaining the competitiveness of its textile sector.

Vertical Integration: The industry's high level of vertical integration, with processes from raw material to finished products occurring domestically, is a significant advantage.

Shortcomings:

Energy Supply: Inconsistent energy supply remains a significant challenge, often disrupting production processes.

Technological Upgradation: There is a pressing need for continuous technological upgrades to meet international standards and remain competitive.

Environmental Concerns: The industry faces critical environmental issues, particularly related to water usage and pollution.

Importance and Economic Role

The textile sector is vital to Pakistan's economy, contributing significantly to GDP, exports, and employment. Despite global economic challenges, Pakistan's textile exports have shown resilience over the last decade, with major markets including the United States, the European Union, China, and the Middle East. International brands such as H&M, Zara, and Levi's source products from Pakistan, underscoring the country's importance in the global textile market.

Export Data (2013-2023):

- 2013: $13 billion
- 2014: $13.5 billion
- 2015: $12.9 billion
- 2016: $12.2 billion
- 2017: $12.4 billion
- 2018: $13.3 billion
- 2019: $13.5 billion
- 2020: $12.8 billion
- 2021: $14.4 billion
- 2022: $15.5 billion
- 2023: $16 billion
- 2024: Is projected to touch $20 billion

Pakistan ranks among the top 10 textile exporters globally, with a significant share in the export of cotton-based products. The country's focus on improving quality and adhering to international standards has strengthened its position in the global market.

Future Outlook

The future of Pakistan's textile industry appears promising, supported by several positive trends:

Sustainability Initiatives: The adoption of sustainable practices, including the use of organic cotton and eco-friendly dyes, is on the rise.

- Investment in Technology: Continuous investments in modernizing equipment and processes are critical for maintaining competitiveness.
- Government Support: Favorable government policies and incentives are aimed at boosting exports and attracting foreign investment.
- Global Market Access: Expanding market access through trade agreements and partnerships is likely to enhance Pakistan's presence in the global textile market.

With these developments, Pakistan's textile industry is well-positioned for growth, contributing significantly to the national economy and strengthening its global market presence.

The textile industry remains a crucial component of the global economy, with its historical significance continuing to evolve in response to modern challenges and innovations. As the industry faces increasing scrutiny over its environmental impact, the development and adoption of sustainable materials and practices are imperative. Countries like Pakistan, with a strong textile tradition, must invest in technology, sustainability, and compliance with international standards to maintain their competitive edge. The future of the textile industry will be shaped by its ability to innovate and adapt to the demands of a rapidly changing world, balancing economic growth with environmental responsibility.

The Textile Industry and New Materials: Exploring Potential in Textile Materials

Pakistan, leveraging its strong agricultural foundation and abundant labor force, stands poised to excel in the production of sustainable textile materials. The country's advantages in organic material cultivation, coupled with a skilled workforce, present significant opportunities to cater to the growing global demand for eco-friendly textiles. This paper delves into the potential of key materials such as organic cotton, recycled polyester, hemp, and bamboo within Pakistan's textile industry, while addressing environmental challenges and sustainable practices essential for growth.

ORGANIC COTTON: HARNESSING SUSTAINABLE POTENTIAL

Organic cotton, cultivated without synthetic pesticides, herbicides, or fertilizers, offers an environmentally friendly and healthier alternative to conventional cotton. Pakistan's established cotton farming infrastructure and favorable climate make it a prime candidate for organic cotton production, positioning the country as a potential leader in this sector.

Advantages

Environmental Benefits: Organic cotton farming improves soil fertility, reduces water consumption, and promotes biodiversity. The absence of harmful chemicals prevents water and soil pollution.

Health and Safety: Farmers benefit from safer working conditions, and consumers receive clothing free from potentially harmful residues.

Quality: Organic cotton fibers, untouched by chemicals, are often stronger and more durable, resulting in high-quality, long-lasting products.

Market Demand: Rising consumer awareness about environmental and health issues is increasing the demand for organic cotton products.

Challenges

Higher Costs: The labor-intensive nature of organic cotton farming, coupled with certification fees and lower yields, can drive up production costs.

Water Consumption*:* While less water-intensive than conventional cotton, organic cotton still requires significant water, particularly in arid regions.

Certification Complexity: Obtaining organic certification can be costly and complex, especially for small-scale producers.

Market Limitations: Despite growth, the market for organic cotton remains smaller compared to conventional cotton.

Prospects for Pakistan: Pakistan's rich history in cotton farming, combined with its favorable climate and skilled workforce, provides a solid foundation for organic cotton production. With increasing global demand and government support for sustainable agriculture, Pakistan has the potential to become a significant player in the organic cotton market. By leveraging its agricultural strengths, Pakistan can access high-value international markets and achieve sustainable growth in this sector.

ENVIRONMENTAL CHALLENGES AND SUSTAINABLE PRACTICES

Challenges

The textile industry faces several environmental challenges that must be addressed for sustainable growth:

Water Consumption: Textile manufacturing is highly water-intensive, contributing to the depletion of freshwater resources.

Chemical Use: Harmful chemicals used in dyeing and finishing processes pose risks to the environment and human health.

Energy Consumption: High energy use in the textile industry leads to increased carbon emissions and climate change.

Waste Management: Textile waste management remains a significant issue, with much of the waste ending up in landfills.

Sustainable Practices

Adopting sustainable practices is crucial to mitigating these challenges: Water.

Recycling and Energy Efficiency: Implementing water recycling systems, energy-efficient technologies, and eco-friendly dyes can significantly reduce environmental impact.

Regulations and Standards: Enforcing stringent environmental regulations and standards can drive the industry toward more sustainable practices.

Consumer Awareness: Increasing consumer awareness about sustainable fashion can boost demand for eco-friendly products and encourage greener industry practices.

RECYCLED POLYESTER: TRANSFORMING WASTE INTO VALUE

Recycled polyester (rPET) is produced by recycling post-consumer plastic bottles.
This process involves collecting, sorting, cleaning, and melting down plastic to create new polyester fibers. Recycled polyester helps reduce plastic waste and conserves natural resources, making it a key component of sustainable textile production.

Advantages

Waste Reduction: Recycled polyester helps mitigate plastic waste and environmental pollution.

Energy Efficiency: Producing rPET uses up to 59% less energy compared to virgin polyester, reducing carbon emissions.

Sustainability: Recycled polyester supports a circular economy by promoting material reuse and aligns with global sustainability goals.

Performance: rPET maintains the durability, elasticity, and resistance to wrinkles and shrinkage of virgin polyester, making it suitable for various textile applications.

Challenges

Microplastic Pollution: Recycled polyester can release microplastics during washing, posing threats to aquatic life and human health.

Limited Recycling Capacity: The capacity to recycle plastic into rPET is limited by technological and economic constraints.

Quality Degradation: Polyester fibers may degrade with each recycling cycle, limiting the material's lifespan.

Chemical Use: The recycling process involves chemicals that, if not properly managed, can have environmental and health impacts.

Potential in Developing Countries, Including Pakistan

Countries like Pakistan, which generate significant plastic waste, have substantial potential to develop a recycled polyester industry. With its robust textile sector, Pakistan can integrate rPET into its production processes, enhancing sustainability and meeting global demand for eco-friendly products. Addressing challenges such as infrastructure, technology, and market acceptance through investment and consumer education will be crucial.

HEMP: ADVANCING SUSTAINABLE TEXTILES

Hemp, derived from Cannabis sativa, is one of the oldest fibers used in textiles. Unlike marijuana, industrial hemp contains negligible THC, making it non-intoxicating. Hemp's fibers, seeds, and oil are utilized across various industries due to their strength and environmental benefits.

Advantages

Durability: Hemp fibers are strong and long-lasting, making them cost-effective.

Eco-Friendly: Hemp requires less water than cotton, grows quickly without chemical pesticides or fertilizers, and improves soil health.

Biodegradability: Hemp fibers decompose naturally, reducing environmental impact at the end of their lifecycle.

UV and Mold Resistance: Hemp fabrics resist UV light and mold, making them suitable for outdoor use and extending their longevity.

Breathability and Comfort: Hemp fabrics are breathable and moisture-wicking, providing comfort in various climates.

Challenges

Texture: Hemp can be coarser than cotton, though modern processing techniques are improving its softness.

Cost: The initial cost of hemp textiles can be higher due to current production and processing methods.

Processing Complexity: Hemp processing requires specialized equipment and knowledge, making it more labor-intensive.

Stigma: The association with marijuana can hinder widespread acceptance and use of hemp.

Future of Hemp in the Textile Industry: The future of hemp in textiles is promising due to increasing demand for sustainable products. As processing techniques advance, hemp's adoption is expected to grow, aligning with global sustainability goals.

Prospects for Pakistan: Pakistan's agricultural expertise and extensive textile infrastructure position it well to develop a strong hemp industry. The country's favorable climate and available farmland support large-scale hemp cultivation. By investing in research and development, Pakistan can improve hemp processing techniques, making it a viable and sustainable alternative to conventional fibers. As global demand for sustainable textiles rises, Pakistan can leverage this opportunity to boost economic growth and establish itself as a significant player in the hemp textile industry.

BAMBOO: AN EMERGING SUSTAINABLE OPTION

Bamboo fabric is derived from the fibers of bamboo plants, known for their rapid growth and minimal resource requirements. Bamboo, one of the fastest-growing plants, can grow up to a meter per day under optimal conditions. However, the conversion process into fabric can involve harmful chemicals, raising environmental concerns.

Advantages

Sustainable Growth: Bamboo is highly sustainable, growing quickly and requiring minimal water and pesticides.

Biodegradability: Bamboo fabric is fully biodegradable, reducing textile waste and environmental impact.

Softness and Comfort: Bamboo fabric is soft, breathable, and moisture-wicking, offering comfort and temperature regulation.

Antibacterial Properties: Bamboo possesses natural antibacterial properties, reducing odors and keeping the fabric fresher.

UV Protection: Bamboo fabric provides natural UV protection, beneficial for outdoor clothing.

Challenges

Chemical-Intensive Processing: Converting bamboo into fabric, especially bamboo viscose, often involves harmful chemicals, posing environmental and health risks.

Higher Cost: The processing steps and chemicals contribute to a higher cost compared to other natural fibers.

Durability Concerns: Bamboo fabric may not be as durable as other materials like cotton or polyester.

Leading Producer: China leads in bamboo textile production due to its extensive bamboo resources and investments in processing technology. This dominance is supported by the country's abundant bamboo forests and established manufacturing infrastructure.

COMPOSITE MATERIALS IN THE TEXTILE INDUSTRY

Composite materials, created by combining different materials with distinct properties, have revolutionized the textile industry. These materials typically consist of a matrix, such as a polymer, reinforced with fibers like carbon or glass. The result is textiles that are stronger, lighter, and more durable than traditional fabrics, impacting various sectors including aerospace, automotive, and defense.

Advantages

High Strength-to-Weight Ratio: Composites offer exceptional strength while remaining lightweight, ideal for weight-sensitive applications.

Durability: Resistant to corrosion, wear, and environmental factors, composites lead to longer-lasting products.

Customizability: Composites can be tailored to specific needs by adjusting the matrix and reinforcement composition.

Thermal and Chemical Resistance: Composites exhibit superior resistance to heat and chemicals, suitable for harsh environments.

Challenges

High Cost: Production and processing of composite materials can be expensive due to specialized equipment and techniques.

Complex Manufacturing Process: Fabricating composites involves intricate procedures and skilled labor.

Recycling Challenges: Recycling composites poses significant difficulties, leading to environmental concerns.

Potential for Delamination: Layers within composites can separate under certain conditions, compromising structural integrity.

Status of Pakistan: Pakistan's textile industry is gradually incorporating composite materials, especially in technical textiles. However, the country is in the early stages of adopting these advanced materials. To fully capitalize on composites, Pakistan needs greater investment in research, development, and technology

PAKISTAN'S STATUS AND PROSPECTS IN TEXTILE PRODUCTION

Pakistan, with its strong agricultural base and established textile industry, is strategically positioned to venture into bamboo textile production. The country's favorable climate supports bamboo cultivation, providing a sustainable raw material for the textile sector. By leveraging its existing infrastructure and expertise, Pakistan has the potential to efficiently incorporate bamboo fibers into its manufacturing processes.

Future Prospects

Sustainable Development: As the global demand for eco-friendly textiles grows, bamboo fabric emerges as a promising option. Known for its rapid growth and low resource requirements, bamboo aligns with the sustainability trend, offering a viable path for the future of Pakistan's textile sector.

Technological Advancements: Technological progress is crucial to making bamboo fabric production more environmentally friendly. Innovations like closed-loop systems, which recycle water and solvents, can significantly reduce the environmental footprint of bamboo textiles, making them a more sustainable choice.

Market Expansion: Rising consumer awareness of sustainable fabrics is likely to increase the demand for bamboo textiles. This trend presents an opportunity for Pakistan to expand its presence in the global market for eco-friendly textiles.

Government Support: Supportive government policies and incentives promoting sustainable agriculture and eco-friendly manufacturing are vital for the growth of Pakistan's bamboo textile industry. These initiatives can play a key role in advancing the sector.

Cost Effectiveness Compared to Other Materials

Cotton: Cotton, while inexpensive and widely used, requires substantial water and pesticide use, making it less sustainable than bamboo. Though the initial cost of bamboo fabric may be higher, its long-term environmental benefits and sustainability can justify these costs.

Polyester: Polyester, a synthetic fiber, is often less expensive and more durable but is derived from petroleum and is non-biodegradable. Despite its higher cost, bamboo fabric offers an eco-friendlier alternative.

Hemp: Hemp, like bamboo, is a sustainable material. While hemp is generally more durable and requires fewer chemicals during processing, bamboo fabric is known for its superior softness and comfort, making it preferable in certain applications.

Bamboo: Bamboo fabric stands out as a promising sustainable alternative to traditional textiles, offering benefits such as rapid growth, biodegradability, and comfort. Although challenges like chemical-intensive processing and higher costs exist, technological advancements and growing consumer demand for eco-friendly products strengthen the prospects for bamboo textiles. For Pakistan, investing in bamboo cultivation and processing could unlock new opportunities in the global textile market.

Lyocell (Tencel): Lyocell, also known as Tencel, is a sustainable fiber made from wood pulp through a closed-loop process that recycles water and solvents. It is biodegradable and offers a sustainable alternative to traditional textiles.

CONCLUSION

Above all, Pakistan holds a significant advantage in the textile industry due to its vast and skilled workforce, coupled with the availability of abundant indigenous raw materials. The country's large labor force, with its deep-rooted expertise in textile production, allows for efficient and cost-effective manufacturing processes. This workforce, supported by generations of knowledge and experience, contributes to the industry's competitiveness on a global scale.

Moreover, Pakistan's access to locally sourced raw materials, such as high-quality cotton, further enhances its edge over many other countries. The ability to produce and process raw materials domestically not only reduces dependency on imports but also ensures a stable supply chain, enabling Pakistan to respond swiftly to market demands and maintain consistent production levels.

This combination of a skilled labor force and readily available raw materials positions Pakistan as a formidable player in the global textile market, providing a competitive advantage that many other countries struggle to match.

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The Impact of the Textile Industry on the Global and Local Ecosystem and How to Support and Encourage Textile Production in Serbia with Preservation of Water Resources

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Abstract. The textile industry with nowadays capacities on a global level has a large share in the pollution of our planet, and above all in the contamination of surface waters with chemical means for washing, finishing, dyeing and finally with the release of large amounts of microfibers into waterways that partly end up in the ground and partly remain present in stagnant, fresh and salt water ecosystems. Also, the impact of pollution caused by textile waste, after the end of the lifetime of the textile product, is not negligible.There are ways to alleviate this pollution to some extent, but the global policy of the leading countries approves the relocation of large textile factories in a country with cheap labor where the concept of environmental protection is not applied and almost nothing is invested in the filtration of waste water. Unfortunately, Serbia is also one of the countries where awareness of the importance of preserving natural resources, watercourses and preserving a healthy ecosystem is at a very low level. In addition to the importance of preserving clean surface water and ways to reduce pollution to a large extent, the paper also defines the most common problems faced by producers of textile products in Serbia and gives a proposal that can help domestic producers to be competitive on the domestic and foreign markets and to drastically reduce the impact of pollution on surface watercourses. Also, the importance of raising awareness about preserving a healthy environment and reducing ecosystem pollution was highlighted.

Keywords: textile industry , waste water , ecosystem , sustainable production , significance of domestic production

INTRODUCTION

Textile industry is one altogether the foremost organized and fast-growing industrial sector. Hence, having a large impact on the economy of the countries and it's, vital role within the growth/contribution in numerous countries is critical throughout the world [1]. Textile wastewater is extremely dirty water, which causes serious damage to our agricultural land, ground and surface water system and aquatic life. The textile industries often do not operate their effluent treatment plants properly, which can be the ignorance of regulatory bodies. The textile industries are one amongst the biggest consumers of water, subsequently, creates an unlimited environmental issue in style of wastewater. The problem of commercial textile effluent is that it is highly carcinogenic in nature and should reason behind several diseases [2]. The textile industry with today's capacities on a global level has a large share in the pollution of our planet, and above all in the contamination of surface waters with chemical means for washing, finishing, dyeing and finally with the release of large amounts of microfibers into waterways that partly end up in the ground and partly remain present in stagnant, fresh and salt water ecosystems. Also, the impact of pollution caused by textile waste, after the end of the useful life of the textile product, is not negligible. There are ways to alleviate this pollution to some extent, but the global policy of the leading countries approves the relocation of large textile factories in a countries with cheap labor where the concept of environmental protection is not applied and almost nothing is invested in the filtration of waste water. Unfortunately, Serbia is also one of the countries where awareness of the importance of preserving natural resources, watercourses and preserving a healthy ecosystem is at a very low level. In addition to the importance of preserving clean surface waters and ways to reduce pollution to a large extent, it is also necessary to look at the most common problems faced by producers of textile products in Serbia and to find a solution that can help domestic producers to be competitive on the domestic and foreign markets and to during production drastically reduce the impact of pollution on surface watercourses. It is also necessary to raise awareness about preserving a healthy environment and reducing ecosystem pollution.

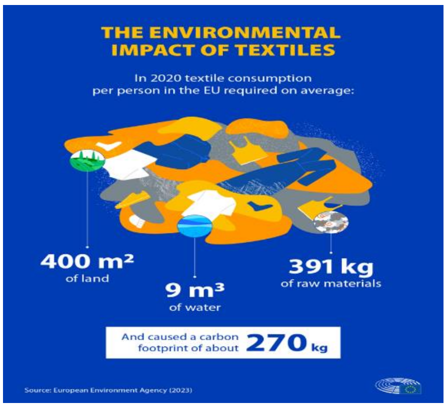

Figure 1. Impact of textile production on natural resources [3]

Microfibers as a problem in expansion.

Figure 2. Microfiber contamination [4]

Microfiber pollution is a key priority area that has gained increased attention, with research estimating “over 14 million tonnes of [microfibers] have accumulated on the world’s ocean floor” and a further 200–500,000 tonnes of microplastic fibers are entering the ocean annually [5].

Almost 700,000 micro fleeces are shed per garment through domestic laundering and 1900 fleeces per every wash. Approximately 2 million tonnes of microfibers are released into the ocean every year [6].

Knit fabrics have been chosen as these are common structures to produce fast fashion items, including, but not limited to t-shirts, jumpers, or socks. Knit fabrics were also reviewed in isolation, as knit fabrics typically release more microfibers than woven fabrics due to structural compactness [7, 8].

Microfibers already contaminate waters to a great extent and are found in organisms of aquatic animals, plankton, crustaceans, fish and mammals.

Humans most often enter in theirs organism micro fibers through the water. Micro fibers are also found in the air, most often near clothes dryers, and thus end up in the lungs, creating lesions and inflammations that can later lead to the most serious diseases.

Pollution of surface water courses and underground water by releasing huge amounts of chemicals for washing, dyeing, finishing... directly into rivers.

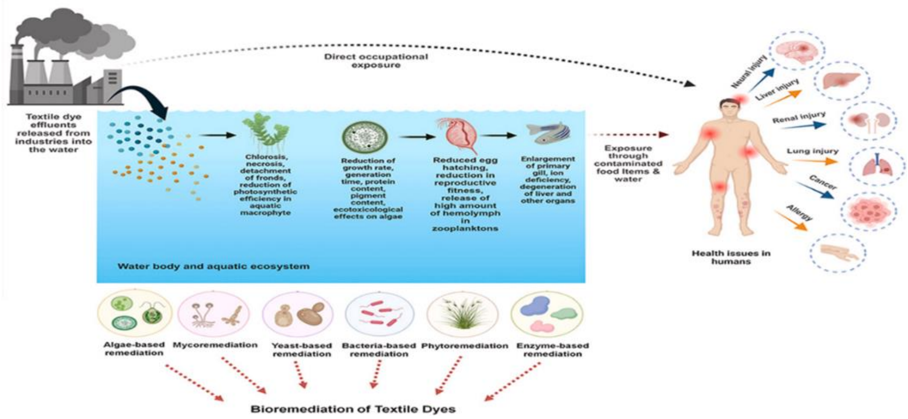

Figure 3. Contamination of the ecosystem by the textile industry [9]

Textile manufacturers in Serbia

Textile production in Serbia is currently at unenviable level. Also, the few domestic producers of textile products did not invest in waste water filtration and preservation of the local ecosystem. Certain foreign manufacturers operating in Serbia (mainly from European countries) have a much better awareness of the importance of preserving watercourses and have installed waste water filtration systems.

In the past year, domestic manufacturers have been informed by the environmental inspection that they have a deadline to install waste water filtration systems and we hope that all domestic textile production will have the necessary filters and filtration basins in the near future.

There are fewer and fewer domestic producers in Serbia because foreign retail chains such as Pepco, which have a wide range of textile products at low prices, represent unfair competition to domestic production.

The vast majority of domestic private producers generally do not have the support of the state in the form of subsidies and the achievement of domestic production, but are usually left to their own devices in the fight with far more favorable offers from foreign competition.

Foreign producers operating in Serbia have received considerable help and support from the state in opening their production, but it often happens that they close their production after a short period of business and leave workers with unpaid wages and debts to suppliers.

How to help domestic producers in Serbia and motivate them to preserve surface watercourses

To begin with, it is necessary to raise citizens' awareness of the importance of buying domestic products. To encourage domestic production, domestic producers in the form of various subsidies, tax benefits, support for starting domestic production, staff training and encouragement and promotion of textile majors in high schools and colleges (education of tailors, engineers, technologists, designers, managers...), encouraging the production of fabrics and knitwear from which domestic producers could be supplied with materials instead of importing from Turkey and China, starting production in larger factories in which the state would be the majority owner (all foreign companies operating in Serbia use our workforce and export their products to the European Union without releasing the manufactured goods to our market), support in the form of subsidies when opening shops with domestic products, prioritizing domestic products over imported ones, promotion of domestic products abroad and support for the sale and marketing of our products to foreign markets.

State aid in the form of subsidies for the purchase of fillets for wastewater treatment and education of producers on the importance of preserving the environment and surface watercourses.

Investments in renewable energy in the form of solar panels and windmills.

Wastewater control and bringing production to a level that is environmentally acceptable and sustainable for all plant and animal life in surface watercourses and the local ecosystem.

Clean water as an invaluable resource

Figure 4. Fresh water as invaluable resource

It is redundant to say that water is an invaluable resource without which there is no life. Today's humanity, without mercy and awareness of this fact, exploits everything that our ancestors left us as an inheritance, and the resources of future generations are already being used up. Unfortunately, there is almost no awareness among individual leaders of the people that clean water, air and soil are the greatest wealth that a country can have and that the future of a nation's survival is exclusively related to the preservation of these resources with environmentally friendly production. It is a fact that in the future fresh and clean water will be the most expensive and that our survival on our land will depend on the preservation of clean water resources.

How to save the planet from pollution and maintain the growing production of textiles in the world:

- Use more natural fibers (preferably organic) in production and produce finished products that are more than 80% natural fibers
- Use environmentally friendly colors (natural colors) and cleaning and finishing products that are biodegradable
- Use filters that will remove toxins from wastewater and microfibers and release completely purified water into the ecosystem
- Use better energy efficiency and renewable sources (sun, wind, bio gas...)
- Use new textile finishing technologies without using water.
- Recycle textile waste to a much greater extent

CONCLUSION

It is necessary for existing and future generations to understand that the future of textile production lies in clean and sustainable production. The planet is already too polluted. Watercourses that are not contaminated by pollution are rare. In the last 50 years, man has mercilessly consumed natural resources and destroyed the ecosystem. Unfortunately, mass production and the desire for enormous profits with as little investment and care for the planet as possible has overtaken the owners of big fashion brands. This type of business certainly leads to a fail because such a concept of production is unsustainable for the planet, for the human race of today and future generations. It is necessary to raise awareness that everything from pollution that enters our ecosystem also reaches our organism, and sooner or later it will affect our health as well as the quality of our life and the lives of people in our environment. Only with clean and environmentally friendly production can we hope for a better future for current and future generations. Also, it is necessary to reach every individual and educate him about the importance of preserving the environment in which water, land and air will not be contaminated with microfibers and chemical agents used to treat textile products, as well as other industrial pollution.

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Valorization of Renewable Materials in the Product Life Cycle

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Abstract. The reconstruction of the product, through the reduction of waste, directly contributes to the preservation of the environment as well as to the reduction of environmental pollution caused by the processing of raw materials for a new product. Innovative development of production processes can contribute to positive changes in sustainable development and circular economy (CE), by re-using, i.e., by returning the material (garment) to a new cycle of production. Fast fashion, low-quality materials, poor choice of materials, inconsistency of the type of material with the season, etc., have led to a significant accumulation of clothing (textile waste). A contribution to solving these problems is the reconstruction of garments with the addition of new details that would give a new face to the product. The reconstruction of fashion products would represent a new path towards the gradual transformation of the entire clothing technology aimed at the development of innovative, "unique" products. Analysis of the life cycle of a textile product through all phases of the cycle leads to ecological - economic solutions. The goal is personalization by reconstructing personal products into new unique products.

Keywords: product life cycle, reconstruction, renewable materials, sustainability, new products, "uniques"

INTRODUCTION

From the aspect of environmental protection, there is a noticeable concern with the growing tendency of premature disposal of textile products in landfills and classifying them in the "waste" category. The reconstruction of the product, through the reduction of waste, directly contributes to the preservation of the environment as well as to the reduction of environmental pollution caused by the processing of raw materials for a new product. The innovative development of production processes can contribute to positive changes in sustainable development and the circular economy (CE), by reusing or returning materials (clothes) to a new cycle of production. Fast fashion, low-quality materials, poor choice of materials, inconsistency of the type of material with the season, etc., have led to a significant accumulation of clothing (textile waste). A contribution to solving such problems is the reconstruction of clothing items with the addition of new details that would give a new face to the product. The reconstruction of fashion products would represent a new path towards the gradual transformation of the entire clothing technology aimed at the development of innovative, "unique" products.

CLOTHING PRODUCT LIFE CYCLE

Every product goes through a life cycle and in all stages it affects the environment to a greater or lesser extent, that is, it damages the environment. It can be said that the life cycle of a product represents a systematic consideration of the impact on the environment [1]. It does not represent only the time of use of the product (lifetime), but the entire effect that the product has on the environment is considered (it means the period from its creation until the end of its life, or some new role/new value of the product) [2]. The life cycle and technological process of clothing production is a complex system consisting of subsystems, i.e. life cycle phases as shown in Figure 1.

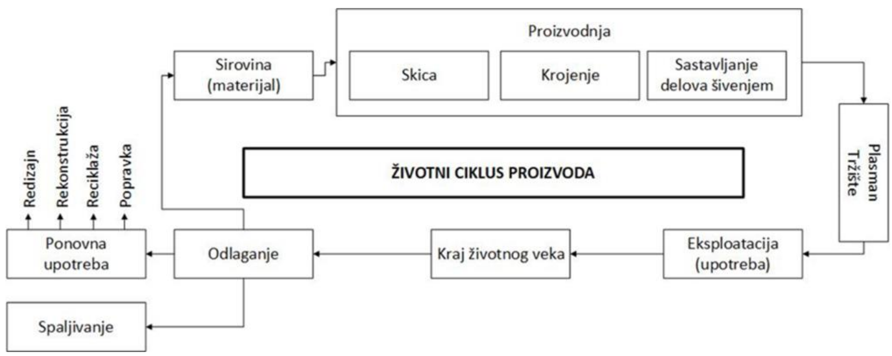

Figure 1. Stages of the product life cycle/technological process of product creation

In the regular production of an article of clothing, the life cycle begins with the selection of fibers, raw materials, materials from which the article of clothing will be made, which implies the exploitation of natural resources, energy consumption, etc. [3]. In the case of reconstruction, the basic material (raw material) for making a new product is a garment. Worn garments are returned to the production cycle. In this way, natural resources are not exploited and energy consumption is reduced. Instead of worn clothes ending up in a landfill, they are reused, returning to the production process. The next phase of the life cycle is production, which starts from the sketch of a new product, through redesign, reconstruction, that is, tailoring and assembly of parts of the garment by sewing. After the production of the garment, packaging and distribution follows, that is, placing the new product on the market. Phase of use and maintenance (operation of the product/carrying of the product). Product life is different for different products. All and/or multiple phases of a product's life cycle have different impacts on the environment and natural resources [4].

The end of the product's life is the stage where it is decided whether the item of clothing is to be reused (returned to the production process) or whether it is inevitable to dispose of it in a landfill. At all stages of the life cycle, designers are in a position to plan the influence of various parameters on the properties and lifetime of the clothing products they design [5]. In the end-of-life phase of a product, there are several approaches that can be applied: redesign the product, reconstruct, recycle, repair/repair, then incineration, biodegradation and landfilling (Figure 2).

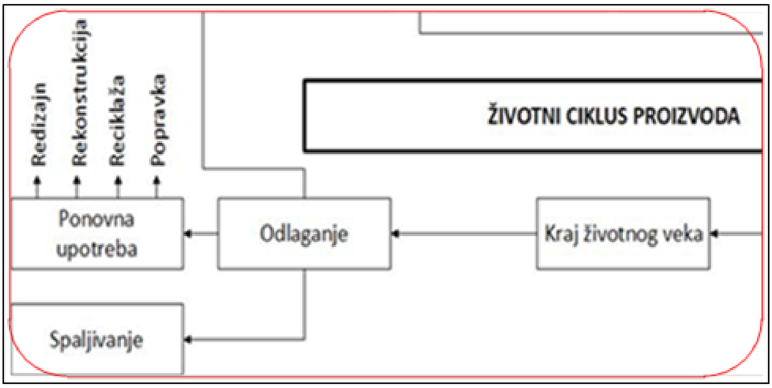

Figure 2. Product direction after the end-of-life phase of the product

An increasingly shorter lifespan of the product is observed, which is considered to be due to the poorer quality of the product. A good innovation, adapted to the current situation, are shopping centers that combine the needs of the modern consumer. In addition to planned purchases, consumers also go to shopping centers for relaxation, socializing, entertainment, and the overall atmosphere. The development of the modern fashion market has led to the development and increasing importance of all phases of the product life cycle in the entire process from the production to the sale of fashion items. In addition to technological development, the market developed in parallel, as did the consumers themselves, who became more and more demanding and sensitive, both in terms of the quality and design of fashion products, and in terms of the speed of services. In addition, a good relationship between sellers and buyers is expected, as well as the willingness to invest additional effort in the organization and arrangement of the space intended for sale. Factors such as the transportation of fashion products and the selection of adequate sales channels are also important because the customer expects timely delivery [6].

Remanufacturing (remanufacturing) is an industrial process in which used products are brought back to life. How products can be designed to facilitate the re-manufacturing process. Research has shown that remanufacturing processes can improve efficiency, that they are environmentally and economically acceptable, that the processing of fashion products is preferable to new production from natural resources. The remanufacturing process is a perspective with all the steps involved that are required to bring a product back to life. According to Furuhjelm [7], environmental legislation is the driving force for adapting production to the environment. Extended producer responsibility is an obligation manufacturer that he is responsible for the end-of-life treatment of his products. The aim of the legislation is to achieve a more sustainable society.

PRODUCT RECONSTRUCTION

Product reconstruction is considered one of the best solutions for the environment, returning the product to its life cycle. By reconstruction/repair, that is, by repair, the product acquires a new value, a new lifespan. The pictures show some of the many examples of reconstruction and redesign of clothing items (fashion products).

Figure 3 represents the students' work/participation in the repair/repair of a white shirt that had cigarette damage on the left front. With the help of details made from CDs, the shirt has a new look, a new face, a new value. The students received a new product that they were happy to wear for evening outings with friends. Black shorts are combined with a white shirt. Shore is made of black classic pants that were not in trend. With the addition of decorations made of chopped CDs, a new fashion product was created.

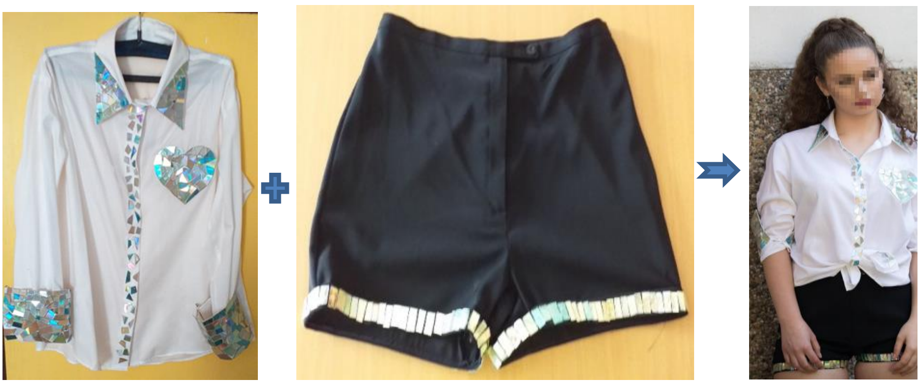

Figure 3. Participation of textile and non-textile materials in the reconstruction of fashion products

The reconstruction of worn-out jeans and other clothing items with additional details created new products, that is, a combination of new denim products was created. The rest of the material from the farica was used to make small purses that served as promotional material (picture 4).

Figure 4. Reconstruction to a new fashion combination

The black blouse with an additional small detail made of aluminum, that is, a can opener called sntntn, got a new face. The next picture is a wedding dress made of curtains. Then the idea of making two or more garments into new products. All products were returned to a new life cycle and found their place on the market (picture 5).

Figure 5. Various ideas woven into new fashion products through reconstruction

Worn jeans can always be reconstructed into new products (clothing items or accessories or fashion details, etc.) (picture 6).

Figure 6. Reconstruction to a new product - a skirt

CONCLUSION

- Fashion products renewed through reconstruction, returned to the life cycle, directly contribute to the preservation of the environment, reduction of pollution and sustainable product development.
- Disposing of products in a landfill is the least favorable option for waste management.
- Personalization in the reconstruction where the customer gets involved and makes a proposal for a new product according to his own wishes.
- The inclusion of individuals in the reconstruction of their clothing is a small contribution to environmental protection. However, by educating and raising the awareness of individuals, it would also lead to a great contribution to environmental protection.

- The reconstruction of fashion products represented a new path towards the gradual transformation of the entire clothing technology aimed at the development of innovative, (unique) products.

- "Prefer to use materials as resources for reconstruction, rather than end up as expensive waste."

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Sustainable fashion

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Abstract. Sustainable fashion has become, thanks to its growing number of advocates and activists, a term that most of us have learned well and we all know roughly what it entails, or at least partly encompasses. We awakened thoughts about the entire planet, about the influence of fashion, as well as our very approach. However, if we really want to change the world and habits when it comes to fashion, we need much more than just knowing the circular life of fashion.

Keywords: sustainable fashion, environment, innovative material, recycling

INTRODUCTION

Fashion is an important part of life, there is a reason why it exists, because in fashion we can find new expressions, suddenly we feel something simple as the right one. In addition, we should know for each item of clothing from which materials it was made or what its life will be after we take it out, it is important who made that item, under what conditions, and what is its real price. So we have to think about clothes and her life before she saw the glitz of windows, runways, magazine covers.

THE IMPACT OF CLOTHING ON THE ENVIRONMENT

We start this thread on the fashion industry and the fact that of the 100 billion garments produced each year, as much as 10 percent annually contributes to global greenhouse gas emissions. Caring about fashion today means caring about its impact on the planet.

This can be reflected in the following aspects:

- Fiber production processes, finishing, dyeing, printing
- Global logistics during production and sales
- Use and maintenance of the product
- Product disposal

In all these aspects there are countless opportunities to reduce the impact on the environment. The whole situation can be considered as a complex problem that requires a creative solution, bold design thinking, rethinking of current practices and open collaboration between different industrial and marketing partners.

When we buy our favorite pieces, it is important to know that the garment is sustainably produced by a 'sustainable' brand that does everything it can to reduce its bad impact on the environment, the feeling that 'shopping' fashion items provides becomes even stronger [1].

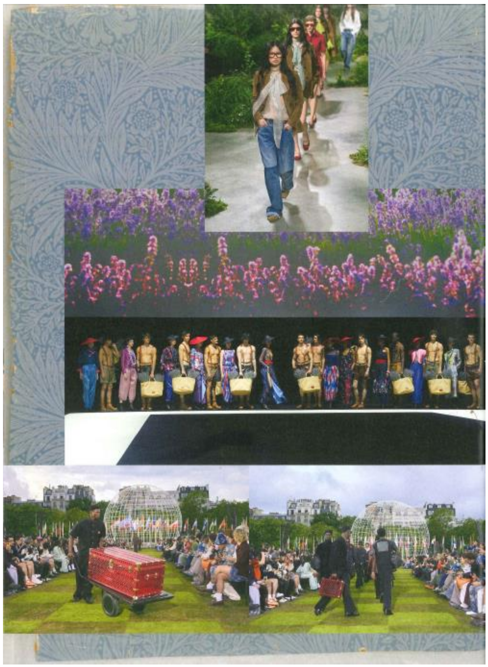

Figure 1. The impact of clothing on the environment

CORRELATION OF FASHION AND SUSTAINABILITY

At the global level, the creativity and innovation of fashion production, which is driven by the new era of sustainable fashion, is explored. In the year 2022, brands, from 'hing street' to 'hing-end', present how their clothes are made, where they are produced and who makes them. And if they haven't shown it, customers won't do their own research, because the more we learn about climate emergencies, the more we realize that the small choices we make as consumers every day are really important, as well as what we need from clothes and what's more important to buy less or buy better .

And this year heralds a new era for the correlation of fashion and sustainability, the basic values are established, businesses are involved, customers buy familiar with all the facts, no one needs to be convinced anymore about the novelty.

The company THREDUP, otherwise one of the leading sites for the resale of clothing, in cooperation with the consulting house GLOBALDATA, gave an annual report that by the end of 2025, the fashion resale market should be worth 77 billion euros, which is devastating compared to the predicted value of the 'fast fashion' industry from 40 billion euros. Because of all this, a new space for creativity, innovation and art appears under the folder as the fashion industry and its fans look to the future.

- Innovative materials
- Application of the recycling principle
- Application of the upcycling principle in home conditions (make new ones from old clothes)
- Luxury clothing rental

At a time when there is an increasing ethical impact on our environment through technological progress in the production of materials and the reinvented system of the 'retail' market, today everything is absolutely possible when it comes to the fashion industry [3].

Figure 2. Vegan Fashion Week in Los Angeles

INNOVATIVE MATERIALS

The production of innovative materials is extremely important for the continuous development of luxury fashion. Almost everything from orange peel, algae, to mushrooms is used to create alternative fabrics. Pineapple leather is found in the collections of brands such as HUGO BOSS, CHANEL, H&M, while GUCCI is launching its own vegan leather [2].

Figure 3. Vegan leather products

Matt Scullin, CEO of biotech company Myco Works, has discovered a revolutionary way to collect mycelium, the vegetative part of mushrooms that consists of a mass of branched but similar colonies found in the soil. Unlike mushroom leather which is a compressed product of mycelium, or vegan leather which is an aggregate of plant waste embedded in a plastic binder, Myco Workos' technology enables the engineering of the mycelium during its growth to create interconnected cellular structures that give it superior strength, durability, quality.

The so-called Mycelium materials can be fully customized in terms of strength, fall, texture, aesthetics and many more criteria from the very beginning of production, which provides unlimited design possibilities while also giving brands more control over their supply chains. An example is Hermès, which collaborated with Myco Works on the production of its 'Sylvania' bag.

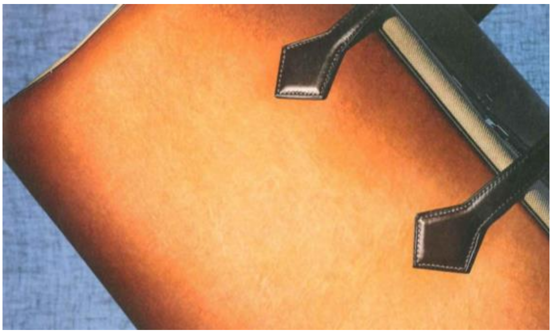

Figure 4. Victoria's mycelium bags from Hermès

In France, ECOPEL is at the forefront of creating high-quality alternatives to animal fur and works with more than 300 fashion brands that have committed to not using animal fur. Back in 2018, the British Fashion Council banned animal fur from every fashion show during London Fashion Week. More and more fashion brands agree to use faux fur, Versace, Michael Kors, Gucci, Armani, anti-fur activist Stella McCartney and many others. [4]

Figure 5. UMI clothing collection made from yarn from the ocean

Virtually all material innovation in fashion is vegan, and it is up to each of us as consumers to accelerate this change by demanding that designers and brands switch to sustainable plant-based materials.

RECYCLING

Innovation happens at every stage of the supply chain, Evrnu is working to bring the tens of millions of tons of textile waste that ends up in landfills every year back into the value chain. Brand partners include Stella McCartney, Adidas, Levi's, its revolutionary technology transforms textile waste into pristine fibers that are of equal or even better quality than the original form and can be recycled many times. This would really change a lot, the percentage of our clothes that end up in landfills is as high as 85, all this offers huge opportunities [6].

GROWTH OF RESALE AND RENTALS

In the future of fashion sustainability, we fashion-loving consumers have a big role to play. When buying a new item of clothing, we should ask the question 'how many times will I wear it', maybe this is where the possibility of buying second-hand clothes is created. The resale market is expanding, made possible by the following sites The RealReal, Vestiaire Collective, Depop. Luxury brands are increasingly taking advantage of this trend, creating partnerships such as Gucci, Burberry with a platform for renting and reselling luxury clothing [5].

Figure 6. Growth of resale and rental (clothing samples)

Valentino has also entered luxury resale with Valentino Vintage, promoting the idea of returning vintage Valentino pieces to key stores around the world in exchange for vouchers. Also French fashion house Jean Paul Gaultier is in the process of releasing its extensive archive for customers to borrow, and has a vintage resale category on its website.

CONCLUSION

Based on all this, we conclude that uniqueness, pure creativity and craftsmanship in designing clothes that bring people joy propels fashion into a brighter, kinder and circular future.

The UN has defined sustainability as 'meeting the needs of the present without compromising the ability of future generations to meet their own needs'. There's clearly a long way to go, but from sci-fi fabrics, to rental clothing and recycled runway curtains, there's no stopping the new innovation currently shaking up the industry as brands begin to put people and the planet above profit.

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Digital Textile Printing as an Environmentally Acceptable Technique

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Abstract. The paper points out that clothes in the concept of fast fashion encourage unnecessary and excessive consumption. This creates large amounts of waste in the textile industry. The paper presents the facts according to which very large amounts of resources are produced and consumed today. This makes the textile industry one of the biggest polluters of the environment. The paper cites the example that conventional printing technologies release many wastewaters containing hazardous chemicals. In contrast, digital textile printing is considered environmentally friendly. It consumes much less water and energy compared to conventional screen printing. Environmentally friendly pre-processing processes are also an integral part of digital printing. An example of good manufacturing practice from the Pakistani company Moti Fabrics (Pvt) Ltd is mentioned.

Keywords: environment, digital textile printing, fast fashion, fashion market.

INTRODUCTION

Worldwide, 25 to 40% of all used textile products become waste. Therefore, sustainability is a constant challenge in the textile industry, one of the world's largest industries. Textile production consumes large amounts of clean water, land and raw materials. As a result, it causes water shortages and reduces the area of agricultural land dedicated to food production. The explanation for these problems lies in the enormous increase in the volume of industrial production of clothing. Between 2000 and 2015, global production doubled to approximately 100 billion items per year, with a projected increase of 63% by 2030. [1]

After the food industry, construction and transport sectors, the textile sector is the industry that pollutes the environment the most. The industrial production of clothes involves a complex production process. The process begins with the acquisition of raw materials, and the finished product is reached through, most often, the following processes:

spinning, weaving, knitting, sewing and finishing. Due to the long and complex production chains and the different stages involved in the production of a garment, it is difficult to accurately define all the parts of the process that affect the environment and how much. Therefore, the overall impact on the environment is seen as the comprehensive impact of the production and use of textile products. The environmental impact of clothing can be reduced during the fiber production process, finishing, dyeing and printing, global logistics, during production and sales, product use and maintenance, and product disposal. [2]

Today, when very large amounts of resources are produced and consumed, the textile industry is one of the biggest polluters of the environment. For example, conventional printing technologies release many waste waters containing hazardous chemicals. In contrast, digital textile printing is considered environmentally friendly. It consumes much less water and energy compared to conventional screen printing. Environmentally friendly pre-processing processes are also an integral part of digital printing. [3]

FASHION MARKET

Efficient mass production in developing countries where labor costs are lower has led to low end prices for garments. Low product prices lead consumers to mass purchases and unsustainable consumer behavior: excessive consumption, very short product usage time, and premature disposal of products. Today the goal is:

- quickly produce economically viable garments in response to changing customer demands,
- the fact is that customers want high fashion at low prices,
- consumers decide to buy clothes that are often poorly made because they do not intend to wear them for years or even more than once.

Growth in consumption and fast discarding of clothing (worn several times and thrown away) leads to an increase in the amount of textile waste. Fashion markets are oversaturated and full not only of new fashion products but also of unsold clothes. Therefore, discount clothing sales in fashion stores have become a permanent phenomenon today. In addition, not all new clothing products often enter stores. It is not a rare phenomenon that some fashion products go directly to the landfill from the production itself. The reason is poor quality or non-compliance with fashion trends and customer wishes. Often the reason is that there is too much to offer in a market that is oversaturated. It is estimated that these unsold clothes make up as much as 5-10% of the entire fashion production. Contributing to this is the fact that fashion companies, in an effort to maintain the reputation of their brands, prefer to destroy unsold items of clothing rather than reduce their price.

New solutions are being sought for these problems. For example, some fashion companies initiate cooperation with designers. Young designers are hired to create unique fashion collections from unsold clothes. These redesigned collections are presented at social events and through social media.

However, many see the solution to reducing unsold clothing in design, that is, in the design of clothing that customers will accept more and therefore use longer. This would significantly reduce the waste of discarded clothes that are worn a few times and thrown away. The market of fashion textile products is seasonal and highly dependent on fashion trends. Exclusive and original design is currently the leading demand in the fashion world. The ability to express individuality with the flexibility to choose different styles, available colors and designs is a growing demand of fashion product buyers. This trend is known as personalization or mass individualization. This trend implies that customers like clothes to the extent that they will use them for a long time. So customers will change the habits acquired in fast fashion to wear purchased clothes several times, or even not wear them, and discard them in a short time. [5-10]

Figure 1. Fashion products created from unsold clothing [4]

DIGITAL PRINTING AS A TECHNIQUE ACCEPTABLE FOR ENVIRONMENTAL PRESERVATION

The demands of the trend known as personalization or mass individualization today can be successfully answered by the digital printing technique with its possibilities of economically profitable production of small production series. Add to that the virtually limitless design possibilities of digital printing.

Digital printing enables:

- production according to the customer's request, i.e. minimum order,
- the profitability of making small production batches, even just one product,
- there is no risk of remaining stock of unsold products from the collection,
- it takes little time and costs are low for the preparation and printing of the first samples and products,
- fewer workers for preparation and printing itself,
- complex images can be created - full color,
- gives designers the flexibility to experiment with their styles,
- minimum required time to market with new products,
- it is not a polluting technology because it does not use water - dry technology. [3]

Digital printing of textiles, e.g. it allows an easy transition from a two-season fashion cycle to a year-round collection launch. The best examples of this are companies: ZARA, H&M, UNIQLO, GAP, Topshop...

Digital textile printing transforms the usual two-season fashion cycle into a year-round collection launch. It helps designers to test and refine samples and designs on-site by the designer or printer, which helps reduce production time. Digital printing helps brands offer a customized proposition to their customers. Brands can create clothing of greater variety and individuality with these technologies.

Figure 2. Digital printer for metric textile materials [3]

As digital printing technology continues to expand in the global fashion and apparel sector, new business models and designs will continue to evolve. These technologies allow fashion and clothing markets to break down certain barriers and enable new opportunities to connect to the supply chain in the fourth industrial revolution. It will also reduce proximity to the end consumer, improve delivery times and produce garments only when the garments are ordered by customers.

Today, the market demands small series and fragmentary fashion items that can be digitally printed on textiles. With this technique, environmentally friendly production series can be made, the production time of which is much shorter than conventional screen printing, and what is also important, the financial investments are smaller. Today, it is evident that the impact of legislation on business and customer demands for environmentally friendly products is rapidly becoming a problem. For this reason, the global market for digital printing on textiles for clothing, home decoration and industrial applications is growing at a rate of over 34% annually.

As more consumers and retailers look to companies that provide environmentally responsible solutions, brand owners are often confused about how to begin achieving their sustainability goals. One must certainly start from the fashion product itself. Examine its raw material composition, packaging, energy use, waste, etc. Then you need to look at the supply chains of raw materials as well as production. With this knowledge, it is possible to start finding new and environmentally friendly ways of production. For example, brand owners can use recyclable or biodegradable packaging for their products.

Digital textile printing is a green option for several reasons. Digital printing helps reduce emissions as digital printers emit far less CO_2 than gravure printing machines.

The amount of waste produced by digital printing is significantly reduced. Unlike traditional printers, digital printers do not require printing plates to create, set up and produce each unit of fashion product. Printing plates degrade over time, requiring the creation of new plates whenever the packaging design changes, resulting in even more waste.

All components used in digital printing, from inks to films, are environmentally safe. They use polymer-based paints that do not emit dangerous pollutants into the atmosphere. These eco-friendly paints use less energy.

The application of digital printing technology in clothing design is an inevitable trend because it has the advantages of quick response and high design quality, which can not only meet people's needs for daily clothing design, but also adapt to the design of clothing with high professional requirements.

The global crisis of COVID-19 has changed business conditions in many ways if we look at logistics in the procurement of textile materials and equipment. Delivery times for textile materials have become significantly longer and more expensive. In this situation, digital printing has a good answer. Namely, clothing manufacturers can purchase only bleached fabrics and knitwear in large quantities and then print them themselves in patterns of their own design. Thereby:

- They achieve lower costs of purchasing textile materials,
- Get to market quickly with your own design
- High productivity printing machines can respond to a large number of market demands
- Customer requests for small orders are handled successfully and cheaply

For example, Pakistani textile company Moti Fabrics (Pvt) Ltd. is using more industrial Mimaki Tiger textile printing units to take its business to the next level. [11]

Figure 3. Some examples of the products of the Pakistani company Moti Fabrics (Pvt) Ltd. [11]

CONCLUSION

Fast fashion clothing encourages unnecessary and excessive consumption. This creates large amounts of waste. Very large amounts of resources are produced and consumed in the textile industry today. This makes the textile industry one of the biggest polluters of the environment. To solve this problem, the paper cites the example that conventional printing technologies release a lot of waste water containing hazardous chemicals. In contrast, digital textile printing is considered environmentally friendly. It consumes much less water and energy compared to conventional screen printing. Environmentally friendly pre-processing processes are also an integral part of digital printing. An example of good manufacturing practice from the Pakistani company Moti Fabrics (Pvt) Ltd is mentioned.

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Challenges and Perspectives of Recycling in Modern Industry: The Case of Pirin-tex Company

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Abstract. This paper present a detailed of recycling materials and the current situation in the industry. It also identifies challenges and proposes improvements in this sector. The peper includes statistical data from the past 10 years, accompanied by an in-depth analysis, as well as an examination of the methods used in recycling, an analysis of the quantities of processed materials, and an identification of the key problems faced by the company. Based on the analysis, concrete ideas will be proposed to improve recycling efficiency, with the goal of educating the public and addressing the challengges we face. The aim of this paper is ro contribute to a better understanding and development of sustainable practices in the field of recycling.

Keywords: company, recycling waste, metal staples, materials

INTRODUCTION

Pirin-Tex company was established in 1993. in Gotse Delchev, Bulharia. The company has built a very strong position in the textile industry, specializing in clothing production and textile waste recycling. It also owns the brand *Rollman*, which is recognized in domestic and international markets. Also, the company collaborates with leading global apparel brands, providing sewing services to brands such as Hugo Boss, Gucci, Burberry, Stella McCartney, Oscar Jacobson, Kuhn, Castell. Her von Eden, and others. The company currently employa around 1.150 workers, and the total area of production facilities and warehouses is 27.500 sqm. It uses modern CAS systems for garment design, including software such as *Lectra* and *Assyst*. This department enables precise design and creation of models according to client requirements.

In addition to production capacities, the company has a modern logistics center that allowa for receiving, storing, and detailed quality control of materials, as well as order distribution. Moreover, it provides forwarding services, ensuring fast and secure transportation of goods to end users.

TEXTILE WASTE RECYCLING AT PIRIN-TEX COMPANY

Pirin-Tex company is licensed to collect and process textile, plastic and paper waste. Since 2004, the company not only collects and recycles its own waste but also has the capability to do so for other companies, particularly those in the textile and apparel industries.

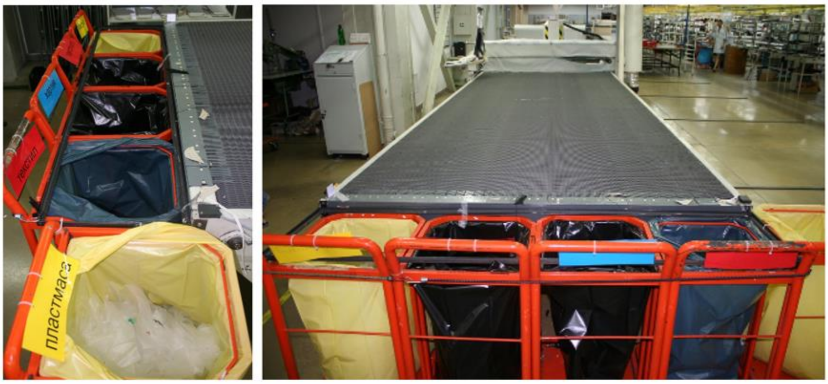

Figure 1. Structure of the waste collestion area in the tailoring workshop

In Chart 1, the percentage of differnt types of waste recycled by Pirin-Tex will be shown. The data is dicided into 4 categories.

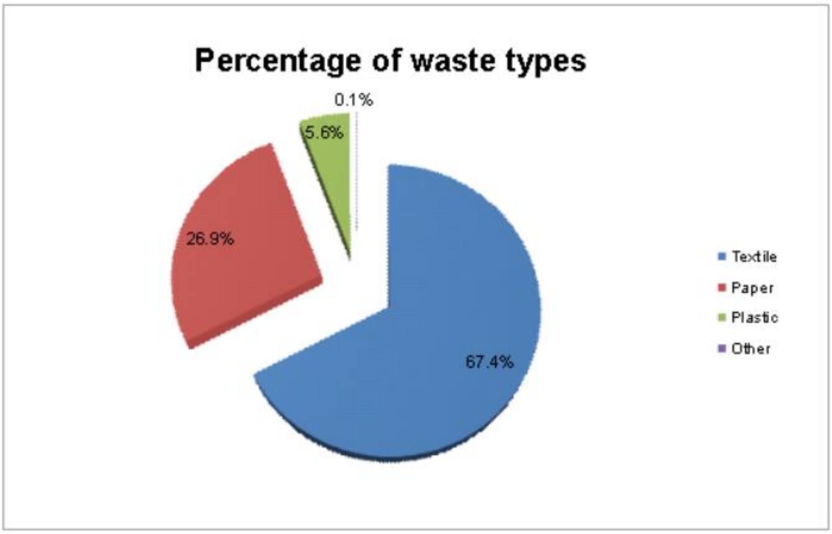

Chart 1. Percentage breakdown of 4 types of recycled waste

The following results are clearly observed:

- Textile waste constitutes the largest portion of total waste at 67.45, indicating that it is one of the most significant types of waste the company handles;
- Paper waste accounts for 26.9%, highlighting the significant use od paper in the production process;

- Plastic waste makes up 5.6%, representing a moderate use od plastic within the company;
- Other types of waste amount to only 0.1%, suggesting that other waste types are minimally represented.

The following Chart 2 provides statistical data on recycled waste expressed in tons over the past 10 years.

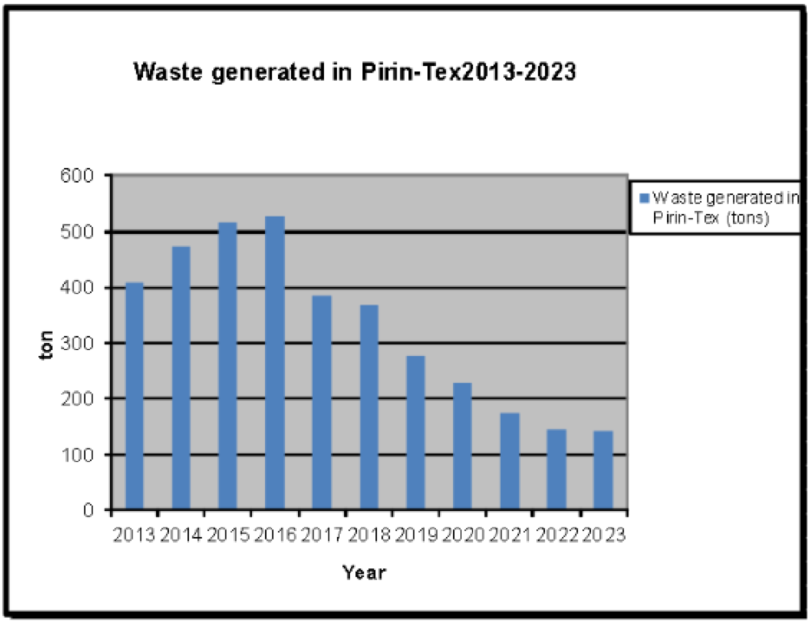

Chart 2. Statistical data on recycled waste over the past 10 years

According to Chart 2, it can be observed that during 2015 and 2016, the amount od recycled waste exceeded 500 tons. In 2014 and 2015, it ranged between 400 and 500 tons, while from 2017 onwards, this amound has been decreacing. One reason for this is the COVID pandemic, which has impacted not only the textile and apparel industry but all sectors of the economy.

Tegarding waste recycing for other companies, Chart 3 shows the results for 5 years from 2013 to 2017.

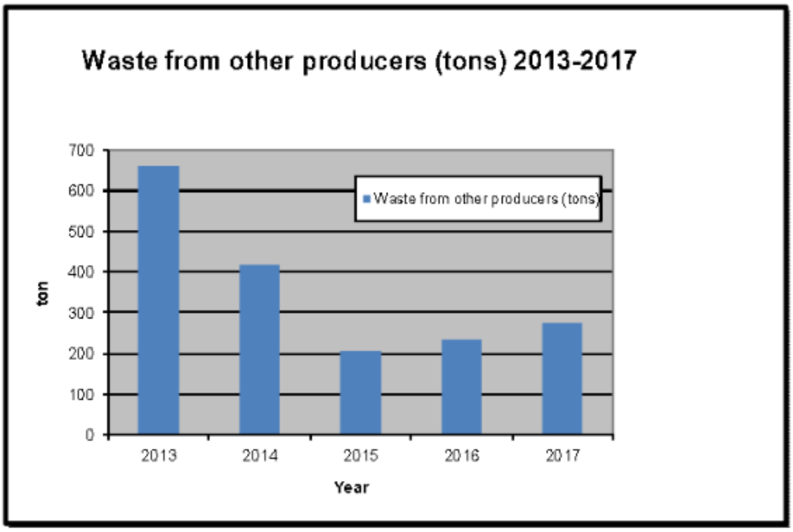

Chart 3. Statistical data on recycling wasted for other companies (5-years analysis)

At Pirin-Tex company, 11 employees are involved in the recycling process. Each of them carefully performs their tasks manually to ensure that the recycled materials are ready for further use. The recycled materials are packed into bales weighing between 450 and 500 kg.

Figure 2. Recycled waste in bales weighing between 450 and 500 kg

Pirin-Tex delivers its sorted materials to companies in the wool recycling industry in Italy, asa well as the non-woven insulation industry in Germany and Greece.

The sorted materials are:

- Worsted yarn,
- Carded yarns,
- Mixed fabrics – dark, light,
- Linning materials.

Figure 3, the data on the use of textile waste as raw material for future applications is shown.

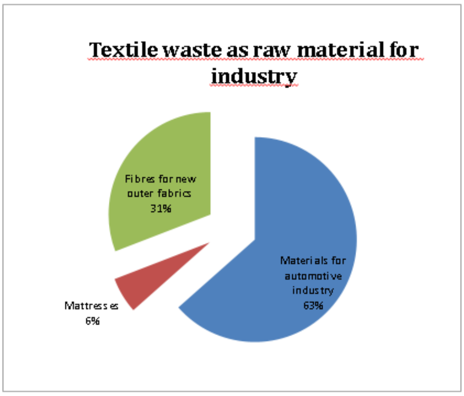

Figure 3. Statistical data on textile wasted as raw material for future applications

We can observe that the largest portion of recycling textile waste from Pirin-Tex is used in the automotive industry, assounting for as much as 63%, while 31% is used for new gabrics, and 6% for mattress production.

PROBLEMS AND PROPOSED SOLUTIONS IN THE RECYCLING PROCESS

Although recycling is one of the most effective ways to reduce waste and preserve resources, the recyclong process is not without its challenges. Many recycling companies, including Pirin-Tex company, face a range of obstacles that affect material recycling processes. These problems can be of different nature and often include a lack od consumer awareness. Understanding and addressing these challenges is crucial for improving the recycling process and achieving long-term goals.

One specific problem faced by Pirin-Tex company is the use of stapes to attach paper to small layers of cutting remnants. In cases where paper is stapled to textile layers, the metal parts on the stapels often remain on the textile after the paper is removed. During the sorting and recycling process, these metal parts are not always properly separated from textile materila.

Figure 4. Example of stapled material and the stapler used

This leads to several problems:

- Metal parts remain in the textile and can significantly hinder the recycling process;
- The presence of metal in the textile can damage machines used for shredding, grinding or processing textiles;
- If metal parts are not completely removed, the quality of the recycled textile fiber decreases, which affects the usability of the final product.

Other problems that companies face include:

- Improper waste separation by consumers – although there is infrastructure for separate waste collection, many consumers do not pay attention to what they throw into the containers. Mixing texiles, plastic and paper complicates the recycling process.
- High energy and labor costs – recycling requires significant energy and labor expenditures, which substantially increases operational costs. However, with reduced demand for recycled materials, this issue can threathen profitability.
- Decreased demand for recycled materials – increasing competition from new, cheaper raw materials in the market affects the demand for recycled materials, leading to waste accumulation and loss of economic opportunities.
- Underdeveloped technology for recycling complex materials – recycling materials such as mixed textiles or complex types of plastics requires advanced technologies that are not always available. This limits the ability to effectively utilize all resources.

The identified problems in the recycling process highlight the need for finding effective ans sustainable solutions that can improve operational processes and reduce the negative impact on the environment. Some of these solutions include:

- Replacing staples with eco-fiendly solutions and biodegradable materials;
- Developing systems for automatic metal detection;
- Installing magnetic separators;
- Conducting educational campaigns;
- Developing new markets and improving quality;
- Establishing waste monitoring and analysis systems.

These proposed solutions aim to improve the quality of recycled materials, reduce operational costs, and enhance the overall efficiency of the recycling system.

CONCLUSION

The recycling process, which is crucial for preserving natural resources and reducing waste, faces a range of challenges that affect its efficiency and sustainability.

The previously mwntioned problems reduce the quality of recyclws materials, increase operational costs, and slow down the recycling process. Despite the developed infrastructure for waste collection, the lack of awareness among citizens/wotkers remains a significant challenge tha must be addresses through education and ancouraging responsible behaviour.

To improve recycling efficiency, it is essential for companies to focus on raising consumer awareness. Additionally, considering alternative methods in the production process, such as avoiding metal staples, can significantly reduce risks and facilitate the recycling process. Investing in innovations and education will enable long-term success in achieving the company's environmental and economic goals.

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Advanced Textile Based Piezo-Triboelectric Nanogenerator for Powering Wearable and Implantable Medical Devices

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Abstract. Wearable and Implantable active medical devices are transformative solutions for improving healthcare, offering continuous health monitoring, early disease detection, targeted treatments, personalized medicine, and connected health capabilities. Powering up their sensing, actuation, stimulation, and communication functions, pose major risks of surgical infections or inconvenience to users. This talk delivers a critical assessment of recent advances in energy harvesting technologies based on advanced fibrous materials that can potentially eliminate the need for battery replacements. With a key focus on advanced textile materials that can close the gaps between these energy needs and the energy that can harnessed by energy harvesters, this speech examines the crucial roles of advanced textile materials in improving the efficiencies of energy harvesters devices. This concludes by highlighting the key challenges and opportunities in advanced materials necessary to achieve the vision of wearable and implantable active medical devices with self-powered functions. Textile structures are inherently flexible, making them well-suited for wearable applications although there are still some major concerns regarding to these issues. However, their electrical performance as nanogenerators is significantly limited when used without any modifications. To address this limitation and challenges, this talk is aimed to address provide different strategies to fabricate textiles-based piezoelectric and triboelectric nanogenerators. Furthermore, it provides a detailed discussion of nanocomposite textiles in various forms, such as fibers or yarns, fabrics, and electrospun nanofibrous webs, which are employed in piezoelectric and triboelectric nanogenerators.

Key words: piezo-triboelectric nanogenerator, wearable, implantable medical devices

INTRODUCTION

Energy scavenging can be available from a variety of sources from the ambient environment including energy in natural forms, such as wind, ocean waves, and solar power; mechanical energy, such as vibrations, engines, and infrastructures; thermal energy, such as joule heating of electronic devices; and electromagnetic energy from inductor coils and also from electronic devices. Moreover, a great amount of energy is available for harvesting such as mechanical energy due to vibration from body movement, respiration, and blood flow in vessels; thermal energy from body heat; and biochemical energy generated during physiological processes and metabolic reactions that have potential utilization in self-powered devices [1]. Renewable power can be obtained by generating electrical energy from light, thermal and dynamic energy. Thermal energy can be conveniently transduced into electrical energy by the Seebeck effect but solar power is probably the most well-known method of this context. Solar cells offer excellent power density in direct sunlight but are limited in dim ambient light conditions and are clearly unsuitable in embedded applications where no light may be present, or where the cells can be obscured by contamination [2, 3]. However, solar and thermal energies are highly dependent on time, location and not universally ubiquitous and accessible. Therefore, human-motion-based energy harvesting has attracted tremendous interest due to growing popularity of portable smart electronics as an independently self-sufficient and sustainable power source [4]. It is well known that the kinetic energy is typically present in the form of vibrations, random displacements or forces and is typically converted into electrical energy using electromagnetic, piezoelectric or electrostatic mechanisms [2, 5, 6]. Human based applications are characterized by low frequency high amplitude displacements. The amount of energy generated by this approach depends fundamentally upon the quantity and form of the kinetic energy available in the application environment and the efficiency of the generator and the power conversion electronics [2, 7].

FUTURE DIRECTIONS AND REMARKS

Piezoelectric nanofibers have the ability to gather the biological energy resulting from human body movements, such as walking [8-10], breathing [11, 12], and heartbeat [13-15]. Moreover, other mechanical energy types such as airflow and vibration can be extracted through these nanofibers [16]. PENGs have been utilized for detecting water velocity and pH [17], monitoring deformation [18], and tracking human motion in self-powered systems [19-21].

Shi *et al.* [22] utilized a flexible (PENG) for energy harvesting. The PENG was made of electrospun fiber mats that contained 15 wt.% BaTiO3 nanoparticles, 0.15 wt.% graphene nanosheets, and PVDF. The PENG generated a peak voltage of 112 V when the finger was pressed and released at fast strain rates. It was also able to generate energy from human movements, such as finger tapping, wrist flexing, and foot stepping. When tested under wrist flexing and finger tapping conditions, the output voltage reached 7.7 and 7.5 V, respectively. Additionally, when the PENG was located under the foot heel and toe, it produced a maximum voltage of 7.8 and 2.8 V, respectively. The heel produced a higher output voltage because it applied more pressure compared to the toe. Choudhry *et al.* [23]. Conducted research on producing electrical energy through bodily movements, specifically running. They utilized two distinct composites: one with impressive piezoelectric characteristics and the other with silicon and multi-walled carbon nanotubes, serving as an electrode. In their investigation, they also experimented with a PZT-silicon-graphene composite structure for an energy picker located in a shoe's shaft and managed to achieve an output voltage of 27 V. A very adaptable deformation PENG was developed using a very thin sheet of aluminum foil. This nanogenerator was designed to detect wrinkles on the human face and track eye movement. The PENG used ZnO NWs and was positioned close to an eye on human skin. When the eye blinked, the PENG adapted to the dynamic wrinkles, deforming as it was highly flexible and conformable. The output voltage and current measured approximately 0.2 V and 2 nA during eye blinking motion.

One of the application areas of nanogenerators is in applications related to vehicles. Various energies are created and wasted in the process of moving a vehicle, so this can be a suitable source to be used as input energy for a nanogenerator. In a study by Ma *et al.* [24], a flexible nanogenerator was developed that has adaptable shape and can fit the curvature of a bicycle tire. The nanogenerator was created by combining ferroelectricity and piezoelectricity, adding PZT and salt to PDMS, and polarization and electrode preparation. The nanogenerator had small dimensions and generated an open circuit voltage of 29 V and short-circuit current of 116 nA. This energy harvesting method is similar to that of automobile tires. Bicycles equipped with nanogenerators have great potential for monitoring their own status and transmitting signals, which could lead to intelligent development. In a study by Dudem *et al.* [25], they developed a PENG by combining BaTiO3 micro stones and Ag nanowires in a PVDF matrix. This PENG was able to effectively harvest energy from various types of vehicular motion, such as bicycles, motorcycles, and cars. The impact force generated by the motion of these vehicles was efficiently converted into electricity by this PENG.

In addition, nanogenerators have a great potential to utilize wasted low energy as an input to generate electrical energy. For example, the energy of sound vibration is usually assumed as wasted energy and mostly do not get attention, while some nanogenerators can use it. Park *et al.* [26] created an energy collection tool that utilized graphene as a clear and flexible electrode. They tested the tool and found that sound vibrations were primarily responsible for generating energy. When exposed to acoustic vibrations of 105 dB, the device produced an output voltage of approximately 7.6 V.

Harvested energy is a promising renewable energy source that can replace traditional batteries. For instance, He *et al.* [27] introduced a wearable self-powered electrochromic supercapacitor that is driven by piezoelectricity. However, since piezoelectric materials have low power output, rechargeable batteries or supercapacitors are necessary to store the harvested energy. To increase energy accumulation, storage cells can be connected in series to expand the voltage range. The voltage of the storage device is crucial for efficient energy harvesting, and a rectification circuit is required to connect the piezoelectric device to the storage cell. A diode bridge rectifier is commonly used as an AC-DC rectifier because the current source is alternating [28]. Ji *et al.* [29] developed a piezo-triboelectric device using BNT-ST/PVDF-TrFE nanofibers module that includes piezoelectric and triboelectric layers. This device can charge a 10 μF capacitor up to 6.5 V in 100 seconds.

CONCLUSION

Wearable electronics based on piezoelectric and triboelectric materials have gained significant traction in recent years, particularly for energy harvesting systems and sensors due to their flexibility and stretchability. Among the various types of wearable electronics, energy harvesting systems, and sensors have improved day by day due to their wide applications. Energy harvesting systems can convert the mechanical energy of the surrounding environment, which is usually considered wasted energy, into electrical energy. One of the most important components of any wearable electronics is the electrode, which needs to be compatible with the mechanical properties of the wearable product in terms of elasticity. In order to achieve flexible and wearable electronics with suitable mechanical properties, it is necessary that all the components of that device have desirable mechanical properties. As a result, to have a wearable energy harvester, flexible electrodes are needed.

The electrospinning method offers a revolutionary approach for producing wearable electronics by enabling the creation of nano-sized fibers from piezoelectric and triboelectric materials. Various factors influence the final product. By carefully controlling and optimizing these parameters, researchers can achieve piezoelectric or triboelectric layers with desired properties. The controllability of these effective parameters has led to the increasing popularity of this method. Electrospun layers with piezoelectric properties have found many applications in the fields related to body movement sensors, vehicle applications, storage, etc. It should be noted that in order to improve the output of production devices with this method, more optimizations are needed. There are various parameters which can be controlled or changed to enhance the output, some of these parameters included piezoelectric materials, structural design of commonly used piezoelectric materials, changing the microscopic morphology of existing piezoelectric, selecting appropriate substrate. The exceptional characteristics and potential for integration with other materials and technologies make fibrous wearable energy harvesting devices a promising component in the future of wearable technology.

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Decreasing Cutting Waste in Apparel Manufacturing

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Abstract. Global market competition creates constant pressure upon clothing manufacturers for decreasing costs, increasing market offer and constant readiness for quick response to market demands. However, textile and clothing manufacturing create substantial amount of waste. After construction and municipality waste, textile waste and plastic are considered high priority risks for environment. For apparel companies the strategy towards increased circularity can be through high material efficiency, increased resources productivity, high assets utilization and modified consumer preference. For apparel companies working on a CMT principle, the main potential for lowering environment harming is maximum use of resources and decreasing waste. The cutting waste in CMT apparel manufacturing company has been investigated. It was shown that application of cutting plan optimization contributes to significant decreasing of cutting waste.

Keywords: textile waste, cutting plan**,** apparel manufacturing**,** cutting waste

INTRODUCTION

Textiles are flexible materials crucial to everyday life, particularly in the fashion industry, contributing about 2% to the global GDP [1, 2]. Over the past two decades, clothing consumption has increased by 400%, leading to environmental concerns due to higher energy use and material circulation [3-6]. Currently, around 80 billion new clothing items are consumed annually [7, 8]. The textile industry is vital role in global trade and it faces challenges in reducing costs to maintain competitiveness and ensure customer satisfaction [9]. On the other hand, clothing is heavily influenced by rapidly changing fashion trends, which shortens the life cycle of garments and increases textile waste [10]. Fast fashion accelerates the influx of products into the market while quickly rendering them obsolete, resulting in significant environmental impacts, including high water consumption and pollution from dyeing and processing [11]. Fast fashion industry produces low-quality clothing at high speeds, negatively affecting resources and communities involved in production and consumption.

The textile industry is the second most polluting, responsible for approximately 1.2 billion tons of greenhouse gas emissions annually—more than international flights and maritime shipping combined [12]. Approximately 91% of a garment's greenhouse gas emissions occur during production, with an estimated 15% of fabric ending up in landfills before becoming a product [13, 14]. It is expected that by 2050 the fashion sector will consume 25% of the world's carbon budget [15]. Currently, 92 million tons of textile waste are generated each year, expected to rise to 134 million tons by 2030 [16], largely driven by fast fashion. The industry contributes around 5% of global waste, with European consumers discarding about 11 kg of textiles per person annually [17]. The industry largely relies on synthetic materials, contributing to greenhouse gas emissions and landfill waste [18]. Textile waste can be classified into pre-consumer and post-consumer categories, where the first one is more recyclable as it remains uncontaminated. Some of the pre-consumer wastes are process waste, damaged clothing waste, cut-sew waste and sampling waste, while the post-consumer waste is generating once the product is sold-out [19, 20]. Innovations like CAD systems and 3D software can enhance marker efficiency, reducing cutting waste and promoting sustainability in fashion production [21]. To mitigate waste, adjustments to sewing patterns and efficient marker plans can reduce cut-and-sew waste and can enhance cutting efficiency [22].

While textile production has increased by over 80% since 1980, recycling rates have stagnated, with only 14.7% of textiles recycled in 2018 [23]. It is inevitable, that the textile industry must transition to a circular economy, focusing on sustainable practices to mitigate environmental impacts. As automation increases across industries, waste management has emerged as a critical barrier to achieving a sustainable environment [24]. Therefore, the concept of sustainable manufacturing aims to balance economic benefits with minimizing environmental impacts. Awareness of pollution from textile production and disposal has risen, highlighting the urgent need for circular economy approaches to address sustainability challenges in the fashion and textile sectors. The circular economy focuses on three key principles: reduce, reuse, and recycle [25]. This approach emphasizes waste reduction throughout production and consumption, encouraging the design of products that can be easily repurposed or recycled. Innovations in materials, production methods, and resource utilization are essential for transforming the traditional linear economy into a sustainable model. Consumers also play a vital role by choosing durable, repairable, and recyclable products, which can stimulate demand for sustainable materials. The transition to a circular economy requires collaboration among stakeholders, including consumers, to promote sustainable practices. Industry 4.0 technologies can also facilitate this transition by enhancing decision-making and resource management, ultimately contributing to a more sustainable manufacturing landscape [26]. The implementation of circular economy principles can be supported by new metrics such as the materials circularity index (CI) and clothing utility (CU) [27]. These metrics aim to enhance sustainability at both personal and societal levels. The Corporate Sustainability Reporting Directive (CSRD), effective in 2023, mandates comprehensive reporting on resource consumption, waste generation, and circular design for companies operating in the EU. This regulation encourages businesses to assess their circularity performance and improve their sustainability practices [28]. The companies working purely on a CMT principle have very limited possibilities regarding product design that enhance circularity. Therefore, the contributions of these companies towards circular economy can be fulfilled through increasing material efficiency, increased resource productivity and increased asset utilization. The paper investigates the possibility of decreasing textile waste in apparel manufacturing company by application of economical cutting plan and application of digital tools.

Experimental

The paper investigates the possibility of decreasing cutting textile waste by application of economical cutting plan and by application of software application of cut planning software. The textile waste is calculated for three random orders processed in a three ways:

- The waste generated usually as it is actually done in in a factory,
- The amount of waste generated if the economical cutting plan is employed
- The waste generated if cut plan software and automatic marker making software is employed.

Economic cutting plan results in processing of cutting order with minimal costs. If we want the order to be cut with minimal costs the cutting lays should be as much as possible longer and as much as possible higher. The longer cutting lays decreases the number of cutting plays and the lost at the end of cutting lays. The longer cutting lays enables more options for high efficiency cutting markers. Therefore, the accent is on decreasing material cost and decreasing labor cost.
When creating economical cutting plan we calculate theoretical number of cutting lays:

$$Theoretical\ number\ of\ cutting\ lays = \frac{Pieces\ in\ cutting\ order}{Maximum\ pieces\ in\ cutting\ lay} \quad (1)$$

Today there are many software programs for cut order planning which enable obtaining optimal solution for the processing of cutting order for very short time. To investigate the possibilities for additional decreasing of production and material costs using advanced technology, the application of cut planning software and automatic marker making (nesting) software is investigated. The cut plan software is applied using the processing constrains (length of the cutting lays and number of cutting plays) previously used in manual optimization and then the markers are processed by automatic marker making software. So this process is used by application of two software packages. Cut plan software enables automatic generation of most efficient cutting plan in relatively short period of time, with minimal number of markers and cutting lays, where the accent is on decreasing material costs. The manufacturing of markers using automatic marker making software the following constrains were used: time for processing: 2 min, maximum utilization of marker: 95% and parallel processing of markers for cutting order. The cutting orders investigated in this case study are randomly chosen from everyday production in the factory. The details of the orders are depicted in table 1.

Table 1. The details of investigated cutting orders

Cutting order number 7, item kids trousers									
Size	4	6	8	10	11	12	14	16	Total
Pieces	34	23	23	36	23	36	36	21	232
Cutting order number 8, item men’s trousers									
Size	38	40	42	44	46	48	48B		Total
Pieces	23	54	62	60	53	18	4		274
Cutting order number 9, item men’s trousers									
Size	30	31	32	33	34	35	36	38	Total
Pieces	80	100	160	140	200	100	120	60	960

Results and discussion

The constraints of cutting lays for cutting order No. 7 are:

- maximal number of cutting plies: 36

- maximal length of cutting lays : 4 sizes in the marker

Therefore theoretical number of cutting lays for order number 7 is: $\frac{232}{144} = 1.61 \sim 2$

The obtained economical plan for processing cutting order no. 7 is:

4	10	12	14	Cutting lay 136 plies
6	8	11	16	Cutting lay 223 plies

The details of economic plan for cutting order 7 is depicted in table 2.

Cutting lays	Sizes in the marker	No of plies	Pieces in the lay	Marker width (m)	Marker length (m)	Marker efficiency (%)
1	4x1; 10x1; 12x1; 14x1	36	144	1.47	3.43	83.10
t	6x1; 8x1; 11x1; 16x1	23	92	1.47	3.39	84.29
	Total:	59	236			

The total quantity of cutting waste generated using various methods of processing cutting order is shown in fig. 1

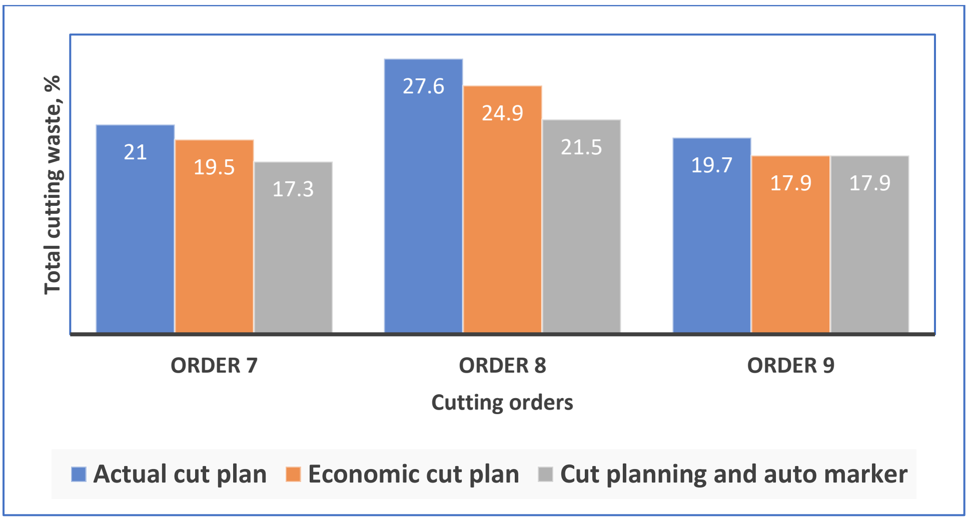

Figure 1. Comparison of total cutting waste using various methods of cut planning

The results shows the decreasing the percentage of total cutting waste by application of economical cut plan and by application of cut planning software and automatic marker making software. For the order number 9, there is no decreasing of the cutting waste by application of digital tools and the cutting waste remains 17.9%. The results confirmed that in all three cases, beside material savings, using CAD tools there is opportunity for additional labor costs savings, due to increased speed for cut planning and marker making.

CONCLUSION

By the application of economical cut plan the total catting waste is decreased from 1.5-2.7% for all three investigated orders.

The application of cut planning and automatic marker making software results in decreasing the total cutting waste from 1.8 to 6.1%.

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The Impact of Zero-Waste Initiatives on Consumer Behavior and Business Models

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Abstract. This paper examines the impact of zero-waste initiatives on consumer behavior and business models, highlighting the interconnectedness of these elements. Increasing consumer awareness and demand for sustainable products drive businesses to adopt zero-waste practices. Younger and higher-income consumers show a strong preference for environmentally friendly products, prompting businesses to redesign products, implement efficient waste management systems, and adopt circular economy models. These practices lead to significant economic and environmental benefits, including cost savings, operational efficiency, and improved brand reputation. Despite the advantages, businesses face challenges such as initial costs and regulatory complexities. Support from governments, including financial incentives and clear regulations, is important. Collaboration between public and private sectors, along with consumer education, further promotes zero-waste practices. This comprehensive approach ensures that zero-waste initiatives are effectively integrated into business models, fostering sustainability and competitiveness.

Keywords: zero-waste initiatives, circular economy, waste reduction, business

INTRODUCTION

Consumer awareness towards zero-waste initiatives has been growing steadily as environmental concerns become more pronounced. Public campaigns, social media movements, and educational programs have played significant roles in elevating the understanding of zero-waste principles among consumers. These initiatives aim to reduce waste by encouraging practices such as recycling, composting, and the elimination of single-use plastics. Increasingly, consumers are becoming conscious of the environmental impact of their purchasing decisions, which is reflected in their preference for products that are sustainable and have minimal packaging [1].

The rise in consumer awareness has prompted businesses to respond by adopting zero-waste practices within their operations. Companies across various industries are re-evaluating their supply chains, production processes, and waste management systems to align with zero-waste principles. This involves a wide range of strategies, from redesigning products to be more sustainable to implementing more efficient recycling programs and reducing the use of non-recyclable materials. Businesses are also exploring innovative approaches such as circular economy models, where materials are reused and recycled to create a closed-loop system [2]. For example, some companies have started using biodegradable materials for packaging, while others are developing products designed for easy disassembly and recycling. The adoption of these practices often requires significant investment and a shift in organizational culture. Training employees, investing in new technologies, and redesigning products are just a few of the steps businesses might take to transition towards zero-waste operations.

Despite the challenges, the potential benefits of adopting zero-waste practices are substantial. Companies can achieve cost savings by reducing waste disposal fees and reclaiming materials that would otherwise be discarded. Additionally, adopting sustainable practices can improve a company's brand reputation, making it more attractive to environmentally conscious consumers and investors [3].

Understanding the various approaches businesses take and the challenges they face is important for developing effective policies and support systems to promote zero-waste initiatives on a broader scale. Policymakers can play a key role by providing incentives for businesses to adopt zero-waste practices, such as tax breaks or grants for implementing sustainable technologies. Additionally, collaboration between businesses, governments, and non-profit organizations can foster innovation and share best practices. Consumer education campaigns that emphasize the importance of zero-waste initiatives and provide practical tips for reducing waste can further support these efforts [4].

The main goal of the paper is to develop a theoretical model for improving business models and competitiveness in the context of zero-waste initiatives and their impact on consumer behavior.

CONSUMER AWARENESS AND ATTITUDES

Consumer awareness towards zero-waste initiatives has been steadily increasing, driven by a heightened focus on environmental sustainability. Public campaigns, social media activism, and educational programs have significantly contributed to this growing awareness. These initiatives emphasize the importance of reducing waste through practices such as recycling, composting, and eliminating single-use plastics. Many consumers now recognize the environmental impact of their purchasing decisions, leading to a preference for products that are sustainably sourced and minimally packaged. However, this shift in consumer behavior is not homogeneous and varies across different demographics. Younger consumers, who are more exposed to environmental issues through education and media, often show a higher propensity to support zero-waste products and practices. Similarly, higher-income groups might have more flexibility in choosing eco-friendly options, although issues of accessibility and affordability can pose significant barriers for other segments of the population. Understanding these demographic variations is important for developing zero-waste strategies that are both effective and inclusive, ensuring broad-based support for sustainable practices [5].

The increasing consumer awareness of zero-waste principles has led many businesses to integrate these practices into their operations. Companies are re-evaluating their supply chains, production processes, and waste management systems to align with zero-waste objectives. This shift encompasses a wide range of strategies, from redesigning products to be more sustainable to implementing more efficient recycling programs and minimizing the use of non-recyclable materials. Businesses are also exploring innovative approaches such as circular economy models, where materials are reused and recycled to create a closed-loop system. For instance, some companies have begun using biodegradable materials for packaging, while others are developing products that are designed for easy disassembly and recycling. Adopting these practices often requires significant investment and a shift in organizational culture, including training employees, investing in new technologies, and redesigning products.

Despite these efforts, businesses face numerous challenges in transitioning to zero-waste practices. The initial costs of implementing zero-waste strategies can be substantial, particularly for small businesses with limited resources. Regulatory challenges and the need to change long-established practices also present significant obstacles. However, the potential benefits are substantial [6]. Companies can achieve cost savings by reducing waste disposal fees and reclaiming materials that would otherwise be discarded. Additionally, adopting sustainable practices can improve a company's brand reputation, making it more attractive to environmentally conscious consumers and investors. Businesses may also find that innovation in waste reduction leads to new market opportunities and a competitive advantage [7].

Developing effective policies and support systems is important for promoting zero-waste initiatives on a broader scale. Policymakers can provide incentives for businesses to adopt zero-waste practices, such as tax breaks or grants for implementing sustainable technologies. Collaboration between businesses, governments, and non-profit organizations can foster innovation and the sharing of best practices.

ECONOMIC AND ENVIRONMENTAL BENEFITS

Economic and environmental benefits of zero-waste business models are increasingly recognized in various industries. Economically, businesses can achieve substantial cost savings through the reduction of waste disposal fees and the reclamation of materials that would otherwise be discarded. By minimizing waste, companies can streamline their operations and improve efficiency, leading to reduced operational costs. For instance, adopting zero-waste practices can result in lower raw material costs as businesses find ways to reuse and recycle materials within their production processes. Additionally, zero-waste initiatives often lead to innovation, prompting the development of new products and services that can open up new markets and revenue streams. Improved brand reputation is another significant economic benefit. As consumers become more environmentally conscious, they are more likely to support businesses that demonstrate a commitment to sustainability. This can translate into increased customer loyalty and market share [8].

From an environmental perspective, zero-waste business models contribute to significant reductions in pollution and resource consumption. By adopting sustainable practices, businesses can decrease their carbon footprint, reduce greenhouse gas emissions, and limit the depletion of natural resources. This is particularly important in industries such as manufacturing and agriculture, where waste and resource use are typically high. Zero-waste practices also contribute to the health of ecosystems by minimizing the amount of waste that ends up in landfills and oceans. For example, businesses that reduce or eliminate single-use plastics help decrease the prevalence of plastic pollution, which poses a significant threat to marine life. The environmental benefits of zero-waste models align with global efforts to combat climate change and promote sustainable development, highlighting the role businesses can play in achieving broader environmental goals.

Implementing zero-waste initiatives, however, presents several challenges. One of the primary obstacles is the initial cost associated with transitioning to zero-waste practices. Investing in new technologies, redesigning products, and training employees require substantial financial resources, which can be particularly burdensome for small and medium-sized enterprises [9].

DEVELOPED MODEL

Based on the addressed literature a theoretical model was developed for improving business models and competitiveness in the context of zero-waste initiatives and their impact on consumer behavior.

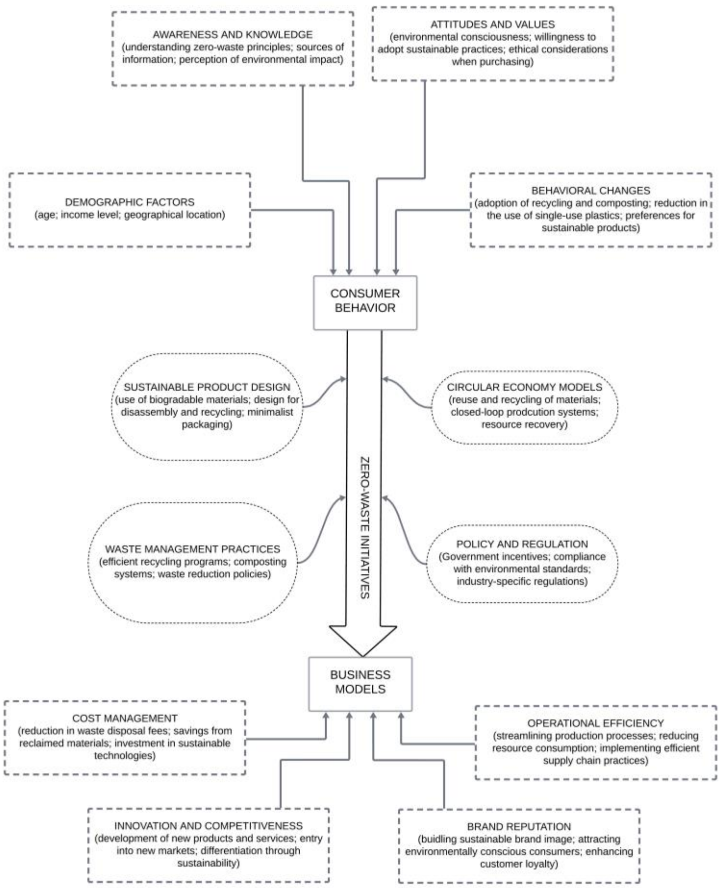

Figure 1. Model for improving business models and competitiveness in the context of zero-waste initiatives and their impact on consumer behavior

Consumer behavior is influenced significantly by awareness and knowledge about zero-waste principles. When consumers are well-informed through sources like social media, educational programs, and public campaigns, they develop a better understanding of the environmental impact of their actions. This heightened awareness often translates into stronger environmental consciousness, which affects their attitudes and values. Consumers who value sustainability and ethical considerations are more likely to change their behaviors, adopting practices such as recycling, composting, and reducing the use of single-use plastics. Demographic factors such as age, income level, and geographical location further shape these behaviors, with younger individuals and higher-income groups typically more inclined to support zero-waste initiatives.

Zero-waste initiatives, driven by consumer demand for sustainability, play a pivotal role in shaping business models. Sustainable product design is one key area where businesses respond to consumer behavior. Companies that use biodegradable materials, design products for disassembly and recycling, and adopt minimalist packaging can meet the expectations of environmentally conscious consumers. Effective waste management practices, such as implementing efficient recycling programs, establishing composting systems, and adopting waste reduction policies, are significant for businesses aiming to align with zero-waste principles. These initiatives not only address consumer demands but also help companies reduce their environmental footprint and improve their operational efficiency.

The adoption of circular economy models further strengthens the relationship between zero-waste initiatives and business models. Businesses that embrace these models by reusing and recycling materials and creating closed-loop production systems can achieve significant cost savings and resource recovery. Such practices support the sustainable values of consumers and improve the company's competitive edge. Policy and regulation are also vital components, as government incentives like tax breaks and grants, along with stringent compliance requirements, encourage businesses to adopt zero-waste practices. These regulatory measures create a supportive environment that fosters the growth of sustainable business models.

SUGGESTIONS AND GUIDELINES

Based on the analyzed literature and the developed theoretical model, the following suggestions and guidelines for improving business models and competitiveness in the context of zero-waste initiatives and their impact on consumer behavior are noted:

- Tax breaks and grants for businesses adopting sustainable technologies can offset initial costs. These incentives encourage companies to invest in zero-waste practices, fostering innovation and reducing environmental impact.
- Establishing well-defined environmental standards helps businesses understand compliance requirements. This clarity promotes the adoption of zero-waste strategies across various industries, ensuring uniformity and effectiveness.
- Funding and promoting educational programs can increase consumer knowledge about zero-waste initiatives. Improved awareness drives consumer

demand for sustainable products, influencing businesses to adopt greener practices.

- Facilitating partnerships between businesses, governments, and non-profits can foster the exchange of best practices. Collaborative efforts lead to innovative solutions and shared resources, making zero-waste initiatives more accessible and effective.
- Using biodegradable materials and designing for disassembly can meet consumer expectations for eco-friendly products. These practices also reduce waste and improve the company's sustainability profile.
- Establishing efficient recycling and composting programs within operations minimizes waste output. Such systems improve resource recovery and align with zero-waste principles, enhancing operational efficiency.
- Reusing and recycling materials within a closed-loop system can reduce resource consumption and waste. This approach not only benefits the environment but also leads to cost savings and new revenue streams for businesses.
- Supporting policies and legislation that promote zero-waste initiatives can lead to broader systemic changes. Advocacy ensures that government actions align with sustainable goals, benefiting the wider community and environment.

CONCLUSION

The integration of zero-waste initiatives into business models has emerged as a important strategy for enhancing sustainability and competitiveness. Consumer behavior plays a pivotal role in this transformation, as increasing awareness and demand for environmentally friendly products drive businesses to adopt more sustainable practices. Younger consumers and higher-income groups, in particular, exhibit a strong preference for zero-waste products, underscoring the importance of targeted strategies that address demographic variations. Businesses responding to these demands by redesigning products, implementing efficient waste management systems, and adopting circular economy models not only meet consumer expectations but also achieve significant economic and environmental benefits.

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The Integration of AI in Sustainable Energy Systems for Optimization

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Abstract. This paper explores the integration of artificial intelligence (AI) in sustainable energy systems, highlighting its potential to improve efficiency, reliability, and environmental sustainability. AI-driven energy management systems, predictive analytics, and intelligent control mechanisms provide advanced solutions for optimizing energy generation, distribution, and consumption. These technologies enable real-time data analysis, proactive maintenance, and precise forecasting, important for balancing supply and demand, particularly with intermittent renewable energy sources. Supporting infrastructure, including robust data collection, secure communication networks, and advanced storage technologies, is essential for the effective deployment of AI applications. Government policies and regulatory frameworks play a significant role in fostering the adoption of these technologies. Enterprises can improve sustainability by integrating AI and renewable energy sources, while individuals can contribute through smart home devices and participation in demand response programs. The combined efforts of these stakeholders can achieve substantial efficiency improvements, cost reductions, environmental benefits, and user empowerment. This paper underscores the transformative impact of AI on sustainable energy systems and outlines strategies for leveraging AI to advance global energy sustainability and resilience.

Keywords: AI integration, sustainability, energy systems, optimization

INTRODUCTION

Artificial intelligence (AI) is increasingly recognized as a powerful tool in the field of energy management, offering innovative solutions to optimize energy distribution and consumption. AI-driven energy management systems are designed to handle the complexities of modern energy grids, ensuring that energy is distributed efficiently and sustainably. These systems leverage advanced algorithms and real-time data analytics to make informed decisions about energy allocation, demand response, and load balancing [1].

Predictive analytics, a subset of AI, plays a pivotal role in the maintenance and monitoring of energy systems. Through the use of machine learning models and data analysis, predictive analytics can foresee potential equipment failures and maintenance needs before they occur. This proactive approach to maintenance helps in preventing unexpected downtimes and extends the lifespan of significant infrastructure [2]. In energy consumption monitoring, predictive analytics can identify patterns and trends that enable more effective energy use. The application of AI in energy consumption monitoring extends beyond industrial uses to residential and commercial sectors as well. Smart meters and IoT devices equipped with AI capabilities can provide detailed insights into energy usage patterns, enabling users to make more informed decisions about their energy consumption. This not only helps in reducing energy costs but also contributes to broader sustainability goals by promoting more efficient energy use [3]. AI-driven solutions thus hold significant promise for advancing the efficiency and sustainability of energy systems, making them an integral component of the future energy landscape. The main goal was to develop a theoretical model for improving sustainable energy systems.

AI-DRIVEN ENERGY MANAGEMENT SYSTEMS AND PREDICTIVE ANALYTICS FOR RENEWABLE ENERGY SOURCES

AI-driven energy management systems represent a significant advancement in the way energy is distributed and consumed, particularly in the context of integrating renewable energy sources. These systems employ sophisticated algorithms and real-time data analytics to optimize the operation of energy grids. They manage the balance between energy supply and demand, dynamically adjusting to fluctuations in energy production from renewable sources such as wind, solar, and hydroelectric power. This real-time management capability ensures that energy is distributed efficiently, reducing waste and enhancing grid stability. The integration of AI into energy management also facilitates the incorporation of distributed energy resources, such as rooftop solar panels and local wind turbines, into the larger grid [4, 5].

Predictive analytics is a important aspect of AI-driven energy management systems, particularly in managing renewable energy sources. Renewable energy production is inherently variable and depends on factors such as weather conditions and time of day. Predictive analytics uses historical data and machine learning models to forecast energy production levels from renewable sources with high accuracy. These forecasts enable grid operators to plan and optimize the distribution of energy, ensuring that sufficient power is available to meet demand even when renewable output is low. This predictive capability is essential for maintaining the reliability of the energy supply and minimizing the need for backup power from fossil fuels [6].

AI-driven predictive analytics also improves energy consumption monitoring and management. Demand response involves adjusting energy usage based on supply conditions, such as shifting consumption to times when renewable energy production is high. This helps to balance the load on the grid and make better use of available renewable resources. In residential and commercial settings, smart meters and IoT devices equipped with AI can provide users with detailed insights into their energy usage, helping them to make more informed decisions about energy consumption and reduce their carbon footprint [6].

AI IN ENERGY STORAGE SOLUTIONS AND AI-IMPROVED ENERGY CONSUMPTION MONITORING

Artificial intelligence (AI) is playing a transformative role in optimizing energy storage solutions, which are significant for ensuring a reliable supply of energy from intermittent renewable sources. Energy storage systems, such as batteries, store excess energy produced during periods of high renewable output and release it during periods of low production or high demand. AI improves these systems by optimizing their operation and management. Through machine learning algorithms, AI can predict energy storage needs based on historical data, weather forecasts, and real-time grid conditions. This predictive capability allows for efficient charge and discharge cycles, maximizing the lifespan and performance of the storage systems [7].

AI also improves energy storage solutions through advanced battery management techniques. These techniques involve continuous monitoring and analysis of battery health, charge levels, and performance metrics. AI can identify patterns and anomalies that indicate potential issues, enabling proactive maintenance and avoiding costly downtimes. For instance, AI can detect early signs of battery degradation or overheating and recommend maintenance actions before failures occur. Additionally, AI can optimize the charging process to ensure batteries are charged in the most efficient manner, taking into account factors such as electricity prices, demand forecasts, and grid stability. This results in cost savings and improved overall efficiency of energy storage systems [8].

Energy consumption monitoring is another area where AI has a significant impact. AI-improved monitoring systems leverage data from smart meters and Internet of Things (IoT) devices to provide detailed insights into energy usage patterns across various sectors. These systems use machine learning to analyze consumption data and identify trends, anomalies, and opportunities for energy savings [9, 10]. For residential users, AI can offer personalized recommendations for reducing energy usage based on individual consumption patterns, helping to lower energy bills and promote sustainable practices. In commercial and industrial settings, AI can identify inefficiencies in energy use, such as equipment that consumes excessive energy during off-peak hours, and suggest corrective measures.

AI-improved energy consumption monitoring also supports demand response initiatives, which are important for balancing supply and demand on the grid. AI can predict periods of high energy demand and coordinate with smart devices to adjust their operation accordingly. For example, during peak demand periods, AI can temporarily reduce the power consumption of non-essential devices or shift their usage to times when renewable energy is more abundant. This not only helps to stabilize the grid but also maximizes the use of renewable energy, reducing reliance on fossil fuels. Additionally, AI can facilitate dynamic pricing models where electricity prices vary based on demand and supply conditions, encouraging consumers to adjust their energy usage in response to price signals.

THEORETICAL MODEL

After analyzing the existing body of literature, a theoretical model for improving sustainable energy systems was developed. The model is presented on Figure 1.

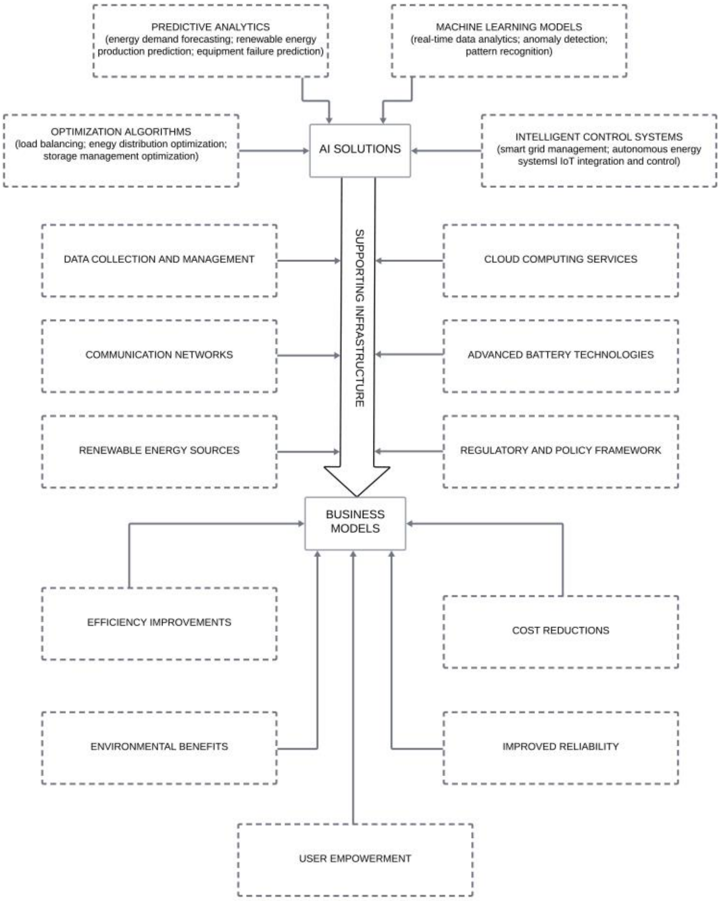

Figure 1. Model for improving sustainable energy systems

AI solutions play a pivotal role in enhancing sustainable energy systems through various interconnected sub-elements that influence and support each other. Predictive analytics, a core component of AI solutions, involves energy demand forecasting, renewable energy production prediction, and equipment failure prediction. Energy demand forecasting allows for accurate predictions of future energy needs, enabling better planning and resource allocation.

Optimization algorithms are another significant aspect of AI solutions, focused on load balancing, energy distribution optimization, and storage management optimization. Load balancing algorithms distribute energy across the grid to ensure that no single part is overburdened, thereby enhancing grid stability. Storage management optimization maximizes the use of energy storage systems, ensuring that energy is stored and released in the most efficient manner possible, which is essential for balancing supply and demand.

Machine learning models support real-time data analysis, anomaly detection, and pattern recognition, forming the backbone of AI-driven energy systems. Real-time data analysis allows for immediate adjustments to energy distribution based on current conditions.

Intelligent control systems integrate these AI capabilities into smart grid management, autonomous energy systems, and IoT integration and control. Smart grid management uses AI to oversee and optimize the entire energy grid, ensuring seamless operation and integration of renewable energy sources.

Supporting infrastructure is important for the effective implementation of AI solutions. Data collection and management through sensor networks, smart meters, and data storage solutions provide the necessary data for AI algorithms to function effectively. Communication networks, including high-speed internet connectivity, secure data transmission protocols, and cloud computing services, ensure that data is transmitted and processed quickly and securely.

Renewable energy sources, including solar panels, wind turbines, and hydro power plants, form the foundation of sustainable energy systems. AI solutions optimize the use of these sources, ensuring that they contribute effectively to the overall energy supply. The regulatory and policy framework, encompassing government incentives and subsidies, environmental regulations, and standardization of technologies, provides the necessary support and guidelines for the implementation and operation of AI-driven energy systems.

The achieved goals of these integrated systems include efficiency improvements, cost reductions, environmental benefits, improved reliability, and user empowerment. Efficiency improvements result from reduced energy waste, improved grid stability, and optimized energy consumption. Cost reductions are achieved through lower operational costs, reduced maintenance expenses, and savings from demand response programs. Environmental benefits include lower carbon emissions, increased use of renewable energy, and sustainable resource management. Improved reliability is realized through improved energy supply security, reduced downtime and outages, and proactive maintenance and monitoring. User empowerment is facilitated by increased consumer awareness, personalized energy management solutions, and greater participation in energy markets.

SUGGESTIONS AND GUIDELINES

The developed model provided insights based on which suggestions and guidelines for improving sustainable energy systems are highlighted:

- Facilitate collaborations between government entities and private companies to develop and deploy AI-driven energy technologies. These partnerships can accelerate innovation and ensure that the best solutions are implemented at scale.
- Invest in educational initiatives to train the next generation of engineers and scientists in AI and renewable energy technologies. A well-educated workforce is important for advancing sustainable energy solutions and maintaining a competitive edge in this rapidly evolving field.
- Develop and enforce data security regulations to protect the sensitive information generated by AI and smart grid technologies. Ensuring the privacy and security of data will build public trust and promote the widespread adoption of these technologies.
- Implement predictive maintenance programs powered by AI to monitor equipment health and performance. This proactive approach reduces

downtime, lowers maintenance costs, and extends the lifespan of significant infrastructure.

- Analyze and optimize energy consumption across the entire supply chain using AI-driven insights. This holistic approach can identify inefficiencies and opportunities for energy savings, contributing to overall sustainability goals.
- Learn about energy-efficient practices and technologies to make informed decisions about energy use at home and work. Knowledgeable consumers can make choices that reduce their environmental impact and support broader sustainability efforts.
- Governments and enterprises can create or support innovation hubs and incubators focused on AI and renewable energy startups. These centers foster creativity and provide resources for developing cutting-edge solutions.
- Establish and enforce energy efficiency standards for buildings, appliances, and vehicles. Stricter standards will drive the adoption of energy-saving technologies and practices across various sectors.

CONCLUSION

The integration of AI in sustainable energy systems holds significant potential for enhancing efficiency, reliability, and environmental sustainability. AI-driven energy management systems, predictive analytics, and intelligent control systems provide sophisticated tools for optimizing the generation, distribution, and consumption of energy. These technologies enable real-time data analysis, proactive maintenance, and precise forecasting, all of which contribute to a more resilient and adaptable energy grid. The ability to balance energy supply and demand dynamically, especially with the inclusion of intermittent renewable energy sources, is a significant advancement facilitated by AI.

The synergistic relationship between AI solutions, supporting infrastructure, and achieved goals underscores the transformative impact of AI on sustainable energy systems. As these technologies continue to evolve and mature, they offer promising avenues for addressing the global challenges of energy sustainability and climate change.

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Heidegger's Critique of Industrial Capitalism

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Abstract. Modern technology, as a generator of industrial capitalism, as Martin Heidegger demonstrates in his later philosophical works, fully exploits Nature, ensuring unprecedented human domination over our planet. Human action is reduced to assessing the value of reality for unlimited human needs, meaning that the Earth becomes a raw material and thought becomes uniform planning, an instrument in the service of technical power - complete domination over the Earth. However, Heidegger's questioning of the essence of industrial capitalism, viewed through the discourse of the Technical Model of the World, should not be understood as a fashionable reactionism, a rebellion against technology, or a romantic longing for some archaic times. Thus, as we will show in this paper, Heidegger's meaning in questioning the essence of the Technical Model of the World is not exhausted by merely marking the technological exploitation of nature. We can already say that his critique of the Technical Image of the World is directed, above all, at the negative way of conditioning our thinking, which within the capitalist model of the world acquires only an instrumental role in calculating and planning the exploitation of natural resources. Man open to technology is no longer the one who dominates and exploits nature. Man in the modern age is a resource for use, like all of reality.

Keywords: nature, technology, technical Image of the world, uniform mind, economic efficiency, industrial capitalism

INTRODUCE

Nature as a standing reserve of resources

"Our questioning of technology aims to prepare us for a more autonomous relationship with it.*"*

Radically rethinking, during the 1950s, the question of the expansive technological development of the modern era, the German philosopher Martin Heidegger aimed to uncover the essence of technology, outlining for us the intellectual horizons within which it is possible to understand the relationship between corporate capitalism and contemporary man as a consumer of technical and technological products. Thus, if we embark on an intellectual adventure through Heidegger's *"forest paths"* [2], we ask ourselves in which direction the modern technological age is moving, and whether this philosopher has successfully sketched out a technologically mediated self-reflection of contemporary man.

According to Heidegger, modern technology constitutes the final metaphysical stage, while in the Technological Picture of the World, he sees a planetary technical manipulation of reality.

Technology dominates the contemporary epoch: "Everywhere we are chained to technology and deprived of freedom." [2], Its role is not merely instrumental [3], nor does it represent merely a set of technical devices in mastering nature, as it is usually presented, but it dominates over man, conditioning our way of life, actions, as well as our attitude towards the world and ourselves. Thus, Heidegger writes: "We can affirm the necessity of using technical devices, but deny them the right to dominate us and thus distort, confuse, and corrupt our nature" [4].

Trying to explain the diagnosis of the time in which we live, Heidegger claims that we interpret and understand all reality, and with it postmodern man, starting from the Technical Model of the World grounded in Western European science [5]. Within technical engineering, all reality (Heidegger writes: different modes of being) is leveled and viewed from the perspective of exploitation and calculation. In his famous depiction of the Rhine River, Heidegger writes that in the modern technical age, the river is no longer seen as a river, but that the river is already calculated into the hydroelectric power plant, that it is built into it just like its foundations and walls, that the river now represents part of the blueprint of the hydroelectric power plant:

"The hydroelectric power plant is placed on the Rhine. It poses a demand on the river to deliver hydraulic pressure, which in turn poses a demand on the turbines to rotate... What now exists as a river, a supplier of hydraulic pressure, it is, thanks to the essence of the power plant" [6].

Within the *Technical Picture of the World*, all reality is objectified and established for exploitation, calculated becomes a commodity and what Heidegger calls: "... a circular movement of exploitation" [7] is realized. Nature is thus interpreted as a collection of accumulated resources. Everything that is, all of reality, is only as a store of energy and accumulated resources since all of Nature is tied in advance to a given T*echnical Picture of the World*, or rather a technical construction of reality: "The revealing that rules in modern technology is a challenging that demands from nature that it supply energy that can be extracted and accumulated as such." [8] and "Nature appears as a huge gas station, a source of energy for modern technical industry" [9]. While in other places, in his philosophical opus, Heidegger attacks the consumerist mentality of the modern age: "This circular movement of exploitation, which takes place for the sake of consumption, is the only process that characterizes the history of a world that has become unholy" [10].

Modern technology, as Heidegger lucidly demonstrates, exploits Nature, ensuring human dominance over our planet. Human action is reduced to assessing the importance of reality for specific needs, turning the Earth into a mere resource [11] Thought becomes a uniform planning tool, serving technical power—complete dominion over the Earth: "...uniformity is the universal criterion; reality rests on the uniformity of planning" [12].

Although it might be tempting to dismiss Heidegger's questioning of the essence of technology, in his later works, as a fashionable reaction, a rebellion against technology, or a romantic longing for archaic times, the critique of the essence of technology, as H.L. Dreyfus points out, is not limited to this dimension. Heidegger himself writes: "There is nothing demonic about technology..." [13]. Heidegger does not advocate a return to a non-technical world but emphasizes the possibility of remaining true to our human nature while maintaining technological progress by keeping *thoughtful thinking* alive, if at all possible within the *Technical Image of the World*.

Therefore, if Heidegger's questioning of the essence of the *Technical Model of the World* does not exhaust itself in marking the technological exploitation of nature, we can already say that his critique of the *Technical Image of the World* is directed, above all, at the negative way of conditioning our thinking."

Instrumentalni um

"The downfall has already happened. The consequences of that event are the givens in the world history of our century" [14].

Addressing the peasants of the Black Forest, Heidegger, in his unconventional critique of the expansion of 20th-century technology, condemns their media consumerism, which distances them from reality:

"Every day and every hour they are glued to the radio and television... everything that modern communication techniques stimulate, attack, and drive human beings – all this is already much closer to people today than their fields around their homes, closer than the sky above the earth, closer than the change from night to day, closer than the manners and customs of their village, than the tradition of their original world" [15].

As we have already hinted, Heidegger's perspective on the *Technical Model of the World* goes beyond the usual framework of problematization. He argues that modern technology is something entirely different from the interpretation of its instrumental role, or even that it serves the progress[16]of humanity: "What endangers man in his essence is the opinion that through peaceful liberation, storage, and direction of energy, humanity can make life bearable and, on the whole, happy for everyone" [17].

In his later works, Heidegger points out that the desire to master technology is illusory because technology increasingly threatens to escape human control: "One wants to master it. This desire to master it becomes all the more urgent the more technology threatens to escape human control" [18].

No individual, group of people, assembly of statesmen or technicians: "...no conference of leaders in trade and industry can stop or control the progress of history in the atomic age" [19]. The danger posed by the technological advancement of civilization is not merely reflected in the rattling of nuclear weapons, ecological catastrophes, or consumerist consumerism. Heidegger is not so much concerned with the contemporary problems caused by the technical-technological progress of industrial capitalism, but rather with the technical modeling of reality that challenges our entire existence to devote itself solely to planning and calculating all of reality: "...man is challenged to determine the being as an inventory of his planning and calculation and to continue indefinitely with this arrangement" [20]. The danger, therefore, according to Heidegger, lies in the reduction and impoverishment of our thinking in the modern technological age! Namely, modern technology demands maximum efficiency: "...to obtain the greatest benefit with the least investment," [21] where by thinking has only an instrumental role [22] in calculating and planning the exploitation of natural resources within the *Technical Model of the World*.

Man is open to technology; he is no longer the one who dominates and exploits nature. In the modern age, man, like all of reality, is a resource to be used [23].

To summarize, the danger, Heidegger writes, lies in the trust in the technical revolution of the atomic age which has: "...been able to so captivate, enchant, and attract man that one day, machinistic thinking could be accepted as the only way of thinking" [24].

Man is a resource

"The exploitation of all materials, including the raw material of man" [25].

Therefore, it is now clear that, according to Heidegger, the civilizational dead-end of the *Technical Model of the World* of industrial capitalism lies in the reduction of thought to its instrumental role of machinations and calculations. Just as the earth and its atmosphere become raw materials within the technological discourse of reality, so too: "...man becomes human material that is determined for predetermined goals" [26]. In other words, man himself becomes: "...mere material and a function of objectification" [27]. Man, with his intellectual potential, no longer hides the fact that he is himself: "...the most important raw material" [28].

The need for human material, like all other resources from Nature, is subject to the same regulation of preparatory arrangement for the sake of maximum economic efficiency. Thus, man also enters the uniformity of the technological age, because only in this way can he cope with what is real: "Already today, a man without a uniform gives the impression of something unreal, something that is unusual and does not belong to this reality" [29].

CONCLUSION

To summarize, within the modern age of technological dominance of the capitalist model of the world, through the objectification of all reality, man as a rational being is, according to Heidegger, himself in growing danger of becoming mere material and a function of objectification. It follows that the dangerous attitude is that technological ubiquity in modern capitalist society brings order to the world, because man's relationship to himself and to everything that exists is threatened by the uniformity of the *Technical Image of the World*, which is dominated by the principle of economic efficiency: "...to obtain the greatest benefit with the least investment."

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4. Dreyfus, Hubert L. (2013). "Heidegger on Acquiring a Free Relation to Technology." *Arhe*, vol. 10, no. 20, pp. 99-104.
5. In accordance with Francis Bacon's famous dictum, "Knowledge is power, power to command nature," we should also understand the fundamental meaning of Western European science, which, in accordance with the imperative of dominating both nature and humans, articulates our relationship to reality: "Science is the way in which everything that exists is presented to us. Therefore, we must say: the reality within which modern man moves and in which he tries to sustain himself is, in its fundamental features, co-determined by what is called Western European science." Martin Heidegger, "Science and Thinking," in Lectures and Conversations, p. 33, Plato, Belgrade 1999.

6. Martin Heidegger, "The Question Concerning Technology" in *Lectures and Conversations*, p. 17, as cited above.
7. Martin Heidegger, "Beyond Metaphysics" in *Lectures and Conversations*, p. 36, as cited above.
8. Martin Heidegger, "The Question Concerning Technology", p. 10 in *Lectures and Conversations*, as cited above.
9. Quote from H.L. Dreyfus, same page 46.
10. Martin Heidegger, "Beyond Metaphysics", as previously mentioned on page 74.
11. It is worth remembering that Karl Marx wrote that the original appropriation of land and natural resources led to the modern formation of capital, calling this phenomenon the primitive accumulation of capital. Hannah Arendt, elaborating on Marx's theory, notes that the primitive accumulation of capital was not a one-time episode in which capitalism was born, but a phase that is cyclically repeated whenever some aspect of the social and natural world is subordinated to market dynamics. Thus, she writes that Marx's: "...original sin of ordinary theft had to be repeated for the engine of capital accumulation not to stall." Hannah Arendt, *The Origins of Totalitarianism*, p. 22, Open Society Fund, Belgrade, 1998.
12. Martin Heidegger, *Being and Time*, pp. 38-39
13. Martin Heidegger, *The Question Concerning Technology*, p. 13.
14. Martin Hajdeger, „*Prevladavanje metafizike*“, u *Mišljenje i pevanje* str.9, Nolit, Beograd 1982
15. Quote from H.L. Dreyfus, ibid., p. 56.
16. Baudrillard argues that social inequality, which was once maintained through economic immobilism, is now reproduced in and through economic growth: "Growth itself is one of the functions of inequality based on technological progress. It is precisely this mechanistic view that encourages the naive illusion of future wealth." Jean Baudrillard, *The Consumer Society*, p. 53, Darma, Belgrade, 2023.
17. Martin Heidegger, "What Are Poets For?", in *Pathmarks*, p. 230, Plato, Belgrade, 2003.
18. Martin Heidegger, *The Question Concerning Technology*, p. 10.
19. Quote taken from H.L. Dreyfus, p. 56.
20. Martin Heidegger, "The Principle of Identity," in *Thinking and Poetry*, p. 51
21. Martin Heidegger, *The Question Concerning Technology*, p. 10.
22. *Max Horkheimer, in his philosophical discourse, highlights that the instrumental use of reason in relation to nature manifests as a drive for unlimited exploitation of nature, and in relation to society as an instrument of domination over people in totalitarian societies, while in democratic societies it leads to a deformation of the very idea of democracy and the loss of individuality.* (Horkheimer, Eclipse of Reason, Svjetlost, Sarajevo, 1989)
23. The unconditional domination of self-consciousness violently preclothes both in a uniformity from which one cannot... escape." Martin Heidegger, "Beyond Metaphysics," in *Thinking and Poetry*, p. 39, Nolit, Belgrade, 1982.
24. Quote taken from H.L. Dreyfus, p. 57.
25. Martin Heidegger, "Beyond Metaphysics," in *Thinking and Poetry*, p. 35.
26. Martin Heidegger, "What Are Poets For?" in *Pathways Through the Forest*, p. 226, Plato, Belgrade, 2000.
27. The same, p. 229
28. Martin Heidegger, "Beyond Metaphysics," in *Lectures and Conversations*, p. 71.
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From Industrial to Surveillance Capitalism

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Abstract. According to the German philosopher Martin Heidegger, modern industrial capitalism establishes the dominance of a uniform model of reality, driven by the principle of economic efficiency, thus post-factually rendering all phenomena of the modern era, as well as man himself, for the purpose of achieving maximum profit. Everything within market capitalism is a commodity, bought and sold. Critically analyzing the contemporary technological age we live in, Shoshana Zuboff argues that we are mere natural resources of human origin for postmodern surveillance capitalism. This unbridled mutation of capitalism, as dangerous to humanity as previous forms of capitalism, with its parasitic logic of producing goods and services, is subordinated to a new global architecture for modifying human behavior and imposing a new global order.

Keywords: capitalism, surveillance capitalism, capital accumulation, human resources

INTRODUCTION

"Don't look down at your feet, but up at the stars." Stephen Hawking

In modern capitalist societies, technology is a reflection of economic goals that direct its operation.

Capitalism has ensured its longevity through its adaptability. It survives, develops, and finds ever new ways to create wealth by satisfying new human needs. The development of capitalism has been marked by the combination of three constitutive principles: private ownership, profit and growth motivation, but it has also adapted its form and norms to each era. Thus, Thomas Piketty writes that: "...there is no single type of capitalism or organization of production... This will certainly be the case in the future. New forms of organization and ownership will yet be invented." Harvard philosopher Roberto Unger, elaborating on Piketty's thought, concludes that market forms can follow countless legal and institutional paths, whereby: "...each of them will have dramatic consequences for every aspect of social life...", and, "...enormous significance for the future of the human race" [2].

Thus, throughout its history, capitalism takes what lives outside the market and turns that life into a commodity. Thus, in addition to Nature, human life is subjected to market dynamics and revived as "labor power" that is bought or sold. Karl Marx called the appropriation of land and natural resources, which led to the modern formation of capital, "primitive accumulation". Hannah Arendt, elaborating on Marx's thesis, wrote that the "primitive accumulation of capital" is cyclically repeated whenever a part of the natural and social world is subordinated to market dynamics."Primitive accumulation of capital", writes Hannah Arendt in her famous work The Origins of Totalitarianism.

Industrial capitalism, as Martin Heidegger has shown, is devastating to nature, and as Stephen Hawking warns us, it could lead to the loss of planet Earth: “Our physical resources are being depleted at an alarming rate. We have given our planet a terrible gift of climate change. Temperatures are rising, polar caps are melting, forests are being cleared, and animal species are being decimated” [3].

Therefore, the capitalist system, driven by a thirst for quick profit and wealth, treats people and the planet Earth: “...as resources to be exploited without remainder or as garbage to be thrown as far away from sight as possible” [4].

Despite the rhetoric of neoliberal theorists who have raised hopes for strengthening freedom and democracy, they have actually contributed to the birth of a market society and a branded world of extreme economic inequality, unimaginable economic exclusions, and new sources of inequality. Thanks to neoliberal market freedoms for the corporate world, at a time when democracy is shaken, a new form of surveillance or information capitalism is born, which, thanks to its instrumental power, threatens to reshape humanity.

Surveillance capitalists, as Shoshana Zuboff has observed, have invented a new commodity fiction taken from the experiential reality of human beings, untouched before entering the market dynamics. Thus, she writes: “Human experience is subordinated to the market mechanisms of surveillance capitalism...” and is reborn as “...behavior...” [5].

Behaviors as commodities, Shoshana Zuboff further explains, are transformed into data and placed on an endless tape where they are processed by machine intelligence and then sold on the market of future behavior. The founders of *Google* realized that human experience on the computer network is completely free and that as a basic material it turns into behavioral data in order to produce behavioral surplus on which a new type of market exchange is based. In fact, in this act of digital disempowerment, a new form of capitalism emerged: surveillance capitalism, born under the auspices of neoliberal market fundamentalism. And so we come to the conclusion that the economic historian Karl Polanyi reached in the first half of the 20th century, that the market dynamics of industrial capitalism will destroy precisely what it buys and sells: “The commodity fiction does not take into account the fact that if the fate of the Earth and people is left to the market, it will mean their destruction” [6].

Do these words now sound prophetic?

Karl Polanyi realized long ago that raw capitalism cannot collapse within itself. Shoshana Zuboff, warning against our despondency, asks us to consider the following: “...if industrial civilization developed at the expense of nature and could now cost us the Earth, information civilization, subject to the dictates of surveillance capitalism, will develop at the expense of human nature and could cost us humanity” [7].

CONCLUSION

If we have the courage to imagine a future in which we do not treat people and nature as consumable goods, we must, according to Naomi Klein, embrace the utopian traditions that have inspired many social movements throughout history. This means having the courage to: “...paint a picture of a different world, a world that, even if it only existed in our minds, can inspire us to fight battles we can win” [8].

For as Oscar Wilde wrote back in 1891:

"A map of the world that does not show Utopia is not worth even glancing at, for Utopia is the only country to which mankind is always landing. And when it lands it looks out and, seeing a still more distant land, sets sail."

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Basic priorities for realizing the vision of sustainable development of companies in Serbia

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Abstract. This paper explores the essential priorities for achieving sustainable development within Serbian companies, emphasizing the importance of understanding local interpretations of sustainability and addressing specific challenges. The paper identifies key barriers, including economic constraints, regulatory complexities, and limited access to advanced technologies. Strategies such as leveraging innovation, improving corporate governance, and fostering public-private partnerships are proposed to enhance sustainability efforts. The role of younger generations and the growing significance of Environmental, Social, and Governance (ESG) criteria are highlighted as driving forces for change. The paper suggests that with the right combination of government support, corporate commitment, and consumer awareness, Serbian companies can successfully integrate sustainability into their operations, thereby improving their long-term competitiveness and contributing to sustainable economic growth in the region.

Keywords: sustainable development, corporate governance, ESG, Serbian companies.

INTRODUCTION

Sustainable development has increasingly become a focal point for companies across the globe, including those in Serbia. As the global economy moves towards more environmentally and socially responsible practices, the pressure on businesses to adopt sustainable strategies has grown. For Serbian companies, realizing the vision of sustainable development involves not only understanding the concept itself but also overcoming significant challenges, adopting effective strategies, and recognizing future opportunities that sustainability can offer. This paper seeks to provide a foundational understanding of these elements, offering insights into the factors that shape the journey toward sustainable business practices in Serbia.

The concept of sustainable development is multifaceted and involves a balance between economic growth, environmental protection, and social responsibility [1]. Sustainable development requires companies to go beyond mere compliance with environmental regulations. It involves integrating sustainability into the core of business operations, ensuring that economic activities contribute positively to society and the environment over the long term. Understanding how Serbian companies perceive and define sustainability is crucial, as it sets the foundation for their approach to integrating sustainable practices. The local interpretation of sustainable development may differ from global norms due to historical, economic, and social factors unique to Serbia, which influences how businesses prioritize and implement sustainability initiatives [2].

Implementing sustainable development strategies is not without its challenges, and Serbian companies face several barriers that can hinder progress in this area. Economic constraints are a significant issue, as many companies operate within tight margins and may lack the financial resources necessary to invest in sustainable technologies or practices. Additionally, regulatory challenges can pose significant obstacles. Furthermore, the lack of technological infrastructure in certain sectors can make it difficult for companies to adopt advanced sustainable practices, such as renewable energy sources or waste reduction technologies. Stakeholder resistance is another critical challenge. In some cases, traditional business practices may be deeply ingrained, and stakeholders, including employees, customers, and investors, may be hesitant to embrace changes that prioritize sustainability over short-term profits. Addressing these challenges requires a comprehensive understanding of the local context and a commitment to long-term planning and investment [3].

Despite these challenges, there are several strategies that Serbian companies can adopt to enhance their sustainability. One approach involves leveraging innovation and technology to drive sustainable practices. For instance, companies can invest in renewable energy, improve energy efficiency, and develop products and services that have a lower environmental impact. Corporate governance also plays a vital role in promoting sustainability. By ensuring that sustainability is a priority at the highest levels of decision-making, companies can create a culture that values and supports sustainable practices. Partnerships and collaborations are another crucial strategy. Companies can work with government bodies, non-governmental organizations (NGOs), and international organizations to access resources, expertise, and support that can help them overcome barriers to sustainability. These collaborations can also help companies align their practices with international standards and best practices, enhancing their competitiveness in the global market [4].

UNDERSTANDING THE CONCEPT, CHALLENGES AND BARRIERS OF SUSTAINABLE DEVELOPMENT IN SERBIAN COMPANIES

In the context of Serbian companies, understanding the concept of sustainable development is crucial for making meaningful progress toward more responsible business practices. Sustainable development is often defined as meeting the needs of the present without compromising the ability of future generations to meet their own needs [5].

Serbian companies are increasingly recognizing the importance of integrating sustainability into their operations, driven by both global trends and local pressures. The awareness of sustainability among Serbian businesses varies, with larger, internationally connected firms often having a more advanced understanding due to their exposure to global markets and standards. These companies may be more familiar with concepts such as corporate social responsibility (CSR), environmental management systems, and sustainability reporting [6]. In contrast, smaller and medium-sized enterprises (SMEs) might still view sustainability primarily in terms of compliance with environmental regulations, rather than as a strategic priority that can drive long-term business success.

Challenges to sustainable development in Serbia are significant and multifaceted, affecting companies across various sectors. Economic constraints are one of the most prominent barriers. Many Serbian companies, particularly SMEs, operate on thin margins and have limited access to capital. This financial pressure makes it difficult for these businesses to invest in sustainable technologies or practices, even when they recognize the potential long-term benefits [7]. Regulatory challenges also present a significant obstacle to sustainable development in Serbia. While the government has introduced various regulations aimed at promoting environmental protection and sustainability, enforcement can be inconsistent. This inconsistency can create an uneven playing field, where companies that invest in compliance may find themselves at a disadvantage compared to those that do not. Furthermore, the regulatory environment in Serbia is often complex and subject to frequent changes, making it difficult for companies to plan long-term sustainability strategies.

Technological infrastructure is another area where Serbian companies face challenges in adopting sustainable development practices. In many sectors, the technology needed to implement advanced sustainability measures is either not available or too expensive. The lack of access to modern technology not only hinders the ability of companies to reduce their environmental impact but also limits their competitiveness in a global market increasingly dominated by sustainable and technologically advanced businesses [8].

Social and cultural factors also contribute to the challenges of sustainable development in Serbia. There can be significant resistance to change within companies, particularly among stakeholders who are accustomed to traditional ways of doing business. This resistance can stem from a lack of awareness or understanding of the benefits of sustainability, as well as concerns about the potential impact on profits and jobs. Additionally, consumers in Serbia may not yet prioritize sustainability in their purchasing decisions to the same extent as consumers in more developed markets, which can reduce the incentive for companies to invest in sustainable products and practices.

Overcoming these challenges requires a comprehensive approach that takes into account the specific context of Serbian companies. Financial incentives, regulatory reforms, and educational initiatives can all play a role in helping businesses overcome the barriers to sustainable development. Simplifying and streamlining the regulatory process could also help companies navigate the complexities of compliance more effectively. Education and awareness-raising efforts, both within companies and among the general public, can help shift attitudes towards sustainability and encourage more widespread adoption of sustainable practices [9].

STRATEGIES, FUTURE PROSPECTS AND OPPORTUNITIES FOR SUSTAINABLE DEVELOPMENT IN SERBIAN BUSINESSES

As Serbian companies grapple with the challenges of implementing sustainable development, they must also consider the strategies that can effectively integrate sustainability into their operations. These strategies are essential for overcoming existing barriers and ensuring that sustainable practices are not only adopted but also embedded within the core of business operations. One of the most effective approaches involves leveraging innovation and technology to drive sustainability. Serbian companies can look to global examples of how technological advancements have facilitated sustainable business practices, adapting these lessons to fit the local context. Investment in renewable energy sources, such as solar and wind power, can reduce a company's carbon footprint and provide long-term cost savings. Energy efficiency measures, such as upgrading machinery and optimizing production processes, not only reduce energy consumption but also enhance operational efficiency, leading to improved profitability [2].

Collaboration with external partners is also a key strategy for enhancing corporate sustainability in Serbia. Companies can work with government bodies to access financial incentives, technical assistance, and regulatory support that can facilitate the adoption of sustainable practices. Partnerships with non-governmental organizations (NGOs) and international organizations can provide companies with access to expertise, resources, and networks that can help them overcome barriers to sustainability. For example, collaborating with NGOs that specialize in environmental protection or social responsibility can help companies develop more effective sustainability initiatives [10].

Looking to the future, the prospects for sustainable development in Serbian companies are promising, particularly as global and local trends continue to push businesses toward more responsible practices. One of the most significant drivers of this shift is the increasing importance of Environmental, Social, and Governance (ESG) criteria. ESG factors are becoming increasingly important to investors, who are looking for companies that demonstrate a commitment to sustainability and responsible business practices. As a result, companies that prioritize ESG are likely to attract more investment, both from domestic and international sources. This trend is likely to continue as investors and consumers alike place greater emphasis on corporate responsibility, making ESG a critical component of business strategy for companies in Serbia [11].

The role of younger generations in driving sustainability within Serbian companies cannot be underestimated. As younger individuals enter the workforce and assume leadership positions, they bring with them a heightened awareness of environmental and social issues, as well as a strong commitment to sustainability. This generational shift is expected to lead to significant changes in how companies approach sustainability, with a greater emphasis on innovation, transparency, and long-term thinking. Younger employees and managers are likely to push for more ambitious sustainability goals, as well as for the adoption of new technologies and practices that can help companies achieve these goals. This shift in mindset will be crucial for ensuring that sustainability becomes an integral part of corporate culture in Serbia, rather than a peripheral concern [12].

By adopting innovative strategies, improving corporate governance, and embracing the opportunities presented by global sustainability trends, Serbian companies can not only overcome the barriers they face but also position themselves as leaders in the transition to a more sustainable economy. This will require a commitment to continuous improvement and a willingness to adapt to changing conditions, but the rewards, in terms of both economic performance and social responsibility, are likely to be well worth the effort.

SUGGESTIONS AND GUIDELINES

Based on the analyzed and presented theory, the following guidelines and recommendations for companies in Serbia were given:

- **Government incentives for sustainable investments**: The government should provide tax breaks, grants, and low-interest loans to encourage companies to invest in sustainable technologies and practices. These financial incentives can reduce the upfront costs of adopting renewable energy, improving energy efficiency, and implementing waste reduction systems.
- **Public-Private Partnerships**: Governments and companies should collaborate through public-private partnerships to develop and implement large-scale sustainability projects, such as renewable energy infrastructure and waste management systems. These partnerships can pool resources and expertise, making it easier to overcome financial and technological barriers.
- **Employee training and education**: Enterprises should invest in training programs that educate employees about the importance of sustainability and how they can contribute to sustainable practices within the company. Empowering employees with knowledge can lead to more innovative solutions and a stronger commitment to sustainability across the organization.
- **Consumer awareness campaigns**: Both government and businesses should run campaigns to raise consumer awareness about the importance of sustainability and the impact of their purchasing decisions. Educated consumers are more likely to support companies that prioritize sustainability, creating a market incentive for businesses to adopt sustainable practices.
- **Access to green technologies**: The government and industry associations should work together to make green technologies more accessible to Serbian companies, particularly SMEs. This could involve subsidies for green technology purchases or creating technology sharing platforms that allow smaller companies to benefit from advanced sustainable technologies.
- **Youth engagement in sustainability**: Companies and educational institutions should engage young people in sustainability initiatives through internships, workshops, and innovation challenges. Involving the younger generation can drive cultural change within companies and introduce fresh, sustainability-focused perspectives.
- **Transparent sustainability reporting**: Enterprises should adopt transparent sustainability reporting practices to communicate their progress and challenges in implementing sustainable practices. This transparency can build trust with stakeholders and encourage a culture of accountability within the company.

CONCLUSION

The pursuit of sustainable development within Serbian companies is a complex and multifaceted endeavor that requires a concerted effort from various stakeholders. Understanding the specific context in which Serbian businesses operate is essential, as it shapes the ways in which sustainability is perceived and implemented. Through a combination of innovative strategies, improved corporate governance, and effective collaborations, Serbian companies can begin to integrate sustainability into their core operations more effectively. Government support, in the form of financial incentives, regulatory reforms, and public-private partnerships, is critical to overcoming the barriers to sustainable development. Simplifying regulatory processes and making green technologies more accessible can significantly reduce the costs and complexities associated with adopting sustainable practices. Additionally, raising awareness among consumers and fostering a culture of sustainability within companies through education and training are essential for creating a business environment where sustainability is not just an option, but a necessity. The path forward for Serbian companies lies in their ability to adapt to these emerging trends and challenges. By embracing sustainability as a core component of their business strategy, companies can not only meet the growing demands of investors, consumers, and regulators but also contribute to the broader goal of sustainable economic development in Serbia. The integration of sustainability into the fabric of Serbian business practices offers a pathway to long-term growth, competitiveness, and resilience in an increasingly sustainability-focused global economy.

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Supply Chain Management in the Age of Climate Change: Challenges and Opportunities for Sustainable Practices

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Abstract. Climate change presents significant challenges for global supply chains, necessitating a shift toward more sustainable and resilient practices. This paper explores the impact of climate-related disruptions on supply chains, emphasizing the importance of vulnerability assessments and risk mitigation strategies. Sustainable supply chain practices, including the integration of renewable energy, circular economy initiatives, and enhanced stakeholder collaboration, are highlighted as critical responses to these challenges. The role of government policies, such as carbon pricing and environmental reporting mandates, is examined in supporting the transition to sustainability. Additionally, the importance of international cooperation and global standards in ensuring consistent and effective sustainability efforts is discussed. The research underscores the collective responsibility of governments, businesses, and individuals in driving the adoption of sustainable practices to ensure the long-term resilience and efficiency of supply chains in the face of climate change.

Keywords: climate change, sustainable supply chains, risk mitigation, renewable energy, circular economy

INTRODUCTION

Climate change has emerged as a defining challenge of the 21st century, profoundly influencing various sectors, including supply chain management. As global temperatures rise and weather patterns become increasingly unpredictable, the traditional frameworks that underpin supply chains are being tested in unprecedented ways. Businesses that once operated with a focus on efficiency and cost minimization now find themselves grappling with disruptions that are both frequent and severe [1]. These disruptions, often caused by extreme weather events, have highlighted the vulnerabilities inherent in global supply chains, forcing companies to rethink their strategies and priorities. The impact of climate change on supply chains is multifaceted, encompassing not only physical disruptions but also changes in resource availability and labor productivity. As a result, the need to assess and mitigate these vulnerabilities has become an important aspect of modern supply chain management.

In response to these challenges, there has been a growing movement towards the adoption of sustainable practices within supply chains. Sustainable supply chain practices represent a significant shift from traditional models, emphasizing the importance of reducing environmental impact and promoting resource efficiency. Innovations in this area include the increased use of renewable energy, the incorporation of eco-friendly materials, and the implementation of circular economy principles, where products and materials are reused and recycled to minimize waste.

While the benefits of sustainable supply chains are clear, the path to achieving them is fraught with challenges. One of the primary obstacles is the high upfront costs associated with adopting new technologies and processes. Many companies, particularly small and medium-sized enterprises, struggle to justify these investments, especially when the return on investment is not immediately apparent. Additionally, the complexity of overhauling existing supply chain processes can be daunting.

The role of policy and regulation in promoting sustainable supply chains cannot be overstated. Governments and international organizations play a key role in setting the standards and frameworks that guide corporate behavior. Policies such as carbon pricing and emissions trading systems create financial incentives for companies to reduce their carbon footprint, while environmental reporting requirements increase transparency and accountability. Public-private partnerships are also emerging as a vital tool in promoting sustainability, as they bring together the resources and expertise of both sectors to drive innovation and investment. These partnerships can help bridge the gap between short-term business goals and long-term sustainability objectives, providing the support needed to make sustainable supply chains a reality [2].

The transformation of supply chains in the age of climate change presents both challenges and opportunities. While the road to sustainability is complex and fraught with obstacles, the potential benefits for businesses and the environment are substantial. Companies that successfully navigate these challenges will not only improve their resilience to climate-related disruptions but also position themselves as leaders in the growing market for sustainable products and services [3]. At the same time, the role of policy and regulation will be essential in creating the conditions necessary for widespread adoption of sustainable practices, ensuring that the global response to climate change is both effective and equitable.

CLIMATE CHANGE AND SUSTAINABLE PRACTICES: INNOVATIONS AND IMPACTS ON GLOBAL SUPPLY CHAINS

The pressures of climate change are significantly reshaping global supply chains, leading to disruptions that challenge traditional business models. As extreme weather events like hurricanes, floods, and droughts become more frequent, supply chains face unpredictable disruptions that expose their vulnerabilities. Industries dependent on just-in-time delivery systems are particularly at risk, as these systems are poorly equipped to handle such uncertainties [4]. The physical impacts of climate change, including fluctuating crop yields and threatened coastal infrastructure, further complicate supply chain operations, with disruptions in one region potentially causing ripple effects across the globe.

Addressing these challenges requires a fundamental shift in supply chain strategies. Businesses must integrate climate risk into their decision-making processes, conduct thorough risk assessments, and develop strategies to mitigate these vulnerabilities.

Diversifying suppliers, investing in resilient infrastructure, and leveraging advanced analytics are key steps in adapting to climate-related risks. Concurrently, there is a growing push towards sustainable supply chain practices, driven by the need to reduce environmental impact and meet consumer demand for eco-friendly products [5].

The transition to sustainable supply chains involves adopting renewable energy, exploring eco-friendly materials, and embracing circular economy principles that emphasize reuse and recycling [6]. While these changes require significant investment and a cultural shift, they are essential for ensuring long-term business resilience. Advanced technologies like blockchain also play a crucial role by enhancing transparency and traceability in the supply chain, allowing businesses to verify and maintain sustainable practices at every stage. As climate change continues to influence global markets, the shift towards sustainable supply chains will be vital for companies to remain competitive and socially responsible.

OVERCOMING CHALLENGES AND LEVERAGING POLICY IN THE TRANSITION TO SUSTAINABLE SUPPLY CHAINS

The transition to sustainable supply chains, while increasingly urgent, presents significant challenges that companies must navigate to achieve their sustainability goals. One of the primary hurdles is the financial cost associated with adopting new technologies, such as renewable energy infrastructure and advanced recycling systems, which require substantial upfront investment. Small and medium-sized enterprises (SMEs) often find these costs prohibitive, particularly when the return on investment is not immediately visible, making long-term sustainability difficult in a business environment driven by short-term financial goals [7].

Beyond financial constraints, companies face the complexity of overhauling established supply chain processes. Transitioning to sustainable practices often involves reconfiguring entire supply chains, from sourcing and production to logistics, which can be especially daunting for large multinational corporations. Stakeholder resistance further complicates this transition, as investors, suppliers, and customers may prioritize short-term profitability over long-term sustainability, requiring companies to clearly demonstrate the economic benefits of sustainable practices to gain support [8].

Regulatory challenges also play a significant role, as variations in environmental laws across regions create compliance difficulties. Effective government policies are crucial in promoting sustainable supply chains, providing financial incentives, setting clear regulatory standards, and fostering public-private partnerships [9]. International cooperation is equally important, as global standards help ensure consistent sustainability efforts and prevent companies from relocating to regions with less stringent regulations. Collaborative efforts between businesses, governments, and international organizations are essential in overcoming these challenges and achieving sustainable supply chains [10].

THEORETICAL MODEL

After analyzing the existing body of literature, a theoretical model for improving sustainable practices in supply chain management.

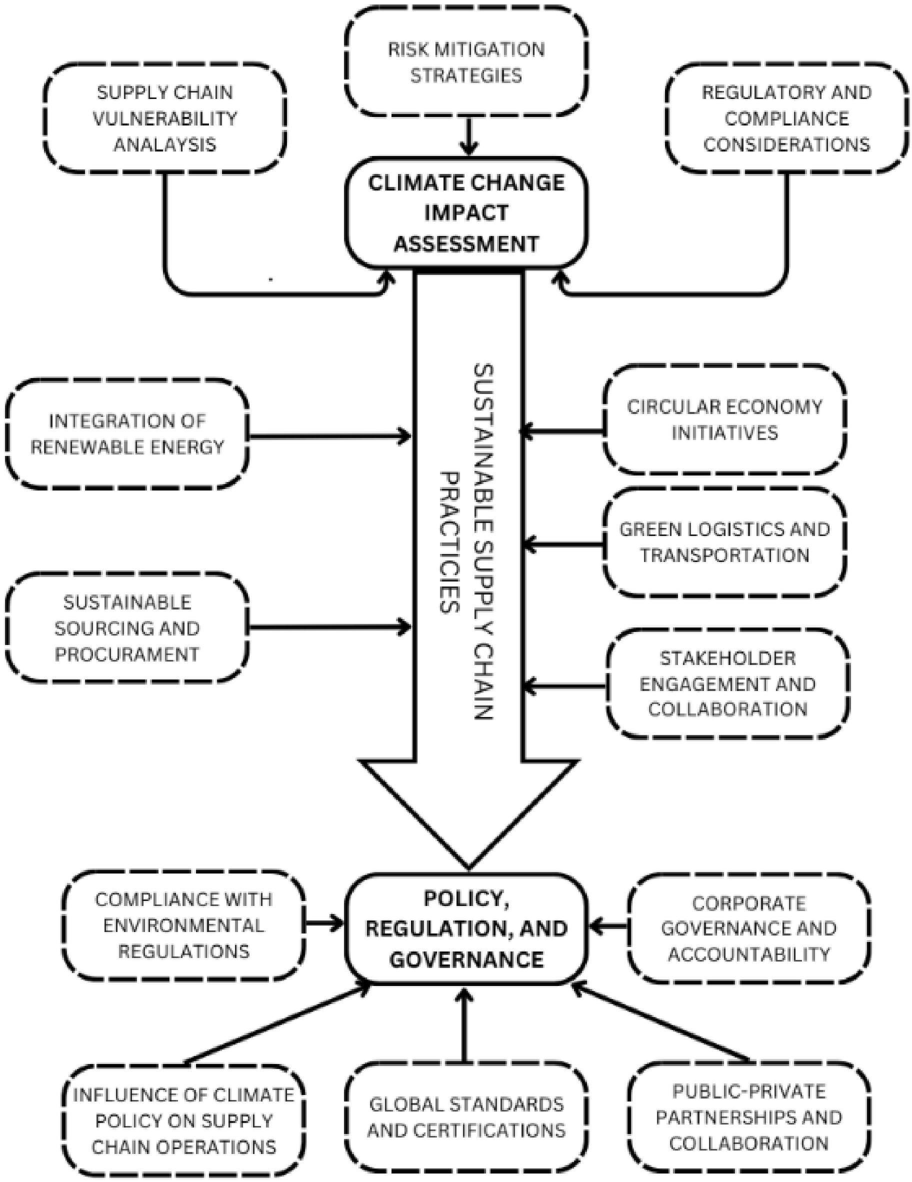

Figure 1. theoretical model for improving sustainable practices in supply chain management.

The relationship between climate change impact assessment and sustainable supply chain practices is deeply interconnected. Effective climate risk assessments guide the development of strategies to enhance supply chain sustainability. For instance, identifying areas prone to extreme weather informs decisions like diversifying suppliers or investing in resilient infrastructure. These actions align with sustainable sourcing and procurement practices, ensuring that supply chains can withstand climate impacts while maintaining environmental and social responsibilities.

Risk mitigation strategies are essential to sustainable supply chain practices. Companies that develop these strategies can better implement renewable energy, adopt circular economy initiatives, and optimize logistics to reduce environmental impact. For example, recognizing energy supply risks may lead a company to invest in renewable energy, reducing carbon footprints and securing reliable power sources. Similarly, risk mitigation can drive the adoption of green logistics practices, like electric vehicles, which reduce emissions and increase supply chain resilience to regulatory changes.

Regulatory and compliance considerations significantly influence supply chain governance and sustainability. Companies that proactively comply with environmental regulations are better positioned to navigate climate policies and international standards. Compliance often requires adopting sustainable practices, such as reducing emissions or optimizing logistics. For instance, a company in a region with strict carbon pricing might invest in renewable energy to align with regulatory requirements and sustainability goals. Compliance also encourages engagement in public-private partnerships and global certifications, furthering overall sustainability.

Sustainable sourcing and procurement are directly influenced by climate policy and regulation. Companies motivated by regulatory compliance and climate risk mitigation may prioritize suppliers with strong sustainability credentials. This approach ensures adherence to environmental and social criteria, supporting broader sustainability strategies that align with global standards and certifications.

The integration of renewable energy into supply chain operations is shaped by both risk mitigation strategies and regulatory environments. Companies recognizing energy supply risks are more likely to invest in renewable energy, often supported by government incentives. For instance, installing solar panels may be subsidized, reducing the financial burden of transitioning to cleaner energy sources. These actions help companies meet environmental regulations and reinforce the link between sustainability and compliance.

The circular economy is linked to climate impact assessment and governance. Circular economy initiatives, focusing on waste reduction and extending material lifecycles, address environmental impacts identified in climate assessments. Companies adopting these principles mitigate environmental risks and align with global standards promoting sustainable resource management. Governance structures ensure these practices are integrated into strategies, with progress regularly monitored and reported to stakeholders.

Stakeholder engagement is also influenced by policy, regulations, and climate assessments. Companies in regions with strict environmental laws may engage with stakeholders, including government agencies and NGOs, to ensure compliance and support sustainability initiatives. This collaboration enhances supply chain sustainability, strengthens relationships, and contributes to overall resilience and long-term success.

SUGGESTIONS AND GUIDELINES

The developed model provided insights based on which suggestions and guidelines for improving sustainable practices in supply chain management are highlighted:

- Implement and enforce carbon pricing mechanisms: Governments should establish carbon taxes or cap-and-trade systems to incentivize businesses to reduce their greenhouse gas emissions. These mechanisms will make it more costly for companies to pollute, encouraging the adoption of cleaner technologies and practices.

- Promote public-private partnerships for sustainable infrastructure: Governments can collaborate with private enterprises to develop resilient infrastructure, such as flood-resistant warehouses and renewable energy systems. These partnerships can provide funding, technical expertise, and regulatory support, ensuring that critical supply chain infrastructure is built to withstand climate impacts.
- Provide financial incentives for sustainable practices: Offering tax breaks, grants, or subsidies for companies that invest in renewable energy, circular economy initiatives, or green logistics can reduce the financial burden of these investments. This support will encourage more businesses to adopt sustainable practices, contributing to broader environmental goals.
- Conduct comprehensive climate risk assessments: Companies should regularly assess their supply chains for vulnerabilities related to climate change, such as extreme weather risks or resource scarcity. These assessments will inform strategies to mitigate risks, such as diversifying suppliers or investing in resilient infrastructure.
- Adopt circular economy principles: Companies should design products for longevity, recyclability, and reusability, minimizing waste throughout the supply chain. Implementing closed-loop systems where materials are continuously reused will reduce resource consumption and lower environmental impact.
- Align with global sustainability standards and certifications: Businesses should pursue certifications like ISO 14001 or Fair Trade to demonstrate their commitment to sustainable practices. Aligning with these standards will help companies meet regulatory requirements, enhance their market reputation, and attract environmentally conscious consumers.

CONCLUSION

The challenges of climate change are transforming supply chain management, requiring a shift toward resilience and sustainability. Disruptions from extreme weather, resource scarcity, and regulatory changes highlight the need for businesses to assess and mitigate climate-related risks. Proactive companies that integrate renewable energy, adopt circular economy principles, and enhance stakeholder collaboration are better positioned to ensure continuity and sustainability. These strategies not only reduce environmental impact but also build supply chains capable of withstanding climate effects.

Government policies like carbon pricing, environmental reporting mandates, and public-private partnerships are essential in supporting these efforts. International cooperation and global standards help ensure consistent sustainability practices, preventing regulatory arbitrage. Individuals also contribute by supporting sustainable businesses and advocating for stronger environmental policies. As climate change continues to impact supply chains, coordinated efforts across governments, businesses, and individuals will drive the transition to a more sustainable and resilient future, opening up opportunities for innovation and growth.

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Investigation of the Impact of Mobile Applications on Awareness of Environmental Issues

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Abstract. This paper investigates the impact of mobile applications on raising awareness of environmental issues and promoting sustainable behaviors among users. Mobile applications have proven to be powerful tools for public education and engagement. Four specific applications were analyzed: Earth Hero, Oroeco, WWF Together, and gReact. Through gamification, personalized feedback, and access to real data, these apps not only inform users about environmental issues but also motivate them to take concrete steps toward reducing their environmental footprint. Research results indicate that mobile applications significantly contribute to increasing knowledge and awareness of environmental issues, as well as changing user behavior.

Keywords: mobile applications, user interaction, environmental education, digital engagement, ecological impact

INTRODUCTION AND OVERVIEW OF MOBILE APPLICATIONS IN ENVIRONMENTAL AWARENESS

Global warming, commonly known as climate change, is a critical consequence of pollution, causing a gradual rise in the Earth's temperature, including its atmosphere, oceans, and glaciers. This temperature increase has reached alarming levels worldwide, with significant implications for global ecosystems and human health. The expansion of industrial activities and economic growth has led to environmental risks such as greenhouse gas emissions, inadequate waste management, and widespread pollution of air, water, and soil [1]. These environmental challenges have both immediate and long-term effects on public health, particularly in developing countries where pollution-related illnesses and fatalities are becoming increasingly prevalent [2].

Environmental awareness, which involves understanding and responding to the impact of human activities on the environment, is crucial for fostering sustainable practices. This includes adopting eco-friendly behaviors such as using sustainable materials, conserving resources, and engaging in recycling and advocacy [3]. In recent decades, there has been a global push towards enhancing environmental awareness, driven by advancements in digital technology that facilitate the dissemination of environmental knowledge. Information and communication technologies (ICT) have emerged as vital tools for global knowledge exchange, allowing individuals to access and share environmental information more easily

[4]. One of the key challenges facing digital platforms and mobile applications is delivering relevant and personalized information that resonates with users [5].

Technological innovations have introduced powerful tools that significantly improve our quality of life. In the digital age, the use of computers and applications has become ubiquitous, with mobile applications emerging as a particularly dynamic and impactful sector. Mobile technology's global reach and increasing accessibility have made it a powerful medium for environmental education. These applications, which run on portable devices, offer a range of features designed to engage users and promote environmental stewardship [6].

Recent advancements in mobile technology, including enhanced computational power, improved bandwidth, and reduced costs, have expanded the potential applications for educational purposes. For instance, over 113 billion applications were downloaded from the Google Play Store in 2023, highlighting their widespread use and influence. Mobile applications hold significant promise for educational purposes, particularly in raising awareness and understanding of environmental issues. However, challenges such as ensuring equitable access, maintaining user engagement, and verifying data accuracy must be addressed to maximize their effectiveness. Future developments in mobile applications are likely to offer new opportunities for advancing environmental education and fostering a more informed and proactive global citizenry [7].case studies of selected mobile applications

In recent years, mobile applications have emerged as powerful tools for promoting environmental awareness and encouraging sustainable behaviors. These applications leverage the widespread use of smartphones to reach a broad audience, providing users with accessible, interactive, and personalized ways to engage with environmental issues. As the environmental challenges facing our planet become more urgent, the role of technology in educating and mobilizing the public has gained increasing attention. Mobile applications, in particular, offer a unique platform to not only inform users but also inspire action by integrating real-time data, generated content by users, and community-driven initiatives.

EARTH HERO APPLICATION OVERVIEW

Earth Hero is designed as a tool to empower individuals to take meaningful actions against climate change. The application targets environmentally conscious users who are looking for ways to reduce their carbon footprint. Its main features include a personalized action plan based on the user's location, lifestyle, and carbon footprint. Earth Hero provides users with specific actions they can take, such as reducing energy consumption, opting for sustainable transport, and making eco-friendly purchasing decisions. It also includes a community feature, where users can share their progress and encourage others to join the cause. Earth Hero stands out for its ability to translate complex climate data into simple, actionable steps that users can integrate into their daily lives. By focusing on individual actions, the application helps users feel empowered to contribute to global climate goals. The application’s impact is twofold: it educates users about the severity of climate change through clear, accessible information, and it motivates them to take measurable steps to mitigate their carbon footprint. Earth Hero’s success is evident in the way it increases user engagement with environmental issues, fostering a sense of community and sharing [9].

OROECO APPLICATION OVERVIEW

Oroeco is an app that allows users to track their carbon emissions and provides personalized recommendations for reducing their environmental impact. The app integrates financial data with environmental impact metrics, showing users how their spending habits contribute to their carbon footprint. It provides detailed analytics on how different lifestyle choices, such as transportation, energy use, and diet, affect the environment. Oroeco's features are tailored to those who want to make informed decisions about their lifestyle and finances in the context of sustainability. Oroeco's strength lies in its ability to connect personal finance with environmental impact, making the abstract concept of carbon emissions more tangible for users. The app effectively raises awareness by showing users the direct consequences of their financial choices on the environment. Its personalized tips are designed to guide users toward more sustainable habits, promoting behavior change over time. Studies and user feedback indicate that Oroeco is particularly effective in helping users understand the broader implications of their daily decisions, making it a powerful tool for environmental education and awareness [10,11].

WWF TOGETHER APPLICATION OVERVIEW

WWF Together is an educational app developed by the World Wildlife Fund (WWF) that focuses on endangered species and conservation efforts. The app uses a combination of interactive storytelling, stunning visuals, and engaging activities to educate users about the importance of biodiversity and wildlife conservation. It features in-depth profiles of various endangered species, highlighting the challenges they face and the efforts being made to protect them. The app is designed for a broad audience, including children, educators, and anyone interested in conservation. WWF Together excels in engaging users through its immersive and visually appealing content. The app's storytelling approach makes complex conservation issues accessible and compelling, fostering a deep emotional connection between users and the species featured. This emotional engagement is crucial for raising awareness and inspiring action. By allowing users to interact with the content, WWF Together not only educates but also encourages users to participate in conservation efforts, whether through donations, advocacy, or lifestyle changes. The app's ability to blend education with engagement has made it a valuable tool for increasing awareness about endangered species and the importance of conservation [12].

GREACT APPLICATION OVERVIEW

gReact is a mobile application designed to engage users in environmental monitoring by allowing them to report environmental hazards and issues directly from their smartphones. The app targets both environmentally conscious individuals and local communities interested in actively participating in environmental protection. gReact features a user-friendly interface where users can report incidents such as illegal dumping, pollution, and deforestation. It also includes a tracking system that enables users to monitor the resolution of reported issues. The impact of gReact lies in its community-driven approach to environmental protection. By empowering users to report environmental issues, the app fosters greater public involvement in environmental monitoring. This not only raises awareness but also pressures authorities and organizations to take action on reported issues.

gReact's effectiveness is demonstrated through its ability to mobilize community action and create a direct link between citizens and environmental authorities. The app's real-time reporting and tracking features significantly enhance the visibility of environmental problems, contributing to more timely and effective interventions.

ANALYSIS OF THE IMPACT ON ENVIRONMENTAL AWARENESS

The selected mobile applications—Earth Hero, Oroeco, WWF Together, and gReact—engage users through intuitive design, relevant content, and interactive features. These apps employ gamification, personalized feedback, and real-time data to create an immersive learning experience. For instance, Earth Hero provides users with actionable steps to reduce their carbon footprint, while Oroeco tracks personal carbon emissions and suggests sustainability tips tailored to individual behaviors. WWF Together uses storytelling and interactive elements to educate users about endangered species, fostering a deeper connection with environmental issues. Through these engagement strategies, the apps effectively contribute to learning outcomes by increasing users' knowledge of environmental problems and enhancing their awareness. Integrating educational content with interactive features ensures that users are not just passive recipients of information but active participants in the learning process. Studies on similar apps indicate that users who interact with these tools are more likely to retain information and exhibit higher levels of environmental consciousness. The behavioral impact of these mobile applications is evident in their ability to motivate users to adopt more sustainable practices. Earth Hero, for example, encourages users to set and achieve sustainability goals, resulting in tangible behavior changes such as reduced energy consumption or increased recycling efforts. Oroeco's personalized feedback mechanism helps users understand the consequences of their actions, leading to more informed decision-making. Available data and user reports suggest that these apps have a positive influence on behavior. For instance, users of gReact have reported increased participation in local environmental initiatives.

CONCLUSION

The conclusion of this research highlights the key role of mobile applications in educating and engaging users on environmental issues. The analyzed applications showed that through interactive and personalized approaches, they can significantly increase awareness of environmental problems and encourage users to take specific actions. These apps not only inform but also inspire users to become active participants in the fight against climate change. Considering these findings, further integration of technology into educational strategies is recommended, as well as the development of new applications that will further empower users in their efforts toward sustainability. Future research should focus on the long-term effects of using these applications on user behavior and on the possibilities of improving their functionalities to achieve even greater efficiency in raising awareness of environmental issues.

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E-learning Platforms for Education in Environmental Physics

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Abstract. In modern education, e-learning is an innovative approach that uses information and communication technology (ICT) to improve the learning process. This paper explores the application of e-learning in the field of environmental physics, emphasizing the importance of interactive platforms that allow students to access educational content flexibly. Through the analysis of different forms of e-learning, such as synchronous and asynchronous forms, the paper indicates the advantages that these platforms bring to education, including increased accessibility, personalization of learning, and the possibility of independent progress. Also, the challenges faced by teachers and students when implementing these technologies are discussed. The goal of this research is to provide insight into the effectiveness of e-learning in understanding and studying the interactions between organisms and their natural environment.

Keywords: e-learning, education, environmental physics, platforms, interactive resources

INTRODUCTION TO E-LEARNING AND ENVIRONMENTAL PHYSICS

E-learning, or electronic learning, is a type of education in which any user who has access to a computer and the Internet can access some e-learning content. In the word e-learning, the letter e stands for technology, while learning means education, which is the definition of e-learning, but with the use of information and communications technology (ICT, Information and communications technology). Electronic learning refers to any form of learning, that is, education that uses computer technology. Today, most teachers and professors use some form of e-learning to teach students in schools [1].

Also, e-learning can be classified into two categories: synchronous and asynchronous. Activities in e-learning can be performed synchronously, ie (at the same time or within a shorter time interval) and asynchronously (at different times, ie without defined target time intervals). Synchronous activities include video conferencing, electronic chat, simultaneous messaging, whiteboards, and screen sharing. In synchronous activities, all participants should participate at the same time. Asynchronous activities allow participants to realize them at a time of their choosing. Time-limited use of e-mail, forums, and documents posted on the web, as well as quizzes and tests whose scoring is automated, are types of asynchronous activities [1].

Physics has always been concerned with understanding the natural environment, and in the beginning, it was often called natural philosophy. Environmental physics is the measurement and analysis of interactions between organisms and their natural environment. To develop successfully, organisms must adapt to the state of their environment. Some microbes can grow at temperatures between -6 and 120 ◦C (degrees Celsius), and when dried, can survive as low as -272 ◦C. On the other hand, higher life forms have adapted to a relatively narrow range of environments by developing sensitive physiological stimuli. When the environment changes, for example, due to natural variation or human activity, organisms may or may not have sufficiently flexible reasons to survive [2].

To understand and investigate the relationships between organisms and their environment, a biologist needs to be familiar with the main concepts of the environmental sciences. He must look for connections between physiology, biochemistry, and molecular biology on the one hand; and atmospheric sciences, soil sciences, and hydrology on the other. One of these connections is precisely the physics of the environment [2].

Traditionally, the educational process in the higher education system includes lectures, exercises, seminars, etc. In the process of studying the subject of environmental physics, the consideration of theoretical material takes place in lectures, and the consolidation of material, teaching methods of solving physical tasks, and setting up and performing experiments take place during laboratory exercises. The teaching of studying the subject of environmental physics is connected with various types of educational work. Experience shows that the success of quality understanding of each topic depends on creating conditions in which the student is an active participant in the educational process. In this sense, the implementation of a combined form of education that integrates traditional regular modules and remote online forms of education opens up special opportunities [3].

OVERVIEW OF E-LEARNING PLATFORMS

In accordance with e-learning, so-called e-learning platforms were also developed. The platforms themselves are, in fact, websites that offer numerous services with which it is possible to realize high-quality online teaching. With these platforms, teachers can create exercises for students to do, and then send multiple materials to students, be it video, audio, text, or any other type of file. Platforms enable communication between teachers and students, but mutual communication between students is also possible. One of the characteristics by which e-platforms differ from each other is manifested through the performance of e-platforms itself. Although there are platforms for which you need to pay a certain amount of money to be able to access them, the most used ones are free [4].

E-learning platforms have an important role, which is to improve knowledge more easily. They enable pupils and students, as well as teachers and professors, to work simpler and faster and to better cooperate for the benefit of mutual progress. Pupils and students can more easily follow their schedules and notifications, but most important of all is the fact that all their teaching materials are in one place. The most famous platforms used in school and higher education for e-learning are Merlin, Loomen, Atutor, WizIQ and Moodle, Dokeos, Docebo, Interact, Blackboard, etc. [1].

EXISTING PLATFORMS

Considering the type, method, and intensity of ICT use, different forms of e-learning find their application in physics teaching. With the increasing availability of computer technologies and the desire for distance from the traditional approach to teaching in educational institutions, computer presentations began to be applied. Teachers use them to supplement and facilitate the monitoring of their presentations, and students to present their work [5].

ICT in education offers various platforms for learning and learning support. An example is the computer platform Arduino, which, in cooperation with available sensors (e.g. temperature or humidity sensor), forms an experimental setup for measuring various physical quantities. In this way, it is possible to connect teaching content and knowledge from physics, electronics, and other similar fields to develop students' STEM competencies. Like similar platforms, Arduino encourages students' motivation and interest in performing physics experiments more innovatively, but compared to other microcontroller platforms, it is cheaper and easier to use.

OPEN SOURCE SYSTEM ATUTOR

ATutor is a free and open-source learning management system designed to adapt educational offerings and increase access to education. Administrators can simply install it and access upgrades as needed. ATutor supports the SCORM 1.24 standard. The main advantages of this tool are compatibility with the SCORM 1.2 format, which is important for exchange rates, speed, availability, and easy installation and maintenance. This system was developed by the University of Toronto [6].

KHAN ACADEMY – PHYSICS SECTION

Khan Academy is a widely recognized e-learning platform that provides free educational resources, including physics courses. What stands out about their physics courses is their accessibility and interactivity, which makes them suitable for different levels of knowledge. On this platform, students can learn through video lessons that explain in detail basic physics concepts like kinematics, dynamics, thermodynamics, electricity, and magnetism, as well as optics and more advanced topics like quantum physics [7].

One of the most important advantages of Khan Academy is that it allows each user to learn at their own pace. In addition to video lessons, the platform offers quizzes and exercises that help test knowledge and ensure that students thoroughly master the material before moving on to more complex topics. In addition, the platform provides personalized recommendations based on the student's progress, which further facilitates the learning process and adapts it to individual needs.

OPEN COURSE WARE (OCW)

OpenCourseWare (OCW) is an initiative launched by prestigious universities such as MIT, allowing free access to educational materials. This platform offers a wide range of courses in different fields, including physics. Physics courses at OCW cover basic and advanced topics, from classical mechanics to quantum physics, thermodynamics, and electromagnetism.

One of the biggest advantages of OCW is that students have access to the same materials used in lectures at MIT, including lecture videos, scripts, assignments, and quizzes with solutions [8]. This allows students to follow at their own pace and use these resources to supplement their regular studies. In addition, OCW is an excellent resource for those who wish to improve their knowledge of physics or prepare for more advanced studies.

ADVANTAGES, DISADVANTAGES, AND OPPORTUNITIES

Among the main advantages of e-learning platforms in comparison to offline teaching, is the possibility of attending classes for a large number of students without the possibility that the rest of the students will interfere with the teaching in any way stands out. Considering that each student follows the lesson independently and solves the attached tasks, the other students do not have mutual contact, and thus less time is wasted, so the students can better concentrate on the assigned material. Namely, students follow classes from home and therefore do not need to travel to the place where classes are held. Thus, they save the time needed for eventual trips to school, and they do not need to spend money on transportation.

CONCLUSION

E-learning has proven to be a key tool in the modernization of the educational system, especially in the field of environmental physics. By using different platforms, students can learn in the way that suits them best, which contributes to their motivation and engagement. Advantages such as flexibility, accessibility, and the ability to adapt content to the individual needs of students make e-learning extremely useful. However, it is important to note that there are also challenges, such as technical equipment and the need for teacher training.

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Exploring Technology's Role in Physics Education

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Abstract. In modern society, environmental education plays a key role in forming environmental awareness and culture. This paper explores the role of technology in physics education, focusing on the application of digital tools, simulations, and interactive applications. The development of technology allows students to better understand complex concepts through practical examples and visualizations. Using educational software such as GeoGebra, students can interactively explore physical phenomena, which contributes to their active learning and development of critical thinking. This paper highlights the importance of integrating technology into education to improve learning efficiency and foster environmental innovation.

Keywords: technology integration, education, environmental physics, digital tools, interactive learning

INTRODUCTION

In the formation of the ecological culture of modern man, an important role is played by the system of ecological education and upbringing. Ecological education represents the understanding of the problem of general greening of the material and spiritual activities of society. The wide range of environmental education enables the necessary synthesis of knowledge, skills, and habits from the natural and social sciences. The educational process in the function of protecting and improving the environment represents the conscious and planned development of knowledge about the human environment throughout life, which aims to develop an awareness of the basic characteristics of the human environment, relationships in it, and relationships towards it, based on which a person will strive to preserve and improve the environment [1].

Physics is a natural science that deals with the study of nature in the most comprehensive sense, i.e. by studying the behavior and interactions of matter in space and time. The development of technology is closely related to the development of science. Science is concerned with gathering knowledge and organizing it, while engineers use that knowledge for practical purposes while simultaneously finding tools for new scientific experiments, which makes science and technology intertwined. Therefore, a true understanding of physics is essential for the development of new technologies and all forms of innovation, from the time of the first industrial revolution to the present day [1].

INTERACTIVE TOOLS IN THE TEACHING

For people to get the required information faster and more efficiently and improve their knowledge, many companies and educational institutions came up with the idea of creating educational software and interactive tools (content) with the help of which they would enable the constant accumulation of knowledge in a very practical and simple way. With this approach, there are more and more educational contents and their application in learning material in schools. Some of the contents are narrowly educational in nature, while others are general educational content that is available via the Internet to anyone who wants to improve their education [2].

SIMULATIONS, ANIMATIONS, AND INTERACTIVE CONTENT

Interactive content includes access to various information, such as video and audio materials, presentations, or multimedia catalogs, in a word, all content is displayed in a modern and attractive way. Ready-made programs with interactive content provide the opportunity to learn at home without the presence of a teacher. The advantages of using computers in teaching are multiple, and interactivity and individual attention can be highlighted as the main ones [3].

Animation is the rapid display of sequences of 2D or 3D images or model positions placed to create the illusion of movement. It is an optical illusion of movement due to the phenomenon of persistence of vision and can be created and displayed in a variety of ways. The most common method of displaying animations is a moving picture or video program [3].

Simulation is a procedure by which the behavior of an object or the development of a phenomenon is investigated on a physical or computer model. It is carried out when work on the real object would be too demanding, expensive, or unethical when the real composition does not yet exist when the behavior of the real composition is too fast (molecular phenomena) or too slow (geological changes) to observe [4].

The advantages of using simulations in teaching physics are [5]:

- Students get a first-hand insight into how scientists think and work
- Students understand the differences, similarities, and relationships between parameters in a model. In this way, they get a sense of which parameters are important for that experiment and what the impact of changing the parameter value is
- Students learn how to use models to predict the outcomes of simulations or experiments
- A well-prepared simulation often builds on a new problem or requires a relationship with concepts that students have previously learned

SIMULATION ON AN EXAMPLE OF KEPLER'S THIRD LAW

The simulations were made using the vPython 7 package for creating 3d animations. The simulations show 2 bodies acting with a gravitational force as an example of Kepler's 3rd law. This simulation is realized by selecting Kepler's 3rd law in the user interface, setting the parameters, and starting the simulation. The simulation shows the movement and prints the ratio a^3/T^2 and these values on the graph. After several measurements, we can easily see that their ratio is always constant [6]. Figure 1 shows an example of a simulation of Kepler’s third law.

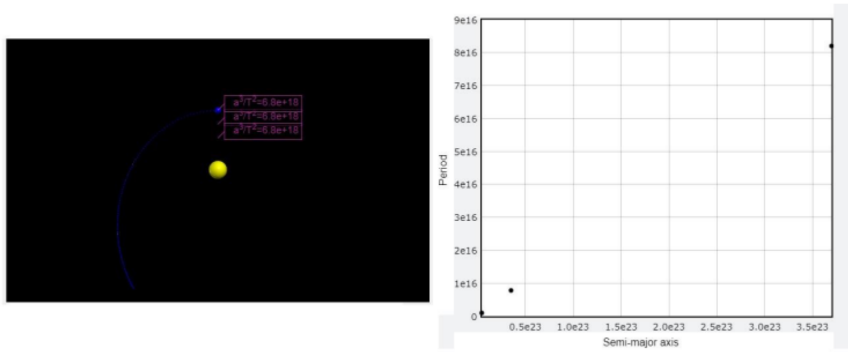

Figure 1. Simulation of Kepler’s third law[6]

DIGITAL TOOLS IN PHYSICS TEACHING

Digital technology enhances research by providing students with the tools to analyze and understand large volumes of complex disciplines and media, including data and photographs. To make the most of the online environment, schools must use social media and digital tools for active and engaged learning as part of the curriculum. Digital tools are transforming education by connecting teachers and students with content, resources, and platforms to improve instruction and personalize learning [7].

OSCILLATION SOFTWARE

Oscillations are educational software intended for physics students to present an analog mathematical model. The software has a broader view of oscillations that is extended to optical and terminal phenomena. Provides students with more information on harmonic oscillatory motion, including phase diagrams, energy, superposition of vertical oscillations, and oscillatory motion selected from all areas of classical physics, optics, electricity, mechanics, and thermodynamics [7]. Figure 2 shows an example of this educational software.

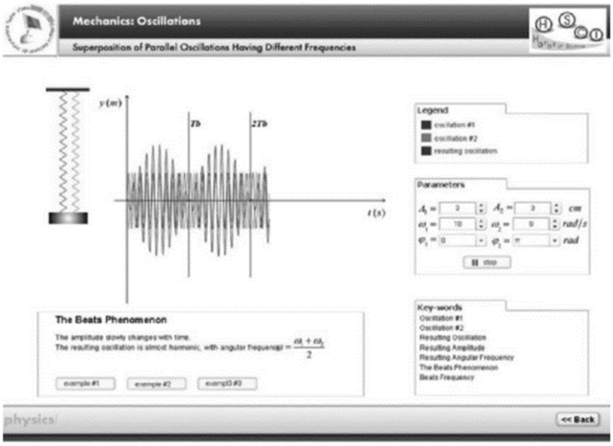

Figure 2. Example of Oscillation software

GEOGEBRA SOFTWARE

GeoGebra is a program that encourages experimentation, a content problem-based approach to teaching, and discovery learning. The user interface is very clear and easy to use (even for beginners), and its features are numerous and very powerful. It is available on various platforms and operating systems, which greatly expands the user base. The special feature of GeoGebra is the simplicity of creating users' materials and sharing them with users around the world. In this way, the program is constantly developing, and new possibilities and ways of application are discovered every day [8].

The software is designed to help mathematics and physics students. The GeoGebra educational software is a valuable teaching resource that can be used to create interactive, dynamic models useful in the study of physical phenomena. The versatility of the software is great, and models can be created in a variety of ways, even by students, under the guidance of a teacher. Research has shown that the educational software GeoGebra provides important intuitive support in the study of oscillatory motion and encourages students to use instruments and methods that are specific to knowledge and scientific research [7]. Figure 3. shows an example of GeoGebra software output.

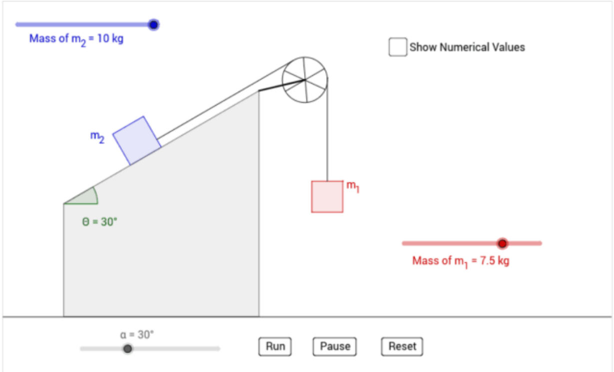

Figure 3. Example of output in software GeoGebra [9]

CONCLUSION

The role of technology in physics education is essential for developing modern educational practices. Digital tools and interactive content enrich teaching and enable students to engage in active learning and research. Integrating technology into physics teaching can significantly improve understanding of complex concepts and encourage students to think creatively. As education systems face the challenges of modern society, teachers and educational institutions must focus on using technology to improve education.

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Enhancing Sustainability Awareness through Educational Technology

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Abstract. This paper explores the role of educational technology in enhancing sustainability awareness among students. As global environmental challenges intensify, it is imperative to integrate sustainability education into the learning process effectively. One of the aspects that should be addressed due to its high potential is the role of technology in education in reshaping attitudes and behaviors of the students about the environment and the importance of their participation in efforts to achieve sustainable development—the impact on student's commitment to sustainability through the inclusion of educational software and other technologies. The way sustainability education can be integrated using technological tools in classroom settings is explored in this paper. The goal is to demonstrate how the digitalization of education can lead to a higher level of sustainability awareness among students.

Keywords: education, sustainability, awareness, environment, technology.

INTRODUCTION

The intersection of environmental awareness among students and the use of technology in education is the main focus of this paper. By reviewing existing studies, the main goal of this paper is to determine how and if awareness about sustainability issues can be increased by including digital tools.

IMPORTANCE OF SUSTAINABILITY AWARENESS FOR STUDENTS

Environmental awareness

Ecological awareness is a skill that gives people information about the natural world, how humans interact with it, and how to identify and address environmental issues.

Researchers aim to obtain a comprehensive picture of the situation when studying people's ecological consciousness, concentrating mostly on the causes of pollution, waste management, and present environmental competence and awareness [1]. Taking into account the huge impact that humans made on natural resources [2] awareness about the current environmental situation is of great importance for achieving the desired and more than needed change in behavior. Environmental awareness is a crucial component of education because it increases people's commitment to preserving the environment and ensuring that it is habitable for coming generations. Environmental consciousness protects human health and safety as well as the welfare of all other creatures on Earth. Since humans are mostly to blame for environmental degradation, they may save the Earth and ensure that future generations have access to the natural resources by adopting small lifestyle modifications. In a similar vein, one can comprehend long-term variations in average weather patterns if they are aware of environmental change. To fulfill the sustainable development goals of climate action and life on the planet, one must be conscious of climate change [2]. The main reason that is listed when elaborating on the importance of environmental awareness is that if an individual has higher environmental awareness, it is more probable that his/her behavior will be more protective toward the environment [3].

Reflection on students

Many students overlook the environmental awareness component of character education. This lack of concern not only fails to preserve and maintain the current environment but also fails to prevent and repair environmental damage, which tends to affect other people and has further implications in exacerbating the environmental concern [4]. Students' environmental care behaviors, which can lessen environmental damage, have been favorably correlated with their environmental knowledge. It is said that students don't care about the environment because they don't want to learn about and comprehend environmental issues [5]. Consequently, to inspire students to take action, teachers should help them comprehend environmental issues.

Increasing awareness through education serves as the foundation for addressing environmental issues from a broad philosophical perspective as well as for sustainability, upkeep, and improvement to create better conditions. The goals of environmental education specifically encompass the following: First, awareness, which seeks to assist pupils in developing sensitivity and awareness of the environment and its issues in general. The second component is knowledge, which tries to teach students the fundamentals of how the environment works and how people interact with it [6]. The third component is an attitude, which tries to support students in forming moral principles, a sense of obligation to the environment, and the drive and dedication to take part in initiatives to protect and improve the environment. The fourth set of skills is designed to assist students in gaining the capacity to recognize, look into, and assist in resolving environmental issues and challenges. Last but not least is participation, which attempts to assist students in gaining real-world experience and applying their knowledge and critical thinking abilities to address and resolve environmental problems [6]. Seeing the world from many angles and comprehending culture are integral parts of environmental education. This education's interdisciplinary design is a comprehensive strategy that unites multiple scientific fields to investigate environmental challenges using a range of teaching techniques. It is envisaged that environmental education would be able to improve awareness of fundamental environmental ideas and the issues that surround them through its considerable capacity to forge links with society [6].

One of the main obstacles observing the attitudes of teachers toward introducing education lessons aimed at increasing environmental awareness is the requirement of time to pass for these changes to be introduced [7]. Education is the primary means of increasing awareness among the younger generation. This necessitates the development of students' capacity for introspection and responsible decision-making, considering the present and potential effects of their activities on the environment, society, and economy. Education for Sustainable Development is one way to achieve this [8]. An abundance of examples shows how sustainable growth can be encouraged in the educational setting, particularly in elementary school [8]. As one way to increase the environmental awareness of students through education, the project-based approach is distinguished by the authors in the study [9]. A student project that makes references to contextual environmental concerns presents the answer. One of the student-centered learning methods, project-based learning aims to help students become more independent so they can respond well to their surroundings. Due to this nature, authors in the study [9] find this approach effective in achieving a higher level of students' environmental awareness. The goal of the green initiative is to raise students' awareness of environmental issues. It should be noted that environmental literacy includes both specific skills to demonstrate a continual attitude of concern for the environment and an understanding of ecological and environmental ideas. This mindset and care for the environment is what motivates someone to act in an environmentally conscious manner [9].

ROLE OF EDUCATIONAL TECHNOLOGY

Digital technologies are fundamental to the overarching issue of the environment. They encourage interest in finding solutions to environmental problems by enabling the use of current data on the condition of the environment and simulating specific events [10]. Digital technology makes it feasible to document occurrences in both the local and distant environments, gather information, make connections, and disseminate and exchange research findings. Within the security of the classroom, natural elements and phenomena can be demonstrated, for example, through quick video demonstrations. The displayed texts can be directly edited by the instructor or student on the screen [10]. One of the recent digital mapping tools used for cartography is Google Earth, an interactive 3D virtual globe using satellite imagery and aerial photographs. Research in the field of environmental awareness and education has been carried out using Google Earth digital maps in schools [11]. For example, it is tested on a sample of middle school student's knowledge of historical oil spills and their ability to recall information after exposing them to Google Earth's list of the 50 most catastrophic oil spills ever. The location, images, and information on each incident, including the kind of spill, the cause, the date, the quantity of oil spilled, and other details, were all included in the Google Earth file that was made and sent to the pupils. The study aimed primarily to create a content knowledge exercise regarding worldwide oil spill disasters based on their spatial and temporal distribution, but it did not disclose the learning outcomes of the students [12].

Video podcasts have been demonstrated to have a favorable effect on students' EE performance in three separate ways: exam scores, self-reports, and practice modifications. The effectiveness of employing video podcasts about alien habitats on students' learning outcomes, for instance, was investigated. The efficacy of learning about far-flung places was evaluated by written questionnaires, focus groups, and summative evaluation findings. Six podcasts were available for students to view in the computer laboratories of the institution or download to their own computers or mobile devices. The virtual learning environment of the university provided access to the podcasts. The findings demonstrate that the students thought the podcasts were beneficial for their active learning and a good addition to the lectures [11]. Computer-Assisted Virtual Environments are one more type of digital technology that can support the goals of environmental education [11].

Digitalization offers an astounding variety of tools, games, and environmental activities, many of which have the potential to be utilized in educational settings. For instance, in the serious game "Climate Challenge," developed by the British Broadcasting Corporation (BBC), the player assumes the role of the president of a European country and must address climate change while maintaining enough popularity to hold onto office. These elements of the game are meant to provide an idea of what might occur as climate change occurs [13]. For young students, these kinds of activities could open doors to meaningful and connected learning inside the confines of the classroom. Furthermore, teaching environmental studies with geography and history gives students a stronger grasp of the spatial and temporal continuum that affects the planet. Virtual travels and explorations may be able to help students envision what it would be like to visit that location or period, both emotionally and physically, even though they cannot provide the same physical perceptions as a traditional field trip. For this reason, they may be a potentially fruitful and sustainable substitute that should be carefully considered [13].

Since digital technologies provide students with fresh perspectives, new technologies like computer simulations, Web 2.0 platforms, and mobile apps present innovative teaching options for enhancing sustainability education. In particular, we suggest that technology-based education benefits society in three ways: it helps with grasping the complexity of societal big dilemmas, democratizes education, and helps educators adapt to new generations of students [14]. Students can benefit from new technologies by using them to better comprehend the scope and size of societal great challenges as well as provide answers to them. Massive international social and environmental problems that cut over national boundaries and could have a detrimental impact on a great number of individuals, communities, and the planet as a whole are known as societal big challenges. Good teaching materials should give clear examples of the kinds of issues that need to be addressed, offer opportunities for experiential learning, and vividly illustrate the results of the actions done. Students can learn about the complexity of sustainability concerns, their roots in numerous disciplines, their inter-temporal aspects, and the challenges of striking a balance between the triple bottom line with the use of new technology like apps and simulations. Web 2.0 tools may also encourage cooperative learning environments where students work together to solve problems. The majority of societal challenges involve cooperation and agreement from numerous groups and parties with competing interests, making this a significant pedagogical benefit [14-15].

CONCLUSION

There are significant indications from the previous works in this field that environmental awareness can be increased by the inclusion of technology in education. Digital tools provide engaging and interactive ways to learn about sustainability and environmental issues. Furthermore, technology facilitates up-to-date information and an opportunity to increase understanding of the negative effects of environmental problems. Compared to the importance of the issue, limited research in this field is surprising at the same time great indicator of a need to expand and foster research in this field. It can be concluded that students may be more proactive advocates of environmental change and protection with the inclusion of technological tools in education.

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Gamifying Environmental Literacy: Advancing Ecological Understanding through Interactive Digital Learning

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Abstract. This paper delves into the innovative intersection of environmental literacy and game-based learning, emphasizing how interactive digital experiences can significantly enhance ecological understanding among students. As environmental challenges become increasingly complex, traditional educational methods alone are insufficient in cultivating a deep, actionable comprehension of sustainability. The paper aims to address the impact that gamification can have in increasing environmental literacy. The paper overviews diverse types of educational games and their estimated impact. By examining examples and current research about the topic, this paper underscores the potential of gamifying environmental literacy to foster a generation of informed and proactive approaches to environmental preservation.

Keywords: Gamification, environmental education, environmental literacy, digital learning.

ROLE OF DIGITAL GAMES IN EDUCATION

Game-based learning has evolved as a novel teaching method that can boost student motivation, emotional engagement, and enjoyment [1]. When discussing the role of digital games in education it is important to take into account the widespread use of digital technology, children and young adults are playing games on digital devices more frequently and for longer periods [2].

The positive impact of game-based learning on students' results is stated in the study [3]. Integrating technology into education through games gives students a compelling learning experience, allowing them to remain focused on the subject without distractions. The use of projectors, computers, and other cutting-edge technical equipment in the classroom can make studying more interesting and enjoyable for students. Student learning can become more dynamic and engaging by creating assignments in class that utilize technological resources [4].

Gamification has been widely used to improve educational institutions and to increase students' attentiveness, motivation, engagement, flow experience, and other beneficial outcomes. Over the last few years, various studies have underlined the importance of tailoring gamification design properties to individual students' needs, characteristics, and preferences [5]. One of the ways how gamification needs to be tailored is to better fit environmental requirements that are imposed by climate changes and risks.

ENVIRONMENTAL LITERACY

Environmental literacy promotes a deliberate approach to maintaining environmental balance. This awareness can also be viewed as an environmental literacy attitude, which demonstrates not just knowledge of the environment but also responsiveness and the ability to propose solutions to environmental challenges. Equipping students with environmental literacy skills is crucial for their future roles as change agents [6]. Ecological behavior, environmental values, and cognitive knowledge are all integrated into environmental literacy [7]. Students who practice environmental literacy at a young age are more equipped to balance development and the environment, resulting in a harmonious relationship between society and nature [6].

Term environmental literacy is a complex term which consists of other connected terms that share meaning with it. One of them is ocean literacy. This term helps understand how this concept developed and specialized over time. According to UNESCO, ocean literacy can improve economic stability and national security as well as help society understand important issues related to a wide range of important ocean-related topics, such as ecology, trade, energy exploration, climate change, biodiversity, the ocean and human health, and building a sustainable future. Ocean literacy is defined as the ocean's influence on humans and their influence on the ocean. Additionally, raising public awareness of these problems and encouraging a shift in mindset is critical to safeguarding the ocean's sustainability through prudent policies, legislation, and management practices. All of these measures contribute to the protection of the oceans and marine environments [8].

Finding strategies to raise environmental literacy levels is a continuous endeavor, given the significance and intricacy of the phrase. Education and the potential for change in that area are key areas for achieving this goal. Games are beginning to be studied as one of the possible means of bringing changes in education that could lead to a higher level of environmental literacy.

DIGITAL GAMES IN ENVIRONMENTAL EDUCATION

Since games naturally simplify and illustrate complicated systems and environmental challenges that might otherwise appear distant or invisible, they can be useful instruments for environmental education. Game-based simulations create a secure, social environment in which people can experience simulated success and failure through their behaviors, making them more capable of using these experiences in later tasks [9]. Applying game design concepts to non-gaming contexts, including altering energy usage patterns, is known as gamification. Clear progression paths with attainable goals, levels, and rewards are among the gamification principles; players are given agency over their actions; strategy and novelty are used to engage players; feedback is given; social comparison or competition is used; and player cooperation is encouraged. These principles can be combined in different ways. Gamification facilitates the development of an environment where people are naturally driven to interact with content relevant to the domain in which desired behavior change occurs [10].

Ouariachi et al. proposed a framework for introducing games in education as a way to increase environmental literacy. To achieve these efforts, the authors emphasized three dimensions that need to be taken into account.

Table 1. Attributes of games that enhance environmental literacy [11].

Dimension	Focus	Attributes
Cognitive involvement	What people think and know (mental effort)	Credible, experiential learning, concrete, challenging, leveling-up, fun, achievable, feedback-oriented, meaningful, narrative-driven, and simulating.
Emotional involvement	What and how strongly people think about climate change	Identity-driven, concrete, challenging, efficacy-enhancing, reward-driven, achievable, feedback-oriented, meaningful, narrative-driven, and simulating.
Behavioral involvement	What and how much do people do to address climate change	Social, efficacy-enhancing, reward-driven, leveling up, fun, achievable, feedback-oriented, meaningful, narrative-driven, and simulating.

Attributes presented in Table 1 according to this framework have an impact on students' engagement in the environmental context. To create inspiring tools, the authors in the study [11], state that it is necessary to appeal not only to the analytical processing system but also to the overall experiential system. This includes playing with reality, highlighting powerful narratives that connect with people's values and experiences, and paying close attention to verbal, written, and audio-visual communication. An engaged experience should also be enjoyable, allowing people to work hard towards specific goals while making them feel good. When these elements combine with social interaction and peer pressure, there is a greater likelihood that acts will be taken and a social movement will emerge [11].

Playing games helps players retain lessons and behaviors by letting them test their actions and instantly experience the negative effects of their actions on their surroundings [12].

It is also indicated that games should be played for a longer period to achieve desired results and alter the behavior of students [12]. Observing the example presented in the study [12] it was noted that all three dimensions presented in Table 1 were fulfilled when educational digital games were introduced.

When combined with conventional teaching techniques, the educational applications "Abouit" and "Labels for your Planet" enhanced the energy-consumption patterns and sustainability understanding of undergraduate business students [10]. These are examples of the impact that usage of the games in even higher education can have on increasing environmental understanding.

Teachers have a responsibility to help students understand how the events in the game relate to one another. The majority of games use intricate systems that challenge players to solve puzzles. EnerCities' indicators demonstrated how player decisions affected the depletion of the available resources. For instance, players may level up the game and increase the population of the city when a high-rise structure is built. The interconnectedness that exists in any environment is demonstrated by the reduction of cash reserves (represented by a money bag image), green cover (represented by a tree icon), and people's happiness (represented by a smiling face). Players learned from this that rapid development does not always translate into rapid building and prosperity. They recognized the significance of a more sustainable, all-encompassing approach to development [13].

Another example is the game *Animal Crossing*. The role of species in the game Animal Crossing's design has an impact on the ability to identify species in real life, with flora mostly serving as adornment. Furthermore, this study implies that survey respondents may accurately measure their naturalistic knowledge in general [14].

Using the example of the game *Stop Climate Change* it is determined that educational games may simultaneously be happy and to learn concepts about climate change [15]. Study [16] specified characteristics of the students' preferences about game characteristics. Senior-grade students choose knowledge-based games to expand their environmental understanding. In terms of gender, boys favor action games while girls prefer knowledge games. This research aims to enhance environmental protection education by using game-based learning to increase children's knowledge, literacy, and practical skills [16]. In a similar vein, the study's conclusions show that the Eco, digital simulated ecosystem, is a useful tool for raising awareness of certain environmental issues related to ecosystems, and recommendations for further Eco deployment are given [17]. Having in mind all said above, the following conclusions may be listed.

CONCLUSION

Having in mind the efficiency of digital games in education and the importance of environmental literacy, the way these terms may overlap should be addressed. Current research shows that great potential lies in digital games as a tool to achieve the desired results in increasing the environmental understanding and literacy of students. The results achieved by games can be strongly associated with the characteristics of the games itself which is presented in some of the research as a significant aspect that needs to be addressed in further research. The role of educators is mentioned but still needs to be analyzed in further research.

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Integrating Environmental Physics into Education: Bridging Theory and Practice for Sustainable Solutions

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Abstract. This paper examines the critical integration of environmental physics into education, aiming to bridge the gap between theoretical knowledge and practical application to foster sustainable solutions. Environmental physics which encompasses the study of physical processes and phenomena in the environment, is essential for understanding and addressing contemporary ecological challenges such as climate change, energy consumption, and pollution. The aim is to highlight the need for a changed approach and multidisciplinary thinking to make a clear understanding of environmental issues. The paper also indicates the possible challenges for teachers and how solutions could be made. An overview of this topic shows the importance of introducing changes into education and teaching students physics while keeping in mind the wider societal and environmental context. With a clear focus on needed changes in behavior, the lesson needs to be adapted.

Keywords: *environmental physics, education, sustainability, teaching*.

ENVIRONMENTAL EDUCATION

There is a need for science learning, including physics, innovations in schools to address the low student participation in environmental management and raise students' understanding of the subject matter. Lack of enthusiasm to learn is one of the contributing causes. Science is the clear and understandable discovery of anything about nature through the accumulation of knowledge in the form of facts, concepts, or principles. The goals of education for sustainable development include learning transformation and a complete system perspective. In actuality, this has meant a stronger emphasis on interdisciplinary and subject-specific teaching strategies as well as a stronger attempt to connect classroom knowledge to real-world applications. The concept of Education Sustainable Development (ESD) presents a quality education perspective that emphasizes lifetime learning, the development of students' abilities, values, and competencies to become change agents, in addition to quantifiable learning outcomes and national standards [1].

The term "across curriculum approach" describes how content and skills are incorporated into already-existing courses in a way that emphasizes those topics (and/or abilities) without compromising the integrity of the courses themselves. One of the most pertinent subjects to apply environmental understanding through is science.

This strategy since there is a link of mutual dependency between the environment and the content [2]. The least amount of environmental knowledge is covered in the physics curriculum. It turns out that the Form Five syllabus for this topic does not include any environmental knowledge at all. Nonetheless, the Form Four curriculum integrates knowledge of energy and ecosystems through the subtopic of "Understanding work, energy, power, and efficiency" within the "Force and Motion" study area. Students gain information about the overall requirement for energy through this topic [2].

It is noted in existing research that physics-interested students are fascinated by nature, science, and environmental problems as well as inventions and discoveries. They'd like to learn more about the latest scientific findings or whether chemical phenomena or nuclear weapons have an impact on environmental problems [3].

Not only are there concerns about how education could influence attitudes and behavior related to the environment, but poorly aligned information can also have a negative effect on students' attitudes. For instance, giving students excessively structured labs can make them have a bad attitude toward science in general and the scientific method in particular. Thus, it is needed to test the hypothesis that adding content relevant to sustainability could have a detrimental impact on environmental attitudes and actions when monitoring them [4].

Due to these reasons, named in the referenced research, further analysis of the ways in which environmental ideas can be incorporated in the education should be directed towards subject of physics.

PHYSICS IN ENVIRONMENTAL EDUCATION

Environmental education can be used to teach subjects like physics that are relevant to daily living. Studying physics involves learning about both natural and man-made events. Students' attitudes toward protecting the environment may grow as a result. Students studying physics can learn about things in their environment that can be investigated scientifically. Students can learn about environmental phenomena and develop a greater understanding of the environment when climate change education is combined with physics instruction. Students who receive climate change education become aware of the signs of climate change in their surroundings and realize how important it is to preserve the environment [5].

To improve students' environmental literacy abilities, the Physics Science e-module on Flipbook combined with the Sustainable Development Goals (SDGs) showed an increase in test outcomes overall. How much pupils' environmental literacy increased after they used the Flipbook-based Physics Science e-module that was connected with the SDGs on energy [1].

The purpose of the study [6] is to increase understanding of the Sustainable Development Goals (SDGs) about the physics of sound. Specifically, noise pollution poses a threat to public health and well-being in industrial, educational, and environmental settings. When people are exposed to environmental noise regularly, it can have detrimental effects on their health. The research employed an interdisciplinary methodology that addressed the Sustainable Development Goals (SDGs) within the framework of STEM (Science, Technology, Engineering, and Mathematics) education. This included workshops for students and a professional development program (PDP) for teachers. To raise awareness of this problem and how it relates to the SDGs, in particular, information and practical exercises about the mechanics of sound are incorporated [6].

Practical problems and ideas

Teaching about climate modeling might be difficult due to students' misconceptions about scientific models. The usage of the term 'model' may cause pupils to conclude that scientific understanding of climate change is particularly uncertain and subject to dispute. Furthermore, students may struggle to understand the interaction of numerous causal components in climate models and interpret analogies (such as 'trapping of heat') too literally [7]. To address these challenges, Tasquier and colleagues proposed a five-lesson curriculum that covered the following topics: a) the nature of scientific models and complex causality; b) the evidence scientists have found supporting climate change; c) physical models of climate change, such as an introduction to thermal equilibrium through heating metal cylinders; ii) building model greenhouses; and d) a discussion of the social and political ramifications of climate change [7].

After empirical research, the authors [7] concluded that the intervention, which included explicit instruction about the characteristics of scientific models, significantly changed the vocabulary students used when discussing modeling and helped them to build a more sophisticated understanding of scientific models. The study emphasizes that teaching students about the nature of scientific models is just as important for teaching them about climate change physics as it is for fostering their understanding of the underlying physical processes.

It is interesting to overview the ideas on how to incorporate sustainability in physics classes but in a practical way. One of the activities that illustrates very well the main idea of this incorporation is the following one:

"*Why does ice float and what proportion of it is below the surface? How does the water level change as floating ice melts and why does meltwater sink? Go cross-curricular and link to the importance of the survival of life under frozen water surfaces*." [7, p.9].

Problem-solving skills, critical thinking, and cross-circular approach are what make this particular activity a great example of how classes should be introduced to respond to the needs of students and to foster previously mentioned skills.

Trying to find how physics teachers' creativity can be fostered to meet the SDG, the authors of the study [8] found that PPTs that incorporate climate change scenarios into classes, can encourage creative thinking. PPTs are forced to consider ways to turn all the negative images of the present and the future—such as global warming, human rights violations, and terrorism—into positive ones to provide solutions for the global issues that are being discussed. These negative images frequently elicit negative emotions like helplessness and apathy. It is stated that these topics need to be addressed carefully but that their effects are estimated to be effective as a tool for teaching environmental education

One of the primary obstacles to promoting these innovative teaching and learning methods in schools is the teachers' insistent demand for professional development in all scientific areas about sustainability. They believe that the main barrier to the widespread adoption of sustainability issues in classroom practice is a deficiency of disciplinary and interdisciplinary abilities [9].

One of the main barriers to implementing these cutting-edge teaching and learning strategies in classrooms is the teachers' adamant insistence on receiving professional development in every branch of science related to sustainability. They think that a lack of disciplinary and interdisciplinary skills is the primary obstacle preventing sustainability topics from being widely adopted in classroom instruction [9].

Fluid physics is the subject of yet another illustration of a concrete lesson plan recommendation. To provide students with a fundamental understanding of fluid mechanics and the relationship between fluid motion (such as that of atmospheric air and ocean water) and the corresponding transport processes in the climate system, this lesson explains the fundamental physical principles of hydrostatics and fluid dynamics [10].

A thermodynamics lecture can be utilized to further clarify it. Important thermodynamic state variables, including temperature and pressure, as well as characteristics, such as latent heat and heat capacity, are introduced in this lesson. Basic ideas of heat transport, including thermal radiation, and the transformation of thermal energy, including conversion efficiency, are given special attention. As a result, it offers the fundamental physical information needed to comprehend subjects like the budget of radiation on Earth and the function of greenhouse gases in the climate system, among others [10].

These examples show how in a practical way physics knowledge can be connected with SDG. These type of activities primary learning goal is for students to gain a comprehensive understanding of the basic ideas behind climate science. Consequently, they can assess the quantitative correlations among greenhouse gas emissions, atmospheric modifications that ensue, thereby affecting the worldwide radiation equilibrium, and eventually, their influence on worldwide temperatures and additional facets of the climate system.

CONCLUSION

Without a doubt, one of the biggest problems society is currently experiencing is the climate issue. Mitigation activity is required across all sectors and scales to reach politically and scientifically agreed-upon limitations on global warming. Education is one of the especially important areas as it impacts the way future generations address climate issues.

It is of great importance to note how specific subjects may resonate with the SDG and influence students to act sustainably. To do so, it is required to provide explanations to them about the negative impact of climate change and various consequences. Teaching has a great deal of responsibility since it helps young people acquire competencies at the nexus of education and research. Learning environments that support a greater comprehension of current research as well as the contextualization of these findings in social discourse are necessary to address the multifaceted nature of the climate catastrophe.

Being aware of the consequences of climate change has the ultimate importance when it comes to the educational goals that correlate with SDG.

Practical solutions that can help overcome existing barriers may help to improve the contribution of education to reducing negative environmental factors.

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Water Quality of the Una River in Novi Grad

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Abstract. This paper presents the results of a study conducted to analyze the physical and chemical characteristics of water in order to assess its quality and potential environmental impacts. Novi Grad, located in the western part of the Republic of Srpska, on the border with Croatia, is only half a kilometer in a straight line from Trgovska Gora, the proposed site for nuclear waste material disposal. The repository, formerly an underground military ammunition storage, raises significant concerns among the residents of this small town, particularly due to its proximity to the Una River, a natural border between Croatia and the Republic of Srpska. Water sampling locations were carefully selected upstream and downstream within the town to establish baseline data for environmental monitoring prior to repository construction and risk assessment.

Keywords: water quality, nuclear waste, environmental monitoring,

INTRODUCTION

The physico-chemical characteristics of water are significant indicators of the condition of a given ecosystem. Along with the biological components, they provide a more complete picture of the ecological conditions of aquatic environments. These water characteristics are the most important factors that determine the survival of fish species, as well as all other aquatic organisms within a water ecosystem [1]. Aquatic organisms live within a specific range of basic parameters (such as temperature, oxygen, pH, ammonia, water hardness, etc.) within which they can function. Any deviation beyond the minimum or maximum limits of these parameters leads to changes in their status, which manifests at various levels (from biochemical changes at the individual level to population and ecosystem-level changes). Therefore, researching water quality is of particular importance, as it constitutes the habitat for numerous aquatic organisms and simultaneously serves as an indicator of the various types of stress to which our surface waters are exposed [2-3].

METHOD

The analysis of physico-chemical water quality parameters was conducted in accordance with the Regulation on the Classification of Water and Categorization of Watercourses [4]. Samples from the rivers were collected from the midstream under aseptic conditions following the prescribed procedure. Simultaneously with the sampling, in situ measurements were conducted, including water temperature at the same depth, air temperature in the shade two meters above the ground, as well as pH values, electrical conductivity, dissolved oxygen concentration, saturation, and turbidity. Dissolved oxygen concentration and BOD5 were determined using a HACH HQ30 flexi oximeter. The pH values and electrical conductivity were measured with a Eutech CyberScan pc 10 pH meter, and turbidity was measured using a Eutech TN100 turbidimeter. The samples were then transported on ice at temperatures up to +4˚C, and within 24 hours, they were analyzed in the laboratories of the Faculty of Natural Sciences and Mathematics at the University of Banja Luka. Using a HACH DR2800 spectrophotometer, color, suspended solids concentration, and concentrations of dissolved ammonia, nitrates, nitrites, orthophosphates, total phosphorus, and sulfates were determined. Zinc and copper concentrations and chemical oxygen demand were determined using a Macherey-Nagel PF-12 photometer, while calcium and magnesium concentrations, total hardness, and alkalinity were determined volumetrically by titration. The organoleptic method was used to determine the odor of the water, with the assessment carried out according to an odor scale (ranging from 0 to 5).

RESULTS AND DISCUSION

In the following paragraph, the results collected from four locations: Rakani, Blatna, Novi Grad (confluence with the Sana River), and Vodičevo will be presented. Water sampling for physico-chemical analysis was carried out at the Una - Blatna, Una - Novi Grad (Sana mouth), and Una-Vodičevo locations on October 21, 2021, while the Una - Rakani site was sampled earlier on September 15, 2021. The tabular presentation of the obtained results for all four locations is shown in Tables 1 and 2.

Table 1. Physico-chemical characteristics of the Una River in the localities of Rakani and Blatna

Parameter	**Measured value**		**Water quality class**	
GENERAL PARAMETERS				
Place	Rakani	Blatna	Rakani	Blatna
air temperature (˚C)	17	16	-	
water temperature (˚C)	18,9	11	-	-

water color (Pt-Co unit)	<5	<5	-	-
the smell of water	0	0	-	-
electrical conductivity (μS/cm)	484	479	II	II
total hardness as $CaCO_3$ (g/m^3)	172	162	I	I
pH value	8,65	8,57	II	II
total alkalinity as $CaCO_3$ (g/m^3)	181	178	I	I
total suspended matter (g/m^3)	1	2	I	II
turbidity (NTU)	1,41	5,39	-	-
OXYGEN REGIME				
dissolved O_2 concentration (g/m^3)	10,29	10,72	I	I
water oxygen saturation (%)	113	97,9	II	I
HPK (g O_2/m^3)	<5	4,8	I	I
BPK_5 (g O_2/m^3)	1,48	2,4	I	II
NUTRIENTS				
total phosphorus (g/m^3 P)	<0,01	0,008	I	I
orthophosphates (g/m^3 PO_4)	0,13	0,15	-	-
nitrite nitrogen (g/m^3 N)	0,003	0,006	I	I
nitrate nitrogen (g/m^3 N)	0,1	0,2	I	I
ammonia nitrogen (g/m^3 N)	0,00	0,02	I	I
OTHER INORGANIC SUBSTANCES				
sulfates (g/m^3)	41	28	I	I
calcium (g/m^3)	420,82	432,84	-	-
magnesium (g/m^3)	430,38	334,36	-	-
total residual chlorine (mg/m^3)	0,02	0,04	I	I

The river Una in the locality of Rakani has water of excellent quality. It is transparent, without specific odors, and is not loaded with suspended matter or nitrogen and phosphorus compounds. The values of all monitored physical and chemical parameters are within the limits for the first class of surface waters. The only exceptions are the values of electrical conductivity and pH value that correspond to the second class of water. The optimal pH value for the development of salmonid fish ranges from 6.5 to 8, while cyprinid species have an optimum development in the range of pH from 6 to 9. Although the value of pH 8.65 was measured on the river Una, which is above the optimum, it is still not limiting for the growth of salmonid species. A somewhat higher oxygen saturation of the water was also measured, which is probably a consequence of the very nature of the water flow. Namely, in rivers, especially in the parts of the stream where rapids and cascades are present, mixing of water and atmospheric air occurs, which results in hypersaturation of the water with oxygen. Although the concentration of oxygen in the water is elevated, it does not pose a potential danger to the ichthyofauna.

The river Una in the Blatna locality is transparent and without specific odors. The water is slightly alkaline since the measured pH value was 8.57, which corresponds to the second class of surface waters. The turbidity value was 5.39, and the concentration of suspended matter was 2 mg/l, which also indicates the second class of solvency. However, it should be emphasized that the sampling was carried out in the late autumn period when, due to the climatic conditions, greater water turbidity is expected. Namely, due to the heavy rainfall characteristic of this period of the year, the surrounding soil is washed away and particles are introduced into the watercourse. A larger amount of suspended matter in the water causes an increased value of electrical conductivity, which is an indicator of the presence of ions in the water, as well as an increased value of biological oxygen consumption, which occurs during the microbial decomposition of organic matter in the water. These are also the only parameters on the basis of which the Una at the mentioned location would belong to the second class of surface water, while the values of all other monitored physical and chemical parameters corresponded to water of the first quality class. The concentrations of all basic nutrients, on which the primary production of the aquatic ecosystem depends, were extremely low. Based on the analysis of the physical and chemical parameters.

Table 2. Physico-chemical characteristics of the Una River in the localities of Novi Grad and Vodičevo

Parameter	**Measured value**		**Water quality class**	
GENERAL PARAMETERS				
Place	Vodičevo	Novi Grad	Vodičevo	Novi Grad
air temperature (˚C)	17	10	-	
water temperature (˚C)	11,4	11,8	-	-
water color (Pt-Co unit)	9	11	-	-

the smell of water	0	0	-	-
electrical conductivity (μS/cm)	493	426	II	II
total hardness as $CaCO_3$ (g/m^3)	154	154	I	II
pH value	8,65	8,64	II	II
total alkalinity as $CaCO_3$ (g/m^3)	190,8	226,8	I	I
total suspended matter (g/m^3)	1	4	I	II
turbidity (NTU)	4,9	4,2	-	-
OXYGEN REGIME				
dissolved O_2 concentration (g/m^3)	10,23	11,15	I	I
water oxygen saturation (%)	95,1	107,3	II	I
HPK ($g\ O_2/m^3$)	<5	<5	I	I
BPK_5 ($g\ O_2/m^3$)	3,48	3,18	I	II
NUTRIENTS				
total phosphorus (g/m^3P)	0,01	0,01	I	II
orthophosphates (g/m^3PO_4)	0,33	0,17	-	-
nitrite nitrogen (g/m^3N)	0,006	0,009	I	I
nitrate nitrogen (g/m^3N)	0,4	0,2	I	I
ammonia nitrogen (g/m^3N)	0,01	0,03	I	I
OTHER INORGANIC SUBSTANCES				
sulfates (g/m^3)	10	10	I	I
calcium (g/m^3)	484,94	448,87	-	-
magnesium (g/m^3)	287,86	323,93	-	-
total residual chlorine (mg/m^3)	0,02	0,02	I	I
METALS				
copper, dissolved (mg/m^3)	-	0,14	-	I

zinc, total (mg/m^3)	-	<100	-	-

Based on the analysis of physical and chemical characteristics, the Una River at the Novi Grad location has water of the second quality class. The increased concentration of suspended substances in water, as well as slightly higher values of turbidity, total hardness, electrical conductivity and biological oxygen consumption, are indicators of the presence of a moderate amount of substances of both organic and mineral origin. As for the basic nutrients on which the primary production of the aquatic ecosystem depends, that is, on which the development of algae and aquatic vegetation depends, only the concentration of total phosphorus corresponded to the second class of surface waters, while the concentrations of various nitrogen compounds in the water are low. The water is rich in dissolved oxygen, and as in the other monitored locations, it has a slightly higher pH value (8.64), which is beyond the optimal limits for the development of salmonid species, but is not limiting for their development. The concentration of copper and zinc in the water was also monitored at the given locality. The concentration of copper corresponded to first-class waters, while the concentration of zinc was below the detection limit of the measuring instrument. The values of the physico-chemical parameters of the water quality of the Una River at the Vodičevo locality indicate water of the second quality class. As in the localities located upstream, the values of pH and electrical conductivity are slightly elevated, which depend on the concentration of ions present in the water, as well as the concentration of total phosphorus, but also of inorganic phosphorus compounds, which encourage the development of algae and aquatic vegetation.

CONCLUSION

The paper presents the results of water quality analysis in the Una River at four locations. Based on the presented results, it can be concluded that the river Una has water of excellent quality, suitable for the development and sustenance of salmonid fish species. Research of this kind at this location is of great importance considering the proximity of the potential nuclear waste disposal site on Trgovska Gora. Also, in addition to this, there are studies with measuring of background artificial and natural radioactivity of air, water and soil [6].

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The Impact of Negative and Positive Feedback Loops on the Earth's Climate

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Abstract. The Earth's climate is influenced by a large number of factors, and in this paper we will analyze the impact of positive and negative feedback loops. Positive feedback loops cause Earth's temperature to increase, while negative feedback loops decrease global temperature. We will study the following feedback loops: Stefan-Boltzmann, evaporation, albedo, oceans, clouds and vegetation. We will use a simple phet simulation in the analysis of cloud and albedo feedback loops, and at the end we will list all the feedbacks that impact on the Earth's climate. Also in this paper, we will analyze the impact of feedback loops on global warming.

Keywords: earth's climate, positive and negative feedback loops, phet simulation, global warming

INTRODUCTION

The climate system consists primarily of the soil, the oceans, the Earth's ice sheets, the atmosphere that surrounds the Earth, and radiation from the Sun, which provides energy. All of them interact with each other and create conditions on and around the surface of our planet, which we call climate [1]. Also, climate represents the mean state of the entire system, averaged over space and time of the parameters that most affect life on the planet, such as temperature and its global and seasonal change. The Earth's climate is influenced by a large number of factors, among which we can highlight the following: processes on the Sun that produce electromagnetic radiation, interaction of solar photons and molecules in the atmosphere, effects of solar radiation on the composition of the atmosphere, fluid dynamics of the atmosphere and ocean, radiation transfers in the atmosphere, anthropogenic factors (release of greenhouse gases into the atmosphere), natural processes of climate change on Earth described by Milankovic's cycles, positive and negative feedback loops. In this paper, we will consider how feedback loops affect on the Earth's climate.

STEFAN-BOLTZMANN FEEDBACK LOOP

In order to explain the concept of negative feedback loop, let's consider the functioning of the human organism. If a person runs, he increases his body temperature, which leads to sweating. Sweating leads to cooling of the body. Similar process occurs when a large amount of energy enters the atmosphere. A classic example of a negative feedback loop, which can be said to be a stabilizer of the Earth's climate, is the so-called *Planck feedback loop*, which is often mentioned in the literature as *Stefan-Boltzmann feedback loop*. If we imagine that the Earth is an ideal absolute black body that absorved and radiates a certain energy [2], then we can, using the *Stefan-Boltzmann law,* write the following expression for the absorved energy:

$$\mathrm{E_{absorved}} = (1 - \mathrm{A}) \cdot \mathrm{S} \cdot \pi \cdot \mathrm{R_Z^2} \tag{1}$$

The same amount of energy the Earth radiates from its surface:

$$\mathrm{E_{radiates}} = 4 \cdot \pi \cdot \mathrm{R_Z^2} \cdot \sigma \cdot \mathrm{T_Z^4} \tag{2}$$

Let's imagine the case of the Earth colliding with a large asteroid. This would lead to a sudden increase in absorbed energy for some external forced energy. A sudden increase in absorbed energy leads to a sudden increase in radiated energy, which leads to a decrease in the temperature of the Earth's surface. It should be kept in mind that the Earth's thermal emission into space mainly originates from colder parts of the atmosphere. In other words, the troposphere absorbs the Earth's radiation and then the upper, colder parts of the atmosphere emit radiation into the cosmos and thus keep the Earth's energy budget in balance. Here, the troposphere will absorb a greater amount of Earth's radiation, while the upper, cooler parts of the atmosphere will emit extra radiation into the cosmos, causing the Earth's surface temperature to decrease.

EVAPORATION FEEDBACK LOOP

The hydrological cycle includes evaporation of water vapor from large water surfaces, condensation of water vapor and atmospheric precipitation. This is called the water cycle in nature. Precipitation will then have decrease the Earth's surface temperature. This is another example of a negative feedback loop (figure 1).

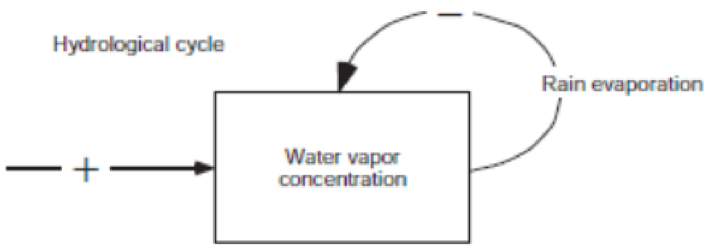

Figure 1. Water evaporation as a negative feedback loop

We can explain this negative feedback loop, in which the temperature decreases, as follows: due to the hydrological cycle, water vapor returns to the atmosphere, which condenses and returns as raindrops back to Earth. However, what happens if the water vapor remains in the atmosphere: there is an increase in the concentration of water vapor, but without returning it as rain back to Earth? Evaporation of water vapor, in that case, represents a positive feedback loop (Figure 2).

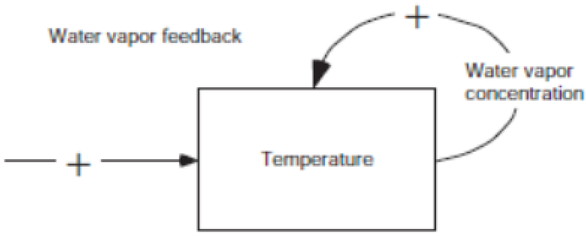

Figure 2. Water evaporation as a positive feedback loop

Therefore, the evaporation feedback loop can have a double effect: an increase or decrease of the temperature.

ALBEDO FEEDBACK LOOP

Albedo, most often expressed in percentages, represents the ratio between the amount of reflected solar energy and the amount of energy that reaches the Earth's surface. Albedo, among other factors, depends on the color of the object from which solar energy is reflected. It is common knowledge that in the summer months it is recommended to wear white T-shirts, and it is also recommended to avoid wearing black T-shirts. The reason is clear: a white T-shirt reflects light, while a black T-shirt absorb light.

As a result of global warming, in the Arctic, the ice is melting and the snow cover is decreasing. Considering that water has a lower power of reflection of solar energy compared to ice and snow, this process leads to a decrease in albedo, which leads to an increase in surface temperature [3]. This is another example of a positive feedback loop shown in the following figure.

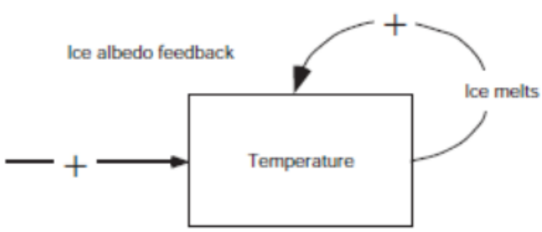

Figure 3. Ice albedo as a positive feedback loop

The decrease in albedo because of bad construction solutions is noticeable in certain parts of Podgorica. Studying the part of Podgorica that is located in front of Delta City, there is a large number of buildings in a small area, between them is concrete or asphalt, calls into question the possibility of life due to high temperatures. The solar energy that reaches these buildings is "trapped", which leads to increased temperature values in this part of the city. This is one of the classic examples of positive feedback albedo loop.

OCEANS AND VEGATATION FEEDBACK LOOP

Earth's climate would be completely different without oceans. They store a huge amount of heat and exchange it in significant quantities with the land and the atmosphere. The amount of water vapor in the atmosphere at any given time primarily depends on the global balance between precipitation and evaporation over the oceans. We can consider both positive and negative feedbacks associated with the ocean.

If the atmospheric circulation were to weaken in tropical areas, this would lead to a disorder in the rising of water from the deeper layers of the ocean towards the surface. This would lead to a weakening of the transport of nutrients to plants, which would slow down the process of photosynthesis, that is, reduce the transfer of CO_2 from the atmosphere to the ocean. An increased concentration of CO_2 in atmosphere leads to an increase in surface temperature. So this is an example of a *positive feedback loop*. On the other hand, if the icebergs in the Arctic disappear during the summer, in response to a warmer ocean, this would create a more moderate and wetter climate near the ocean. This process could theoretically lead to encouraging the spread of polar forests, which would lead to an increase in CO_2 consummation and could affect in the reduction of CO_2 concentration in the atmosphere.

In previous research, vegetation has always been an example of a *negative feedback loop*. Experiments have shown that oranges are much larger in areas where there is a high concentration of CO_2. Therefore, vegetation uses CO_2 for its growth and reduce the presence of this greenhouse gas in the atmosphere

CLOUD AND ALBEDO FEEDBACK LOOP SIMULATION

If water vapor condenses into a cloud, that cloud can cause negative and positive feedback. The mean global radiation of high clouds contributes to the warming of the atmosphere, low clouds cool atmosphere, while middle clouds balance between thist two processes. The albedo of clouds, averaged over the entire Earth, is slightly higher compared to their warming by the greenhouse effect, so it follows that clouds radiatively cool the atmosphere compared to the Earth without clouds. The following phet simulation demonstrate the change in surface temperature due to the presence or absence of clouds.

Phet Simulations are interactive simulations that can be used at all levels of education from elementary school to college. The user can choose the content that offers the greatest degree of interactivity. [4] Among others, this site has a phet simulation that models the greenhouse effect and this simulation has three parts: waves, photons and layers. The first and second part of the simulation, in which light is shown as a wave or as a photon, demonstrate the dependence of the earth's surface temperature on the concentration of greenhouse gases. We can also study what effect the appearance of clouds in the atmosphere can have on the global temperature.

The third part of the simulation deals with the dependence of the temperature of the earth's surface on albedo, intensity of sunlight and absorption layers. The temperature of the earth's surface can be shown in Celsius, Fahrenheit and Kelvin with the possibility of displaying the energy balance and soil temperature. If we have “normal” concentration of greenhouse gases, earth's surface temperature would be 13.8°C. But if put clouds in atmosphere, withouth changing concentration of greenhouse gases, earth's surface temperature would be 4.4°C. (figure 4)

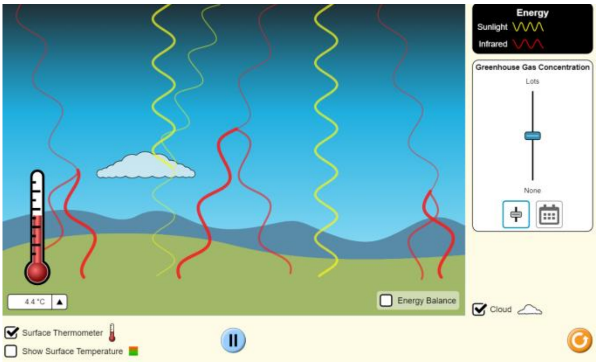

Figure 4. Phet simulation - cloud negative feedback loop

As can be seen in the simulation, the solar energy in this model is immediately reflected by the clouds, so the same amount of energy does not reach the Earth's surface as in the model of the Earth without clouds. This leads to a decrease in the surface temperature approximately by 10°C compared to the previous model. In the third part of the simulation, there is possibility of changing the albedo of the Earth. On the figure 5 we can see that in this model, in which the intensity of the Sun's energy does not change and if there are no layers of absorption of infrared light, the surface temperature of the Earth would be -17.9°C.

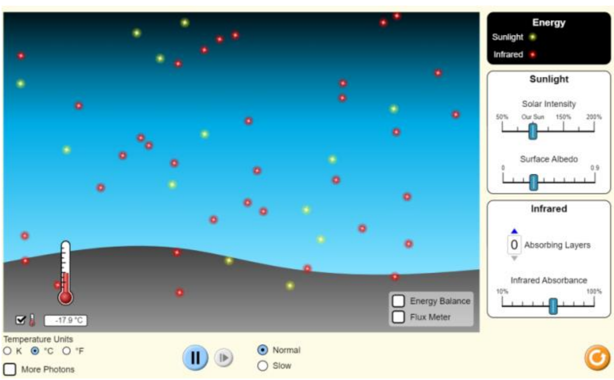

Figure 5. Phet simulation - solar intensity, surface albedo, absorbing layers

The following table shows the dependence of the surface temperature on the change in albedo. In the analyze of this table, it can be concluded that increasing the albedo decreases the surface temperature, and this is a negative feedback loop. However, as a result of global warming, the melting of ice and snow cover occurs and this leads to a albedo decrease and increase in surface temperature. This process, as discussed in previous chapters, is called positive feedback loop.

Table 1. Dependence of the surface temperature on the changing albedo

Albedo (%)	Temperature (°C)
0	5.9
10	-1.4
20	-9.3
30	-17.9
40	-27.6
50	-38.5
60	-51.3
70	-66.7
80	-86.6
90	-116.3

In the previous chapters, we analyzed how negative and positive feedback loops affect the Earth's climate. This is a simplified model because the feedback loops are connected to each other. We have already said that the melting of ice leads to a decrease in albedo, which contributes to an increase in temperature. An increase in temperature means an increase in the possibility of fire. Large fires increase the concentration of CO_2 in the atmosphere, which is one of the most important greenhouse gases. A higher concentration of CO_2 in the atmosphere leads to an increase in temperature, which contributes to the additional melting of ice. Once started, it seems that the process of global warming is unstoppable because of the existence of positive feedback loops such as the previous one.

LIST OF SOME FEEDBACK LOOPS

Feedback loops in the next table are divided into three categories: physical, biological, and human [5]. Symbols indicate increasing (↑), decreasing (↓), and changing. (Δ) Abbreviations correspond to circulation (circ.), concentration (conc.), temperature (temp.), atmospheric (atmos.), chemical (chem.), sequestration (seq.), biogenic volatile organic compounds (BVOCs), ozone (O_3), evapotranspiration (ET), biological pump (bio.), and dimethyl sulfide (DMS).

Table 2. List of some feedback loops

Name of the feedback loop	**Effect of climate change**	**Effect on climate change**	**Positive or negative feedback loop**
		physical feedback loops	
1. Planck	↑ temperature	↑ heat loss	negative feedback loop (-)
2. Water vapor	↑ increasing concentracion	↑ green house effect	positive feedback loop (+)
3. Ice albedo	↑ ice melting	↓ albedo	positive feedback loop (+)
4. Sea level rise	↑ sea level	↓ albedo	positive feedback loop (+)
5. Snow cover	↓ snow cover	↓ albedo	positive feedback loop (+)
6. Solubility pump	↑ atmos. CO_2 level	↓ CO_2 abosrption by ocean	positive feedback loop (+)
		biological feedback loops	
7. Freshwater	↑ aquatic plant growth rates	↑ CH_4 emissions	positive feedback loop (+)
8. Forest dieback	↑ amazon and other forest dieback	↓ CO_2 sequestration	positive feedback loop (+)
9.Sahara/Sahel greening	↑ rainfall in Sahara and Sahel	↑ CO_2 seq. by vegetation	negative feedback loop (-)
		human feedback loops	
10. Human mobility	↑ movement (traveling)	↑ CO_2 emissions	positive feedback loop (+)
11.Human conflict	↑ conflict (↓ resources)	↑ military GHG emissions	positive feedback loop (+)

It should be emphasized that for a certain number of feedback loops, which are not listed in the table, it is not very clear whether they belong to a negative or positive feedback loop. This once again indicates the complexity in climate modeling as well as the complexity in examining the impact of feedback loops on the climate.

DISCUSSION

In general, feedback loops have an important impact on the Earth's climate either as climate stabilizers (negative feedback loops) or as factors that influence the occurrence of global warming. (positive feedback loops) Some of the feedback loops appears regardless of the anthropogenic influence. Scientists has identified 27 global warming accelerators known as amplifying feedback loops not be fully accounted in climate models. Some of the positive feedback loops significantly reinforce global warming because of their connection to greenhouse gas emissions. On the other hand negative feedback loops can be solution for stopping global warming. Generally, scientists believe that feedback loops affect the increase in global temperature. In order to explain this, we need to introduce the concept of climate sensitivity.

Climate sensitivity can be defined as the amount of surface warming resulting from each additional watt per square metre of radiative forcing. Alternatively, it is sometimes defined as the warming that would result from a doubling of CO_2 concentrations and the associated addition of 4 watts per square metre of radiative forcing. In the absence of any additional feedbacks, climate sensitivity would be approximately 0.25°C for each additional watt per square metre of radiative forcing. Stated alternatively, if the CO_2 concentration of the atmosphere present at the start of the industrial age (280 ppm) were doubled (to 560 ppm), the resulting additional 4 watts per square metre of radiative forcing would translate into a 1 °C increase in air temperature. However, there are additional feedbacks that exert a destabilizing, rather than stabilizing, influence, and these feedbacks tend to increase the sensitivity of climate to somewhere between 0.5°C and 1.0°C for each additional watt per square metre of radiative forcing.

CONCLUSION

Climate models predict that Earth's global average temperature will rise an additional 4°C during 21st Century if greenhouse gas levels continue to rise at present level. [6] Climate change is predicted to impact regions differently. Temperature increase are expected to be greater on land than over oceans and greater at high latitudes.

A warmer average global temperature will cause the water cycle to “speed up” due to a higher rate of evaporation. We are looking at the futere with much more rain and snow. Increase in concentration of evaporation in atmosphere, generally speaking, affects in rising global temperature. However, some of the clouds are involved in negative feedbacks loops. As the climate warms, snow and ice melt. Melting of glaciers, ice sheets and othe snow and ice on land in the summer will continue to be greater than the amount of precipitation that falls in the winet. In total amount of snow and ice on the planet will decrease. Because of this we will have much more absorved energy than reflected energy, and albedo will decrease.

Ocean is absorving CO_2 that would otherwise stay in the atmosphere. At some point, seawater will become satureted with CO_2 and unable to absorb any more. At that point CO_2 will land in the atmosphere increasing the rate of greenhouse warming. This is a real possibility since there is no water mixing and only the upper layers of the ocean absorb CO_2. In the future the oceans, one of the most powerfull negative feedback loop, can change and become positive feedback loop. Will life on Earth even be possible?

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Society of Physicists of Eastern Herzegovina

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Abstract. The Society of Physicists of Eastern Herzegovina, founded on December 22, 2017, in Trebinje, emerged from the collaborative efforts of local physics educators with a mission to advance the popularity and engagement of science, particularly physics. Established as the sole physicists' association in the Republic of Srpska, the society faced initial challenges due to limited institutional support and a lack of central coordination. The primary objective was to support talented students in physics competitions, which led to notable student achievements. Expanding its reach, the society initiated the Physics Festival and later the Winter Physics School, which aimed to spark interest in physics among a broader student base. The Winter Physics School, starting in 2018, has grown in scope and impact, benefitting from the dedication of educators and contributors who volunteer their time during the winter break. The society's efforts have gained regional recognition, and ongoing collaboration is encouraged to further the advancement of physics education and outreach.

Keywords: education, science popularization, physics festival, whinter physics school, physics competitions

INTRODUCTION

The Society of Physicists of Eastern Herzegovina was founded on December 22, 2017, in Trebinje. This initiative stemmed from the collaboration among physics professors and teachers from Trebinje who shared a common vision. Our organization is dedicated to being a key driver in the popularization of science, with a particular emphasis on physics. We strive to offer young enthusiasts engaging and interactive ways to connect with the world of science.

Establishing the society was a challenging process, primarily due to a lack of understanding and support from relevant institutions. Despite being the only physicists' association in the Republic of Srpska, we still face the issue of not having a central organization with which we could collaborate to advance the promotion and popularization of science, especially physics.

The initial goal of our association was to support talented students preparing for physics competitions. This goal was set into motion due to the fortuitous timing when my colleagues Maksim Mičeta, Dobroslav Sljepčević, and I began our careers in education as physics professors. Our shared enthusiasm for improving the state of physics education led us naturally to the idea of founding this society. Initially focused on Trebinje, our efforts have since expanded across the Republic of Srpska.

Physics Festival

Beyond working with talented students and preparing them for competitions—where our students have achieved notable results—we also aimed to engage students who previously showed less interest in physics. In pursuit of this, we organized the first Physics Festival in Trebinje, followed by similar events in neighboring towns such as Ljubinje and Bileća. Organizing these festivals was quite challenging due to the lack of necessary equipment for demonstration experiments in our schools and other institutions. However, with considerable enthusiasm, support from skilled craftsmen who volunteered their time, and the use of surplus materials, we successfully created a range of impressive demonstration devices.

Figure 1. First Physics Festival in Trebinje

Beyond One notable success story is that of a student who was in seventh grade at the time of our first festival. Initially, he had little interest in physics and a low grade in the subject. However, after participating in the Physics Festival, his enthusiasm for physics and other sciences was reignited. Today, he is a student at the Faculty of Electrical Engineering in Belgrade, has won numerous awards in physics, and has even become one of our best demonstrators, creating several demonstration devices himself.

Figure 2. Physics Festival in Trebinje

Winter Physics School

The original aim of our association was to support and prepare talented students for competitions. Not wanting to limit our efforts to just our own students, we also aimed to assist other students preparing for similar competitions. This led us to organize our first Physics School.

Figure 3. Winter Physics School

Our inaugural Winter Physics School took place in 2018 under modest conditions, but it remains one of our most cherished achievements. The sessions were held in the cold classrooms of "Jovan Dučić" Gymnasium and the American Corner (National Library Trebinje) from January 15 to January 19, 2018, daily from 09:00 to 13:00. Students from Trebinje, Ljubinje, and Bileća participated in this event.

Participants in the first Winter Physics School were divided into three groups based on their educational levels. The first group, comprising elementary and first-year high school students, focused on mechanics. The second group, made up of second-year high school students, tackled problems and lectures on thermodynamics and fluid dynamics. The third group, consisting of third and fourth-year high school students, explored advanced topics in physics, including electrostatics (such as electric vehicles and energy storage) and astrophysics

Figure 4. Winter Physics School

Encouraged by the success of the inaugural Winter Physics School, we have organized subsequent events—second, third, fourth, fifth, and this year's sixth Winter Physics School—with increasingly sophisticated organization and collaboration. We have been fortunate to work with numerous colleagues from beyond our region who have generously supported and responded to our calls, even though we held the Winter Physics School during the winter break when many people spend time with their families. Their dedication and sacrifice for the advancement and popularization of physics are truly commendable.

Figure 5. Winter Physics School

I would like to take this opportunity to express our gratitude to all the colleagues who have selflessly participated in the Winter Physics School. Alongside the popular lectures, laboratory exercises, and problem-solving sessions, we also organized recreational activities, including one-day trips to nearby cities such as Kotor, Herceg Novi, and Mostar. Additionally, we arranged guided tours of our city’s landmarks (such as the Museum of Herzegovina, Tvrdoš Monastery, Crkvina, and the Trebinje Hydroelectric Plant) and social gatherings with music and refreshments in the evenings.

Figure 6. Winter Physics School

Our efforts have garnered significant attention not only from students within the Republic of Srpska but also from an increasing number of students from the broader region. Finally, I would like to extend an invitation to all colleagues interested in collaborating with us. Together, we can work towards improving the position of science and physics in our society and continue to inspire and educate future generations.

Figure 7. Winter Physics School

CONCLUSION

The Society of Physicists of Eastern Herzegovina has made significant contributions to the popularization of physics and the improvement of education in the region through its activities. Despite the challenges faced during its establishment due to a lack of institutional support, the organization has successfully achieved its goals through various initiatives such as the Physics Festival and the Winter Physics School. These activities have not only assisted talented students in preparing for competitions but also inspired other students to develop an interest in physics. By establishing these programs, the society has managed to attract attention and support from various regions, demonstrating the importance and need for such initiatives. These efforts have shown how enthusiasm and dedication from educators can have a lasting impact on education and the popularization of science. The society's ongoing work, with further collaboration and support, has the potential to enhance the position of physics in society and inspire a new generation of scientists.

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Sustainable Diets: Bridging the Gap Between Human Health and Environmental Stewardship

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Abstract. The intersection of diet and environmental sustainability is a growing field of research, emphasizing the need for dietary patterns that support both human health and ecological balance. This paper explores how plant-based diets, compared to animal-based diets, can significantly reduce environmental impacts such as greenhouse gas emissions, land use, and water consumption. By analyzing recent data and modeling future scenarios, the study highlights the potential for dietary shifts to mitigate climate change while enhancing food security. It also examines the role of policy and consumer behavior in driving these changes, emphasizing the importance of integrating environmental considerations into dietary guidelines. This research underscores the critical link between what we eat and the health of our planet, suggesting that sustainable diets are essential for achieving global environmental goals.

Keywords: diet, environment, health, sustainability

INTRODUCTION

Sustainable diet is one that promotes human health and well-being while minimizing environmental impacts, ensuring the health of ecosystems and natural resources for future generations. It is nutritionally balanced, providing all the essential nutrients required for optimal health, while also being environmentally responsible. This type of diet emphasizes the use of locally sourced, seasonal, and plant-based foods, reduces food waste, and limits the consumption of resource-intensive products such as meat and highly processed foods. The sustainable diet supports agricultural practices that protect biodiversity, conserve water, reduce greenhouse gas emissions, and promote soil health. Ultimately, it strives to achieve a balance between meeting current dietary needs and safeguarding the planet's health for future generations.

Sustainable diets represent a crucial intersection between human health and environmental stewardship, addressing the urgent need to balance the nutritional requirements of a growing global population with the preservation of the planet's ecosystems. As the world faces rising rates of diet-related chronic diseases, such as obesity, cardiovascular disease, and diabetes, it becomes evident that our current food systems must evolve to support both human well-being and planetary health. At the same time, food production is one of the primary contributors to environmental degradation, accounting for significant greenhouse gas emissions, land use, and depletion of water resources. A sustainable diet is one that minimizes these environmental impacts while providing adequate nutrition to support health across all stages of life. This requires rethinking agricultural practices, reducing food waste, and promoting dietary patterns that are not only nutritionally adequate but also aligned with ecological sustainability. The challenge lies in designing diets that are accessible, affordable, and culturally appropriate, particularly in diverse socio-economic settings. While reducing meat consumption has been identified as a key strategy, it is important to consider the broader picture, where diverse plant-based foods, seasonal produce, and local sourcing can contribute to sustainability. Bridging the gap between health and sustainability demands interdisciplinary collaboration between nutrition experts, environmental scientists, policymakers, and the public. Ultimately, promoting sustainable diets is essential not only for mitigating climate change but also for addressing the global burden of malnutrition and chronic diseases. This paper aims to explore the pathways to achieving sustainable diets and the role of both individual and systemic actions in fostering a healthier, more sustainable future.

MATERIALS AND METHODS

For this review paper, a comprehensive literature search was conducted using academic databases such as PubMed, Scopus, and Google Scholar to identify relevant studies on sustainable diets, human health, and environmental impacts. Studies published between 2000 and 2023 were included, with a focus on peer-reviewed articles, reports from international organizations, and government publications. Key themes explored included the relationship between dietary patterns, food systems, and environmental sustainability, as well as the health outcomes associated with various dietary shifts. Articles were selected based on their relevance to the topic and methodological rigor, including both observational and intervention-based studies. The findings were synthesized to highlight the most current evidence and to identify gaps in research, offering a comprehensive understanding of sustainable diets.

RESULTS AND DISCUSSION

As we gain a better understanding of the principles behind a healthy, lower environmental impact diet, the challenge lies in altering population-wide dietary patterns and food choices. Historically, efforts to improve dietary habits have had limited success, despite the well-established benefits of a healthy diet for individuals. Shifting dietary habits to reduce environmental damage will likely be even more difficult, particularly because there is no immediate personal benefit to such changes. A recent study examining various "pro-environmental behaviors" (including actions like limiting flights, recycling, reducing food waste, and using less energy) found that while adopting a lower environmental impact diet was seen as the most feasible change, it was also the one people were least willing to make, with fewer than 10% of the population sample expressing readiness to do so. [1]The global discourse surrounding food systems has traditionally focused on production, with efforts aimed at reducing environmental impacts. However, the focus is now shifting towards human health, as we have the capability to produce enough food for both current and future generations. The new challenge lies in ensuring that the food system contributes to improved human health. This shift in focus calls for a “fork to farm” approach, emphasizing the need for “healthy foods from healthy soils.” Defining a "sustainable diet" is complex, as it involves the entire food supply chain and considers health, environmental impact, affordability, and cultural factors. Future food systems must provide nutrient-rich, affordable food options while also being restorative to the environment in terms of land, water, and energy use. To achieve this, changes must occur in both food supply and the demand for healthy food.

The global food system's impact on both human and planetary health has become a critical issue, with growing recognition of the need for transformation to meet the demands of a population projected to reach 9.7 billion by 2050. [2,3] Reports emphasize the importance of ensuring access to nutritious food while minimizing environmental harm.[4] Agriculture is identified as a major contributor to global environmental change, responsible for about 40% of land use, 70% of freshwater consumption, and 19-37% of global greenhouse gas emissions. [2,4] Even with immediate reductions in fossil fuel emissions from other sectors, current food production practices would hinder achieving the Paris Agreement's climate goals, especially the 1.5°C target.

In the UK, meat consumption is increasing, outpacing plant-based protein intake [5], and many people resist reducing meat due to cultural preferences [6]. Despite adequate protein intake, misconceptions about protein needs persist, partly due to media-driven high-protein diet trends [7]. Reducing meat consumption can lower greenhouse gas emissions, but the environmental benefits depend on the food substitutes, with some replacements potentially increasing emissions [8,9]. These findings highlight the complexity of shifting diets for health and environmental sustainability.

A study found that over 80% of participants correctly identified the recommended proportions of fruits, vegetables, dairy, and high-fat/sugar foods in a healthy diet[10]. However, more than 65% confused the recommended proportions of starchy carbohydrates and protein, overestimating protein's role in the diet. Many individuals, influenced by the perception that starchy foods are "fattening" and by low-carb diet trends, believe these should be minimized [11]. These misconceptions present a significant barrier to achieving a balanced, sustainable diet.

CONSLUSION

The pursuit of sustainable diets represents a crucial intersection between human health and environmental sustainability, addressing the dual challenges of rising global health concerns and escalating environmental degradation. This review highlights the multifaceted nature of sustainable diets, emphasizing the need for a dietary approach that supports both human well-being and the preservation of natural resources for future generations. The evidence points to the significant role that dietary patterns, food systems, and agricultural practices play in shaping both health outcomes and environmental impacts. Shifting global dietary habits, particularly reducing the consumption of resource-intensive foods like meat, is essential to mitigate the adverse effects on planetary health. However, this transition requires overcoming substantial challenges, including cultural preferences, misconceptions about nutrition, and the need for accessible, affordable, and culturally appropriate food choices.

The findings underscore the importance of interdisciplinary collaboration among nutritionists, environmental scientists, policymakers, and the public to create food systems that are not only nutritionally adequate but also ecologically sustainable. Sustainable diets should prioritize locally sourced, seasonal, and plant-based foods while reducing food waste and fostering agricultural practices that protect biodiversity and minimize environmental harm. Furthermore, addressing the environmental impact of food production, particularly agriculture, is essential for achieving global climate goals and ensuring the long-term health of ecosystems.

Given the growing global population and the increasing burden of diet-related chronic diseases, the need for a transformation in our food systems has never been more pressing. The shift towards sustainable diets must be coupled with broader systemic changes, including rethinking agricultural practices, promoting healthy eating habits, and ensuring that food systems are resilient and capable of meeting the nutritional needs of future generations. Ultimately, achieving sustainable diets is critical not only for mitigating climate change and environmental degradation but also for improving public health and reducing the global burden of malnutrition and chronic diseases. Further research and policy initiatives are required to close knowledge gaps and drive actionable solutions that promote the widespread adoption of sustainable diets, ensuring a healthier, more sustainable future for all.

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Long-Term Parallel Radon Concentration Measurement at TCAS

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Abstract. Air quality strongly affects human health. In closed spaces high radon concentrations in the air can cause lung cancer. Therefore, monitoring air quality is always recommended. We did one year-long radon level measurement at the Technical College of Applied Sciences in Zrenjanin. We parallelly measured radon with two different types of detectors (Fido track detectors and Airthings detectors) to compare radon concentrations and establish the reliability of the results. The obtained results are shown.

Keywords: indoor radon, CR39, airthings detectors

INTRODUCTION

Radon is an odorless and colorless inert gas, which is radioactive and can not be noticed by the senses. Radon originates from the decay of radium from uranium decay and it is present in rocks. Radon is the dominant natural source of ionizing radiation on the Earth [1] and its daughters are radioactive, too. The most important isotope of radon is ^{222}Rn.

Radon escapes from the ground and is present in the atmosphere in small detectable amounts. It can also be present in buildings and houses, which it enters directly from the ground via holes. Once in a while, radon can also be found in building materials, natural gas, or water. Thus occasionally radon concentration in dwellings can be rather large and dangerous for humans, so monitoring radon concentration in closed spaces is necessary.

At the Technical College of Applied Sciences in Zrenjanin (TCAS) in 2022 and 2023 we did some short-term few days long monitoring of radon concentrations in the rooms withing the College building, to see if there were some potential spaces with very high radon concentrations [2]-[6]. Later in 2023 [7] and 2024 we started long-term monitoring because radon concentration changes both during the day and also with different seasons. Besides this, in our National legislation radon concentration limits are given on an annual level. We did one year-long radon concentration measurement realized via two consecutive six months long measurements (July-December 2023 and January-June 2024). This is described in this paper.

DETECTORS

Radon concentration measurements were realized, in each of the rooms by simultaneously using two types of detectors, Fido Track Detectors [8] and Airthings radon detectors [9], [10].

Fido radon detectors (see Figure 1, [8]) are plastic track detectors. These detectors are made by Niton Company and they are passive CR39 type detectors. Detector's small plastic cylindrical boxes are a few centimeters long and wide. At the beginning of the measurement, they are taken out of protective boxes and exposed to the air in the room for a few months (two to six months). There is a diffusion chamber in the detectors and heavily charged particles leave tracks when passing through plastic. At the end of the measurement, detectors are again put in protective boxes and sent to a certified laboratory (in our case Niton Lab) for analysis, where they are treated with appropriate chemicals that make tracks visible. With the help of optical microscopes and adequate software, tracks are then counted and radon concentrations are obtained.

Figure 1. Photo of FIDO track detector (made by Niton).

We also used Airthings radon detectors for radon concentration measurement. These detectors for home use are active-type detectors. We worked with two models, the Correntium Home Radon Detector (see Figure 2, [9]) and the View Plus Radon detector. These two models have the same principle of work. The photodiode inside the detectors performs as a film on which passing particles leave tracks. Tracks are used to reconstruct radon decay events. Detector precision increases with the time of measurement. When the detector measures a radon concentration of about 200 Bq/m^3 for seven days (two months), its precision is 10% (5%). Detectors can measure radon concentrations up to 10000 Bq/m^3. View Plus Radon detector is a "smart" version and it also measures additional air quality parameters.

Figure 2. Photo of Airthings Correntium radon detector.

MEASUREMENTS

Weather changes together with temperature, humidity, and pressure oscillations influence radon concentration. Therefore, longer measurements give a more realistic estimation of radon level. At the beginning, of 2022 and 2023, we did short-term measurements to get the first rough estimation of radon concentration at TCAS. Then in the second part of 2023 [7] and the first half of 2024. we did two consecutive six-month-long measurements to obtain yearly concentrations at TCAS. We did the measurements with Fido track detectors and Airthings detectors simultaneously in four rooms (in the basement and ground floor) with the highest radon concentrations obtained during previous test measurements. Rooms were in standard use during the measurement period. Detectors (Airthings and Fido track) were placed on tables one near the other, and also far from walls, doors, windows, and heating bodies. Radon concentrations were measured in the period January-June 2024 are given in Table 1 below. Estimated errors for these measurements are also presented. Annual values are given in Table 2. Statistical Z-test [11] was also calculated and presented in both of the tables to understand the statistical difference between results obtained with different detectors.

Table 1. Radon concentration values were measured at TCAS with CR39 and Airthings radon detectors for six months (winter and spring 2024.).

Room	CR39 - radon concentration (Bq/m^3)	Airthings - radon concentration (Bq/m^3)	Z-test score
Creativity Studio (ground floor)	34(9)	44(1)	1.11
Library (ground floor)	23(7)	26(1)	0.43
Storage for technical equipment (basement)	39(10)	37(1)	0.20
Office 138 (ground floor)	35(9)	48(1)	1.44

Table 2. Radon concentration values were measured at TCAS with CR39 and Airthings radon detectors during one year-long measurement (July 2023.- June 2024.).

Room	CR39 radon concentration (Bq/m^3)	Airthings radon concentration (Bq/m^3)	Z-test
Creativity Studio (ground floor)	38(9)	46(1)	0.78
Library (ground floor)	26(7)	28(1)	0.28
Storage for technical equipment (basement)	37(9)	37(1)	0
Office 138 (ground floor)	39(9)	47(1)	0.89

The maximum annual radon concentration measured at TCAS is 47 Bq/m^3 and the minimum value is 26 Bq/m^3. Radon concentration values presented in Table 1 and Table 2 are similar. All the Z-test values are below 1.96 as required, so there is good statistical match between the two sets of results measured with different detectors.

CONCLUSION

Regular radon level monitoring is required by our National legislation, where 400 Bq/m^3 (200 Bq/m^3) is the radon level limit for old (new) buildings and 1000 Bq/m^3 is the upper threshold for the work environment [12]. European regulations imposed a limit of 300 Bq/m^3 for radon concentration in all closed spaces [13], while the World Health Organization advises less than 100 Bq/m^3 [14]. Yearly radon concentration measurements at TCAS show that radon concentrations are below our national and also international radon level limits. So there is no danger for people to stay at TCAS. Results obtained with two different types of detectors (Fido track and Airthings) show good match, which is additional confirmation that the obtained results are reliable.

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Energy and Its Nonrenewable Sources in the Environment

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Abstract. The first section of this paper will explore the concept of energy, its fundamental forms, and the law of energy conservation. The second section will examine nonrenewable energy sources, specifically focusing on the global outlook for energy consumption from these sources.

Keywords: energy, conservation of energy, nonrenewable energy sources

INTRODUCTION

As is widely known, "energy" refers to a physical quantity that describes the ability of a body to perform work and is expressed in joules (J) in the SI system. In physics, energy appears in various forms, including mechanical, internal, magnetic, electrical, electromagnetic, chemical, and nuclear. The energy we use on Earth, except for nuclear and geothermal energy, generally originates from sunlight, transforming photosynthesis. As the global population grows and technological advancements continue, the demand for energy increases. Currently, fossil fuels are the primary energy source, contributing to environmental changes, particularly weather patterns and climate.

The paper will begin with an overview of one of the fundamental principles in physics – the law of energy conservation. This will be followed by discussing the basic classification of energy sources into renewable and nonrenewable categories, specifically focusing on nonrenewable sources. The final section will present statistics on the share of energy derived from these sources in global commercial energy consumption.

THE LAW OF CONSERVATION OF ENERGY

One of the fundamental laws of nature is the law of energy conservation. In the oldest physical theory, mechanics, this law is interpreted as the so-called law of conservation of total mechanical energy, according to which the sum of the kinetic and potential energies of particles in an isolated system, acting on each other through conservative forces, remains constant, i.e. $\sum_{i=1}^{N}(E_{ki} + E_{pi}) = \text{const}$. In thermodynamics, the law of conservation of energy is formulated in the form of the first law (principle) of thermodynamics, which states that the amount of heat exchanged between a thermodynamic system and its surroundings is equal to the sum of the change in internal energy of the system and the work performed by the system, i.e. $Q = \Delta U + A$. In other physical theories, the statement of this law may differ slightly in terms and quantities used. However, fundamentally, at the core of all formulations of the law of conservation of energy is the fact that energy in an isolated physical system, and thus in nature as a whole, i.e. the universe (which is a closed system), cannot be created or destroyed, but only transformed from one form to another.

ENERGY SOURCES

As mentioned in the introduction, all forms of energy on Earth, except for geothermal and nuclear energy, generally originate from solar energy, which is transformed into other forms of energy through photosynthesis or other processes.

Energy sources on the planet can broadly be categorized into renewable and nonrenewable sources. Renewable energy sources include solar radiation, wind, water currents, tides, wave energy, geothermal energy, and biomass, while nonrenewable sources include fossil fuels (coal, oil, natural gas) and nuclear energy.

NONRENEWABLE ENERGY SOURCES

As previously noted, nonrenewable energy sources encompass fossil fuels and nuclear energy. However, to be more accurate, all energy sources on Earth can be considered nonrenewable; the key distinction lies in the timescale over which they are utilized.

Fossil fuels, which include coal, oil, and natural gas, are substances in various states of matter with a high concentration of hydrocarbons. They form from the compression of accumulated plant and animal remains under intense pressure within the Earth's crust. When these fuels are burned—through a reaction with oxygen—their chemical energy is transformed into heat, released in an exothermic reaction. The energy released during this process is called the fuel's calorific value. For instance, lignite coal has a calorific value of $15\ \frac{\mathrm{kJ}}{\mathrm{g}}$, gasoline $47\ \frac{\mathrm{kJ}}{\mathrm{g}}$, natural gas $54\ \frac{\mathrm{kJ}}{\mathrm{g}}$ and so on. However, harnessing all the energy released this way is impossible due to inherent energy losses. The ratio of useful energy to the total energy released is called the efficiency, expressed as $\eta = \frac{E_\iota}{E}$.

Coal is a solid fossil fuel that was first used as a heating source 3,000 years ago in China. Today, it remains an essential fuel for heating homes and industrial plants and in thermal power stations, where the heat released from burning coal is converted into mechanical energy and then into electricity. Global coal reserves are ten times greater than oil and natural gas, and at the current extraction rate, these reserves are expected to last for thousands of years.

Oil is a viscous liquid, ranging in colour from dark yellow to green or black, with a density of $820\ \frac{\mathrm{kg}}{\mathrm{m}^3} - 920\frac{\mathrm{kg}}{\mathrm{m}^3}$. It is a mixture of various hydrocarbons and compounds containing nitrogen, sulfur, and oxygen. Different derivatives are produced during refining, including kerosene, gasoline, diesel, solvents, lubricants, asphalt, and products such as pesticides, plastics, synthetic fibres, paints, and pharmaceuticals. There are about 65,000 oil reserves worldwide, with 65% of global reserves in the Middle East. Estimates indicate that approximately 1.1 terabarrels of oil remain, sufficient for less than 40 years of global consumption at the current rate.

Natural gas is a mixture of hydrocarbons in a gaseous form, mainly consisting of methane (90%), along with smaller amounts of propane, ethane, and others. It is typically found in the same locations as oil. Due to its relatively low cost and high efficiency (75%–95%) is often favoured over other fossil fuels. Additionally, natural gas burns cleanly, producing water, minimal impurities, and half the carbon dioxide emissions compared to other fuels. Estimates indicate that the world's natural gas reserves are enough to supply demand for 60 years and possibly even 200 years, depending on the consumption rate.

Nuclear energy originates from the strong interaction between nucleons within atomic nuclei. This energy can be released through fission, where heavier nuclei split into lighter ones, or fusion, where lighter atomic nuclei combine to form heavier ones. When released uncontrollably during these processes, this energy is used in fission (atomic) and fusion (thermonuclear, hydrogen) bombs. In controlled settings, such as nuclear power plants, the energy produced from nuclear fission – mainly involving uranium – is harnessed to generate electricity.

Nuclear energy began being utilized for military and civilian purposes in the 1950s. It is worth mentioning that fusion processes can yield more energy than fission. However, achieving fusion requires temperatures of around 100 million Kelvin and the plasma at these temperatures must be confined to ensure the continuous and controlled progress of the fusion reactions. Overcoming these technological hurdles –currently the focus of extensive research in scientific labs worldwide – could eventually lead to the development of fusion-based nuclear power plants. These plants would rely on easily accessible fuels, such as deuterium. At the same time, the byproduct of the process, in addition to the electricity generated, would be helium– a gas that is harmless to the environment.

In global commercial energy consumption, energy from nonrenewable sources accounts for 93%, with 87% coming from fossil fuels (oil – 37%, coal – 26%, natural gas – 24%) and 6% from nuclear energy. The remaining share in global consumption is attributed to hydropower at 6%, while all other renewable energy sources make up only 1%.

One of the main issues with extracting energy from nonrenewable sources is the byproducts of fossil fuel combustion and the radioactive waste produced by nuclear power plants, which, without proper management, can lead to environmental contamination. Moreover, the use of nonrenewable energy sources contributes to the emission of greenhouse gases, increasing their concentration in the atmosphere. This, in turn, intensifies the greenhouse effect, driving up the planet's average annual temperature. Coupled with the potential risks of disasters (such as Chernobyl and Fukushima) and the limited reserves of energy stored in nonrenewable sources, these factors underline the importance of advancing technology and techniques to improve the efficiency and utilization of renewable energy, also known as "green energy."

CONCLUSION

This paper begins with a general overview of the concept of energy. It outlines the classification of energy based on its various forms and discusses the law of energy conservation. After presenting the division of energy sources on Earth, special attention was given to the key characteristics of nonrenewable energy sources, their capacities, and their proportional representation in global commercial energy consumption. Finally, the paper highlights the challenges associated with exploiting nonrenewable energy sources.

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Green Energy Opportunity

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Abstract. Following the introductory remarks on energy and its various forms in nature, the main section of the paper will explore the fundamental characteristics of renewable energy sources, including solar power, wind energy, hydropower, tidal energy, wave energy, geothermal energy, and biomass energy.

Keywords: energy, forms of energy, renewable energy sources

INTRODUCTION

Energy, as a physical quantity, measures the ability of a body to perform work. It manifests in various forms: mechanical, internal, electrical, magnetic, electromagnetic, chemical, and nuclear. The total energy of an isolated system (including the entire cosmos) remains constant over time, reflecting one of the most fundamental laws of nature known as the law of energy conservation. In other words, within an isolated system, one form of energy can be converted into another, but the system's total energy always remains unchanged.

All forms of energy on Earth, except nuclear and geothermal energy, derive from the solar radiation emitted by the Sun. Energy sources on our planet can broadly be categorized into two groups: renewable and non-renewable sources. Renewable sources will not significantly decrease over several human generations, including solar radiation, wind, water currents, tides, wave energy, geothermal energy, and biomass. Non-renewable energy sources encompass fossil fuels (coal, oil, natural gas) and nuclear energy.

RENEWABLE ENERGY SOURCES

Renewable energy sources (Green Energy Resources) generate clean, eco-friendly energy, often referred to as "green energy." More precisely, energy from these sources is produced in ways that do not lead to environmental pollution. The following text will outline the main characteristics of "green energy" sources.

Sunlight is a renewable energy source from which solar energy is converted into other forms in passive and active solar systems. In passive solar systems, solar radiation is absorbed and re-emitted as heat radiation. Essentially, these systems involve the passive absorption of heat (for example, specific materials used in building construction). Active solar systems, used since the mid-20th century, capture thermal energy through solar collectors (panel and vacuum types) and generate electricity via photovoltaic cells based on the photovoltaic effect.

Wind energy is converted into electrical power through wind turbines, often called “windmills”. These turbines function based on the principle of electromagnetic induction, discovered by English physicist and chemist Michael Faraday in 1831. The capacity of a single wind turbine can reach up to 5 MW. Wind farms with these turbines are typically located in regions where wind is a frequent occurrence throughout the year, such as the Košava area of Banat (Kovačica, xVršac).

Hydropower is based on the natural water cycle and is Earth’s most widely used renewable energy source. Hydropower has been harnessed for centuries, initially in watermills, and by the late 19th century, hydroelectric power plants began to be built. In these plants, the potential energy of water stored in reservoirs is converted into kinetic energy as it falls. This kinetic energy is then transferred into kinetic energy of the turbine rotors (generators), where it is further transformed into electricity through electromagnetic induction. In 1925, 40% of the world’s electricity came from this renewable source. Today, the use of hydropower has increased by 15 times. Still, the use of fossil fuels has also risen, causing the share of this “green energy” in global electricity production to decrease to about 20%.

Tides occur due to the gravitational forces exerted by the Moon and the Sun on Earth’s water surfaces. The rise and fall of water levels along coastlines, which happens twice a day due to Earth’s rotation, is used in tidal power plants to drive turbines and generate electricity, following the same principle as hydroelectric power plants. On average, the difference in water levels between high and low tide along the world’s coastlines is about 1 meter. However, tidal power plants are only economically viable in areas where the tidal range exceeds 2 meters.

Waves are driven by the wind. The energy of the waves, and thus their power, is proportional to the square of the wave height $E \sim H^2$. In other words, the energy a water wave carries is proportional to the square of the change in the water level. This energy is converted into electricity in so-called shore generators designed to harness wave energy. It is worth noting that, in addition to shore-based systems, there are also systems that operate in deep waters.

Geothermal energy is the internal energy of the Earth, responsible for phenomena such as the movement of tectonic plates, the uplift of mountains, volcanic eruptions, and earthquakes. In geothermal power plants, this energy is harnessed and converted into electricity.

Biomass refers to any organic material that can be utilized as an energy source. This includes, for example, wood, harvested crops, solid waste, manure, methane gas, alcohol-based fuels… Textile waste, such as byproducts from raw and finished textile materials and products derived from them in home industries, the textile industry, automotive and aerospace industries, and the construction sector, can also be categorized as biomass. The amount of biomass generated in organized production processes is often significant. For instance, a company may generate up to 35% of textile waste in the textile industry relative to the total fabric used. Waste is typically incinerated, stored for reuse as secondary raw material, or sent to recycling and processing centres. Incineration remains the most common method for converting waste and biomass into energy. 90% of the energy produced from biomass combustion comes from burning wood. This process generates "green energy", providing a solution to waste management and helps mitigate potential environmental pollution. Additionally, energy can be extracted from biomass using other methods. For example, the so-called bioenergy plants often use methane released from manure to power turbines and produce electricity.

PERSPECTIVES OF USING "GREEN ENERGY"

Non-renewable energy sources currently contribute 93% of global energy production, while renewable sources account for the remaining 7%, with hydropower making up the most significant portion at 6%. The limited capacity of non-renewable resources and their environmental impact – particularly concerning climate change (the greenhouse effect) and potential pollution – underscore the need for technological advancements to enhance "green energy" sources. Simultaneously, as part of sustainable development strategies, there is a focus on improving energy efficiency and reducing energy consumption by minimizing the energy required to produce goods and services, developing more efficient energy storage solutions, and cutting energy losses across all sectors.

CONCLUSION

After an introduction to energy, its various forms, and the classification of energy sources on Earth, the paper discusses the main characteristics of renewable energy sources, including solar radiation, wind, water flows, tides, wave energy, geothermal energy, and biomass. It also explores the methods, opportunities, and prospects for expanding the use of "green energy" sources, driven by the limited capacities of non-renewable sources, the need to address waste issues, and the broader goal of environmental conservation and energy efficiency.

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Sensors in the System of Industrial Automation and Regulation of Physical Parameters

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Abstract. In order to increase efficiency, product quality, reduce production costs and increase capacity, industrial automation and process management were applied. Modern measurements are mainly based on converting physical quantities into electrical signals. Amplification and processing of the electrical signal, remote transmission and reading of the results have been perfected, and in addition, high metrological quality is achieved in terms of accuracy, sensitivity and reliability of measurements. The conversion of mechanical, chemical, biological and process quantities into an electrical signal is performed using various converters, transmitters, etc. In recent times, the term "sensor" has been used for these devices. By applying sensors in technological processes, the development of industrial automation is enabled.

Keywords: automatic control system (ACS), sensor, signal, analog, digital

INTRODUCTION

Automation comes from the ancient Greek word - (self - management). Industrial automation is the use of systems, such as computers, to control industrial production processes, with the intention of replacing human operators. Today, automation is primarily used for the purpose of increasing quality during the production process, as well as reducing production costs. However, all new controllers, which are the main part of the process, have the ability to connect to the Internet, thus they also have remote servicing and error detection [1].

Signals are carriers of information that form the basis for establishing communications and relationships in any information system. Signals are therefore material carriers of information. A signal in itself is not information at the same time. Signals transmit information.

Analog signal - It is a time continuous signal. Examples of analog signals are sound, temperature, air pressure, etc.

Digital signal - It is a time discrete signal. Examples of digital signals are switch states (on or off), binary code in computers (0 or 1), Morse code, and others.

Programmable Logic Controller or *PLC* is a programmable (programmable device), logic (executes logic algorithms), controller (computer). *PLC* is mostly used as a central part of control automatic systems in industry, its program or algorithm can be changed quickly and easily and is suitable for quick solutions and applications. Ordinary computers would not withstand the operating conditions in which the controllers operate for years without any problems [2].

SCADA (Supervisory Control And Data Acquisition) is a system for measuring, monitoring and controlling industrial systems. Every process in the industry, which makes sense to automate, can find the application of SCADA systems and networks. They can be used from simple monitoring of temperature, air humidity, pressure, to very complex monitoring and control of factory production processes [3, 4].

Machines cannot replace professional knowledge (know-how), but they are often more efficient than humans in performing repetitive functions, [5].

Levels of industrial automation systems

The levels of industrial automation - Process / Machine are shown in Table 1, and are divided into three levels. The first level contains sensors and executive bodies, which are in direct connection with the process, that is, the machine and represent the "eyes and hands" of the controller. The second level is the automatic management process. The third level involves supervisory management: supervision of the production system, maintenance and quality control [6].

Table 1. Levels of Industrial Automation – Process / Machine

Process / Machine	**Levels of Industrial Automation**
(1) Sensors, Actuators	Devices (Embedded) h/w, s/w
(2) Automatic control	In real time (Real time) s/w, Special h/w
(3) Supervisory management	On-line, Real-time s/w General h/w

It is not necessary that all of the above levels be fully automated. That is, the levels of sensors and actuators, as an automatic control system, must necessarily be automated. Specifically, the equipment and systems at level (1) are realized in the form of microprocessor systems at the level of software and hardware. Equipment and systems at level (2) are implemented in the form of integrated microprocessor systems, software and hardware. Level (3) - supervisory management, includes supervision of production, maintenance and quality control, at the level of software and hardware.

The process of realization of levels (1) and (2) is carried out through the following steps:

1. description of the technological process, i.e. (technologies of system operation),
2. determination of the logical function in the form of a combined table, canonical form,
3. minimization of logical functions,
4. determination of logical diagrams of logical functions,
5. selection of the technology of physical realization (and eventual adaptation of the logic diagram according to the chosen technology of physical realization),
6. creation of a management scheme for the chosen technology of physical realization.

Sensors technique

Means for obtaining information in automatic control system - ACS, provide information about the characteristics of process parameters. Modern measurements are mainly based on converting physical quantities into electrical signals. Amplification and processing of the electrical signal, remote transmission and reading of the results have been perfected, and in addition, high metrological quality is achieved in terms of accuracy, sensitivity and reliability of measurements. The conversion of mechanical, chemical, biological and process quantities into an electrical signal is carried out using various converters, transmitters, etc. In recent times, the term *sensor* has been used for these devices, which coincided with the development of materials and technologies, the application of micromechanics and a high degree of integration of components and great possibilities in processing information using microelectronics.

Sensors - sources for obtaining information in ACS

Information on the behavior of basic parameters: temperature, flow, level, pressure, time, position, etc. is of particular importance for the management of technical systems. Temperature and flow typically account for more than half of all measurements taken for management purposes. In the management of technological facilities (power plants, chemical plants, heating plants), 80% of all measurements are made only on temperature and flow measurements. Other quantities (viscosity, acidity, conductivity, etc.) account for less than 10% of all measurements. However, in other areas of management, the share of temperature and flow decreases, so that in agriculture temperature accounts for 16.7%, and in individual production only 9%. But, in these areas, there is a greater number of measurements of other quantities, especially position, time, mass, etc. Information is essentially obtained by measuring physical quantities that characterize the behavior of the process [5, 7].

Classification of sensors

The division of sensors is not simple - it is done in relation to one of their properties: the nature of the measured quantity, the type of output signal, the nature of the output quantity, internal structure or reliability.

The division into active and passive sensors is not straightforward. Some authors make this division based on whether the output signal of the sensor is based on the energy of the measured quantity (passive sensor) or whether the measured quantity modulates the energy of an external source (active sensor). For example, sensors with an electrical output signal can be passive or active.

According to this interpretation, passive sensors are actually direct-type measuring devices, because the energy necessary for measuring and transporting the output signal is taken from the measurement object. Examples are: resistive sensors, capacitive sensors, inductive sensors.

Active sensors are measuring instruments of the indirect type, which receive the energy necessary for measurement from an external source. The external source is usually electric, pneumatic or hydraulic. Examples of active sensors are: electromagnetic sensors, thermoelectric sensors.

In general, passive sensors are simpler in construction and cheaper than active sensors, so the choice of one or the other for a specific measurement is a matter of compromise between price and required measurement resolution.

There are basically several groups of circuits where sensors are used: measuring circuits and amplifiers; analog computer amplifiers; A/D converters; and microcomputers ie. processors (microcontrollers).

In the process industry, processing circuits are mostly used, which convert the sensor signal into a current signal 4 – 20 mA, [7].

Physical principles of sensor operation

In the construction of sensors, greater importance is attached to energy as a carrier of information, especially electricity due to the ease of manipulation. The basic forms of energy determine six signal domains:
- the radiation signal domain (ra) refers to all radiation, from radio waves to γ radiation,
- domain of mechanical signal (me), refers to the external parameters of the object such as position, dimension, velocity and force,
- domain of thermal signal (th), has only one signal - object temperature,
- domain of electrical signal (el), refers to electrical parameters: voltage, current, resistance, capacity,
- the domain of the magnetic signal (ma), has one parameter - the intensity of the magnetic field,
- chemical signal domain (ch), refers to the internal structure of matter, with concentration, crystal structure and aggregate state.

Measurement of non-electrical signals begins with conversion to electrical signals, and then processing is performed. Based on that, the principles of sensor operation are based to the greatest extent on the basic laws of electrical engineering. For example, there are resistive sensors, capacitive sensors, inductive sensors, etc. [5, 8].

Structure of sensors

Sensors are devices that can measure various physical quantities such as temperature, pressure, velocity, acceleration, position, light intensity, etc. and provide a review of the measured physical quantity in the form of an electrical signal, e.g. voltage, current, resistance, inductance, etc. Sensors can be analog or digital [9, 10].

Analog sensors provide analog outputs (voltage, resistance). The analog output of the sensor is read by the microcontroller with the help of an AD converter.

Digital sensors directly provide digital binary outputs corresponding to the measured quantity.

Most often this sensors communicate with a microcontroller. The structure of the sensor is given in Figure 1.

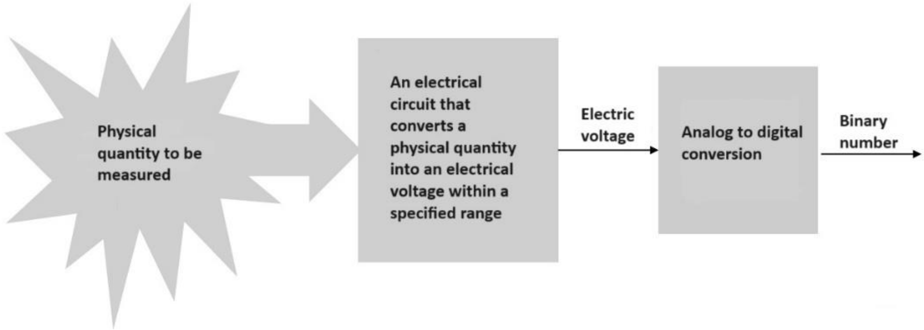

Figure 1. Structure of the sensor

Digital sensors contain electronics for converting a physical quantity into a voltage, and an analog-to-digital converter, and often, in addition, electronics for communication with the controller.

Analog sensors contain all or part of the electronics for conversion, while analog-to-digital conversion takes place in the microcontroller itself.

Conversion of a physical quantity into an electrical voltage (example of temperature measurement)

There are materials that change their resistance due to a change in temperature (the measured physical quantity causes changes in electrical characteristics).

Resistors that change their resistance due to temperature changes are called thermistors.

PTC – *Positive Temperature Coefficient* thermistors whose resistance increases with increasing temperature;

NTC – *Negative Temperature Coefficient* thermistors whose resistance decreases with increasing temperature.

Figure 2 shows the dependence of resistance on temperature.

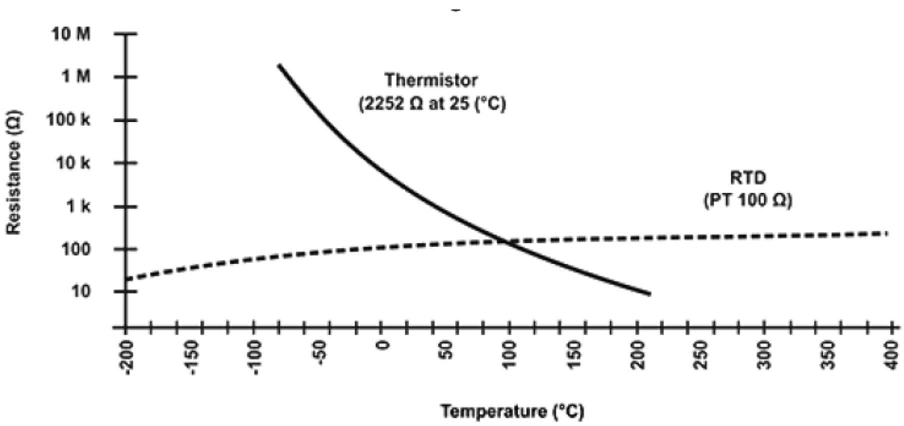

Figure 2. Dependence of resistance on temperature

RTD (Resistance Temperature Detector) is device made of pure metal wire, usually platinum (Pt 100 Ω, t = 0 ºC) or copper, which always increases in resistance with increasing temperature. The major difference between thermistor and RTD is linearity: thermistor is highly sensitive and nonlinear, whereas RTD is relatively insensitive but very linear.

Resistance depends nonlinearly on temperature:

$$R(T) = R(T_0) \cdot e^{\beta \cdot \left(\frac{1}{T} - \frac{1}{T_0}\right)} \tag{1}$$

where is:
R (T_0) - resistance measured at a specific temperature
β - coefficient that depends on the material

If we know the resistance of the thermistor, we can calculate the temperature:

$$T(R) = \frac{1}{\frac{1}{T_0} + \frac{ln\frac{R}{R(T_0)}}{\beta}} \tag{2}$$

CONCLUSION

Modern measurements are mainly based on converting physical quantities into electrical signals. Converting physical and process quantities into electrical signals such as temperature, pressure, velocity, acceleration, position, light intensity, etc. it is done using different converters, transmitters, etc. In recent times, the term *sensor* has been used for these devices.

Information on the behavior of basic parameters: temperature, flow, level, pressure, time, position, etc. is of particular importance for the management of technical systems. In the management of technological facilities (power plants, chemical plants, heating plants), 80% of all measurements are made only on temperature and flow measurements. Other quantities (viscosity, acidity, conductivity, etc.) account for less than 10% of all measurements.

In the construction of sensors, greater importance is attached to energy as a carrier of information, especially electricity due to the ease of manipulation.

Measurement of non-electrical signals begins with conversion to electrical signals, and then processing is performed. Based on that, the principles of sensor operation are based to the greatest extent on the basic laws of electrical engineering. For example, there are resistive sensors, capacitive sensors, inductive sensors, etc.

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Stable Isotopes of Water and Managed Aquifer Recharge

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Abstract. The stable isotopes of hydrogen and oxygen (specifically, deuterium and ^{18}O) are known for their use in hydrogeology. They are used, among other things, to study reservoir mixing and recharge processes in karst aquifers, as well as to estimate the mean residence time of groundwater and the average elevation of recharge areas. This paper presents the use of ^{2}H and ^{18}O in the design and monitoring of managed aquifer recharge (MAR). MAR is a promising climate change adaptation strategy based on the artificial recharge of aquifers. In addition to an overview of the available literature, the BLUE RECHARGE project is briefly presented, in which ^{2}H and ^{18}O are used to test the feasibility of MAR in Croatia.

Keywords: climate change, hydrological extremes, adaptation strategies, stable isotopes, artificial recharge

INTRODUCTION

Many adaptation strategies are being developed to increase resilience to the hydrological extremes associated with climate change. Managed aquifer recharge (MAR) is one of these promising methods. This article first explains the basics of isotope hydrology and MAR and then gives a brief overview of the results of isotope research related to various MAR programs. Finally, a short description of the first project in the Republic of Croatia to incorporate isotope research into the MAR implementation strategy is given.

BASICS OF STABLE ISOTOPE HYDROLOGY

Isotope hydrology is a field of hydrology and geochemistry that uses isotopes to study different parts of the water cycle. Although both stable and radioactive isotopes are used in isotope hydrology, in this paper we focus only on the stable isotopes of hydrogen (^{1}H, ^{2}H) and two of the three stable isotopes of oxygen (^{16}O, ^{18}O).

The stable isotope composition of water is represented by the "delta value", where δ (‰) = R_{sample} / $R_{standard}$ – 1. R_{sample} stands for the ratio of the abundance of the heavier to the lighter isotopes in the sample, while $R_{standard}$ represents this ratio in the standard. The delta scale for water is the VSMOW scale, named after the international standard for water, VSMOW (Vienna Standard Mean Ocean Water). Delta values of naturally occurring fresh water that has not been exposed to significant evaporation are normally negative. A negative delta value means that the amount of the heavier isotope in the sample is lower compared to the standard.

There is a linear correlation between ^2H and ^{18}O values in natural waters, i.e. a Global Meteoric Water Line (GMWL): $\delta^2H = 8 \cdot \delta^{18}O + 10‰$ [1].

The origin and patterns of moisture transport have a significant influence on the isotopic composition of precipitation. There are also complex dependencies between the isotopic composition of precipitation, air temperature, and the amount of precipitation. Fractionation processes during the phase change cause variations in the isotopic composition of the water [2]. A simple theoretical example of the influence of evaporation and condensation on the stable isotopic composition of water is shown in Figure 1. Compared to the evaporating body (e.g. the ocean), water vapor is depleted in heavy isotopes. On the other hand, heavy isotopes are more abundant in rain than in residual vapor. If there is no further evaporation after the precipitation has reached the subsurface, its isotopic composition remains unchanged. However, the mixing of water with different isotopic compositions (e.g. due to different precipitation inputs) causes fluctuations in the stable isotopic composition of groundwater [3].

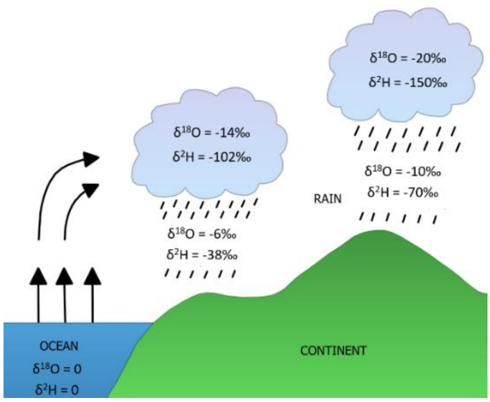

Figure 1. A theoretical example of the changes in the isotopic composition of water in the atmospheric part of the water cycle [4].

Typical examples of the use of stable hydrogen and oxygen isotopes in hydrology are the characterization of karst aquifers [5,6], the determination of the mean residence time of water [7,8], and, in general, a better understanding of various hydrological processes [9–11].

MANAGED AQUIFER RECHARGE

MAR is an example of sustainable water management in regions where anthropogenic or natural factors threaten water quantity and/or quality. It can be a useful tool to balance groundwater levels and prevent excessive water abstraction. MAR is also often used to recharge aquifers with declining yields and to regulate saltwater intrusion into coastal aquifers. Therefore, MAR is one of the possible adaptation strategies to reduce vulnerability to climate change and hydrological variability.

There are many recharge techniques for MAR, including induced bank filtration, infiltration ponds and basins, flooding, excess irrigation and sprinkling infiltration through forest floors. For more information on MAR methods, see [12]. River water, rainwater, lake water, desalinated water, and recycled waste water can all be used as MAR inflow sources. MAR practices are widespread throughout the world [13]. In the EU, most MAR activity is in the Netherlands and Germany, while in the Mediterranean the most active MAR sites are in Spain and Tunisia.

EXAMPLES OF STABLE ISOTOPE STUDIES IN THE MANAGED AQUIFER RECHARGE

Although MAR appears to be a promising technique for adapting to climate change, caution is needed as it is not suitable for all places affected by water scarcity. It can be difficult to select a good MAR site as a number of parameters need to be considered, including topography, soil characteristics, aquifer properties, and the availability of surplus surface water.

Stable isotopes as an instrument for characterizing aquifers and investigating the interaction between surface water and groundwater have also found application in MAR. The best practice for a MAR project would be to start using isotopic methods as a component at the planning stage. The basic geochemical and isotopic properties of an aquifer and the waters involved should be monitored over a sufficiently long period of time to ensure that normal variations in the isotopes and geochemistry of the groundwater are known. This will help to understand how a natural groundwater system responds to artificial recharge as well as to the simple mixing of infiltrated water with local groundwater.

One of the main reasons why the stable isotope technique should be included in MAR implementation planning is the need to quantify the input of surface water into the subsurface from a volumetric and spatial perspective [14]. In the example described in [14] the determination of δ^2H and $\delta^{18}O$ was carried out to monitor the efficiency of the infiltration process, to calculate the ratios of infiltration water and local groundwater, and to control the flow paths of the infiltrated water.

Parimalarenganayaki et al. [15] presented the application of stable isotopes to understand the recharge processes from the MAR structures. This was a semi-arid area where almost the entire annual precipitation falls within a few days. The result is flooding during the monsoon and water shortage in the summer season. In the example described, the water was stored by so-called check dams (small, temporary structures built in areas of concentrated runoff, such as swales, channels and ditches). Understanding the interaction between the groundwater and the water stored in check dams helped to identify the areas that have benefited from the implementation of MAR. For the study, samples were taken from the check dam as well as groundwater samples from nearby wells. In addition to determining the presence of stable isotopes, electrical conductivity (EC) and chloride (Cl) were also measured. The study showed that MAR has a positive effect on the state of the groundwater in wells up to 1.5 km away from the check dam.

García-Menéndez et al. [16] reported hydro-geochemical changes during MAR in a coastal aquifer with saline groundwater as a result of seawater intrusion. They used stable water isotopes as well as EC, Cl, and nitrate ions to determine the mixing ratio of injected water and groundwater.

Due to the significantly different isotopic composition of desalinated seawater (usually positive delta values) and natural groundwater (usually negative delta values), stable water isotopes are very well suited as tracers for predicting future mixing and spreading trends when desalinated water is used as MAR inflow [17].

BLUE RECHARGE PROJECT

Excessive abstraction of water from coastal aquifers, rising sea levels, and the increasing frequency of extreme events such as droughts and storm surges can lead to a particular threat to coastal aquifers: the intrusion of seawater into the aquifer and the resulting salinization of water sources. The process of salinization can be quite rapid, but the restoration of aquifers, which involves both soil and freshwater quality, is a slow, long-term process. The coastal aquifers in Croatia and Italy are extremely vulnerable to this phenomenon.

The general objective of the Italian-Croatian Interreg project BLUE RECHARGE is to achieve and maintain a good chemical and quantitative status of groundwater in the southern part of the Istrian peninsula (Croatia) and in the coastal area of the Po Valley (Italy) – both under significant influence of the sea. With the project, the partners involved hope to help reverse the current trend of overexploitation of underground water resources, improve groundwater quality, increase the implementation rate of the MAR, and promote the sustainable use of water resources.

A key element of the project is the creation and dissemination of an integrated knowledge system on the hydrogeological structure of aquifers, the identification of groundwater recharge areas, the chemical and qualitative status of aquifers, the status of water reserves, etc. The project also includes a campaign to raise awareness and increase the active participation of water resource users in the rebalancing of groundwater stocks by presenting the feasibility and environmental sustainability of the proposed technical solutions.

The determination of the isotopic composition of the water will be carried out during the planning of the implementation of the MAR in the Istria case study. The study includes monitoring the isotopic composition of precipitation at five sites and groundwater sampled from existing wells in the study area. The data on the isotopic composition of precipitation and groundwater will be complemented by data on air temperature, pressure, relative humidity, wind speed, precipitation amount, evapotranspiration, soil moisture, and solar radiation as well as EC, Cl and temperature of groundwater. The aim of this case study is to determine the origin of the precipitation and groundwater, to estimate the area and average recharge altitude of the corresponding aquifer, to determine the reaction of the aquifer to precipitation inputs, to estimate the average residence time of the water in the subsurface and the status of the water reserves.

CONCLUSION

MAR practices are widespread around the world, but even so, the implementation of a MAR project may have to overcome strong public opposition in addition to possible legal and environmental problems.

A scientific approach to MAR planning, involving a combination of different disciplines, will ensure an efficient and successful implementation of MAR and also contribute to a better acceptance of this practice not only by experts but also by the general public. Isotope studies are an extremely useful complement to traditional hydrogeological methods and have already proven their applicability both in MAR planning and in monitoring MAR implementation.

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GIS-Based AHP Analysis for Solar Power Plant Location Suitability in The City of Pirot, Serbia

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Abstract. Renewable energy sources, including solar energy, represent the path for progress and development of modern countries. Serbia has a great potential for using solar energy, but it is mostly used in the private households. By using AHP method in GIS software, the map of suitability of locating a solar power plant in The City of Pirot was obtained. The results show that 7.74% of the City has high suitability for locating solar power plant, and 65.71% of the territory is very unsuitable.

Keywords: geoinformatics, spatial analysis, Serbia, solar energy

INTRODUCTION

With the continual population growth in the past few decades, the demand for electricity is increasing proportionally. Non-renewable energy sources are being overly consumed, and in addition to that, they pollute the environment during the processing or use. For these reasons, alternative sources of energy – solar, wind, geothermal energy etc. – are being studied and implemented more intensively. The most positive aspects of using alternative energy sources are their renewability and almost no negative effects on the environment. This is why alternative energy sources, including solar energy, represent the path for progress and development of all modern, and especially less developed countries [1,2].

Nowadays, science is also increasingly concerned with the study of renewable energy sources and their optimal use. As a large nubmer of factors must be taken into consideration for constructing solar power plants, analytical hierarchical process (AHP) analyses are oftenly used for decision-making. In recent years, it has been noticable that geographic information systems (GIS) are increasingly being used to perform spatial analysis in choosing the most optimal location for setting up a solar power plants [3-5].

The use of solar power in Serbia is usually limited to generating energy for water heating in the households [6]. Although Serbia is far from the European average in terms of the use of solar energy, it was determined that the average solar radiation in Serbia is even 40% higher than in the rest of the Europe, on average [7]. The share of solar energy in total energy production in Serbia in 2021 was 0.04%. Increasing the capacity to produce energy from solar radiation would help reduce the use of coal, and therefore environmental pollution [7,8].

The City of Pirot is located in the southeast of Serbia (Figure 1). It is the third biggest City in Serbia with the area of 1232 km^2. The City is bordering four other municipalities in Serbia and the Republic of Bulgaria. According to 2022 Census of Population, Households and Dwellings, 49601 inhabitants live in the City, of which 34942 live in Pirot. There are 73 settlements on the territory of the City, and 45 of them have less than 100 inhabitants [9]. There are four protected areas in the City: National Park “Stara planina”, Special Nature Reserves “Jerma” and “Krupačko blato”, and Natural Monument “Bigar river valley”.

The research area was chosen to study the potential for using solar energy to generate electricity in an economically underdeveloped region. Although the rivers in the City of Pirot have hydropower potential, most of them are small, located in protected areas and serve to irrigate local arable land and for the needs of the local population. Their use for the purpose of obtaining electricity would damage the environment and it would be important to examine other possibilities of obtaining electricity in this area.

METHODOLOGY

AHP method is a structured decision-making method that helps addressing complex decision problems by breaking them down into a hierarchy of simpler sub-problems. It was developed by Thomas L. Saaty [10] and it involves three main steps. The first one is decomposing the decision problem into a hierarchy of more manageable parts. After that, pairwise comparisons are conducted to establish priorities among the elements. Finally, the results are synthesized to determine the best decision. The hierarchy typically includes the goal at the top, followed by criteria and sub-criteria at intermediate levels, and the decision alternatives at the bottom. By assigning numerical values to the relative importance of each element and using mathematical calculations, AHP provides a clear rationale for decision-making, allowing for both qualitative and quantitative factors to be considered.

In analyzing optimal solar power plant sites, there are many criteria that are being used: global tilted irradiation/irradiance (GTI) [1,6,11-13], land use/land cover (LULC) [1,6,11,13], altitude [6], slope and aspect [1,6,13], distance from settlements (Ds) and roads (Dr) [6,12,13], protected areas [6,11,12], transmission lines [12,13], other climatic elements [1]… In all of the papers, data on GTI is used, while the other criteria are quite different. Most papers use distance from the protected area, in order to reduce the impact on the environment as much as possible. LULC is also an important criterion, since it is not suitable to build solar power plants on already built-up areas, or to cut down the forest for construction. Slope and aspect are important physical-geographic criteria. Distance from settlements and roads are significant for reducing the transportation costs of building solar power plants. This is why these criteria are chosen for assessing an optimal location for building solar power plants in the City of Pirot. The ranking is made based on the rankings in other research papers. The selected criteria are shown in the Table 1.

The highest rankings of LULC were given to land use classes of pastures (231) and natural grasslands (321). After them, second highest ranking is given to sparsely vegetated area (333). The areas of complex cultivation patterns (242), areas preoccupied by agriculture (243), transitional woodland-shrub (324) and burnt areas (334) are of medium suitability for locating a solar power plant. Unsuitable lands are represented by non-irrigated arable lands (211), fruit trees and berry plantations (222) and moors and heathland (322). Completely unsuitable lands include discontinuous urban fabric (112), industrial or commercial units (121), mineral extraction sites (131), construction sites (133), sport and leisure facilities (142), broad-leaved forests (311), coniferous forests (312), mixed forests (313) and water bodies (512). The least suitable LULC classes and protected areas are excluded from possibility of locating solar power plant.

Table 1. Criteria selected for determining solar power plant sites

Criteria	Adequacy ranking	Source	Access date
GTI (kWh/m^2 per year)	(5) 1550-1630	[14]	May 2024
	(4) 1400-1550		
	(3) 1250-1400		
	(2) 1150-1250		
	(1) 1088-1150		
Slope (in %)	(5) 32-110.62	[15]	January 2024
	(4) 12-32		
	(3) 5-12		
	(2) 2-5		
	(1) 0-2		
Aspect (sides of the world)	(5) S	[15]	January 2024
	(4) SE, SW		
	(3) E, W		
	(2) NE, NW		
	(1) N		
Distance from settlements (in m)	(5) 0-500	[16]	May 2024
	(4) 500-1000		
	(3) 1000-1500		
	(2) 1500-2500		
	(1) >2500		
Distance from roads (in m)	(5) 100-500	[17]	May 2024
	(4) 500-1000		
	(3) 1000-1500		
	(2) 1500-2000		
	(1) 0-100; >2000		
LULC (Corine Land Cover codes)	(5) 231, 321	[17]	May 2024
	(4) 333		
	(3) 242, 243, 324, 334		
	(2) 211, 222, 322		
	(1) 112, 121, 131, 133, 142, 311-313, 512		

After ranking criteria, the pairwise comparison matrix was formed, based on other scientific papers. The most important criterion is GTI, after which come aspect, Dr, LULC, slope and Ds. The matrix is then squared, rows are added and divided by their sum to get the final weights. Initial matrix and final weighs are given in the Table 2.

Table 2. Pairwise comparison matrix

	GTI	Slope	Aspect	LULC	Ds	Dr	Weight
GTI	1	6	3	5	6	4	**0.457**
Aspect	0,33	0,50	1	2	3	1	**0.140**
Dr	0,25	2	1	1	2	1	**0.127**
LULC	0,20	2	0,50	1	2	1	**0.113**
Slope	0,17	1	2	0,50	1	0,50	**0.100**
Ds	0,17	1	0,33	0,50	1	0,50	**0.063**

All the criteria were visualized in GIS software QGIS 3.28.12 by raster layers. The layers were reclassified based on the rankings in Table 1. After that, all layers were multiplied by their AHP weights and added to get the map. Protected areas, as well as 1 km buffer around them, and the least suitable LULC classes were given value 0 and were multiplied with previously made map. Finally, the map was reclassified so that all pixels with values 0-1 get value 1, 1-2 value 2, 2-3 value 3, 3-4 value 4 and 4-5 (including 5) value 5.

RESULTS AND DISCUSSION

Based on the previous criteria, the final map of suitability of locating solar power plant in the City of Pirot was calculated and is given in Figure 2.

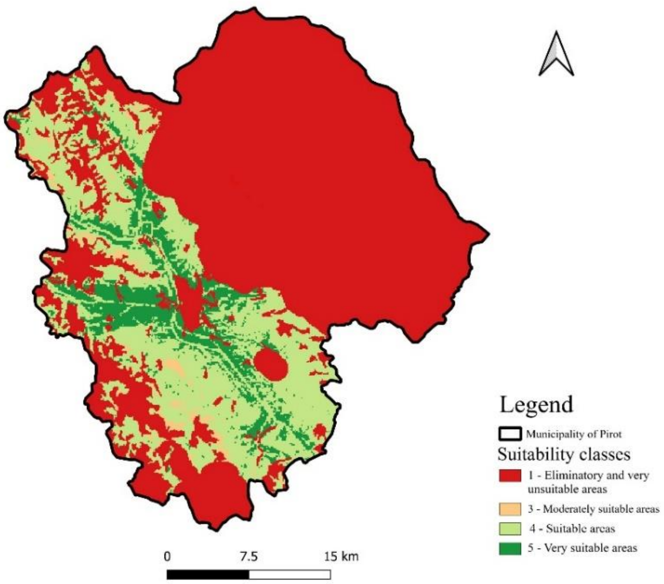

Figure 2. Suitability of locating solar power plant

According to used criteria, 65.71% of the territory of the City of Pirot is very unsuitable for locating a solar power plant. That is the case because a large part of the City is either under a protected area or some kind of urban, anthropogenic area. Only 1.57% of the territory is moderately suitable for locating solar power plant. Almost a quarter (24.98%) of the territory represent suitable and 7.74% very suitable areas for locating a solar power plant. Those areas are located in the central part of the City, near Pirot, other larger settlements and main roads.

CONCLUSION

The energy of the Sun has a great potential of use in today's conditions of increasing energy needs. Although Serbia has a greater potential for using solar energy than some other European countrie, this type of energy has not been sufficiently researched and used. Based on the used criteria, only 7.74% of the City of Pirot has very high potential for setting a solar power plant and around a quarter of the territory has high potential. Since a big part of the municipality belongs to protected areas, solar power plants cannot be installed on over 65% of the territory. Future work may examine the efficiency of possible solar power plants and what would be economical gain for this region.

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Renewable Energy Potential and Utilization in Vojvodina, Serbia: Opportunities and Challenges

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Abstract. The research explores the renewable energy potential and utilization in Vojvodina, Serbia, focusing on the region's geographical and climatic suitability for solar, wind, and biomass energy. Vojvodina's flat terrain, abundant sunlight, consistent wind patterns, and significant agricultural activity provide a strong foundation for renewable energy development. Despite these advantages, the region currently relies heavily on fossil fuels, underscoring the need for further investment in renewable infrastructure and technology. Economic benefits include job creation, energy independence, and long-term cost savings, while environmental benefits encompass reduced greenhouse gas emissions and improved air quality. Challenges such as financial constraints, regulatory hurdles, and the need for a skilled workforce are addressed through comprehensive strategies involving policy support, public-private partnerships, and educational programs. This study emphasizes a collaborative approach to achieving a sustainable and resilient energy future for Vojvodina.

Keywords: Sustainability, renewable energy, policy challenges

INTRODUCTION

Renewable energy presents a significant opportunity for Vojvodina, a region in northern Serbia known for its fertile plains and continental climate [1]. The geographical and climatic conditions in Vojvodina are conducive to various forms of renewable energy generation. The region's flatlands, rivers, and lakes, combined with hot summers and cold winters, provide a unique environment that can support solar, wind, and biomass energy projects. Understanding the specific characteristics of Vojvodina's geography and climate is crucial for assessing the potential for renewable energy utilization [2]. This assessment forms the foundation for developing and implementing effective renewable energy strategies tailored to the region's natural resources and climatic conditions.

In recent years, there has been a growing interest in expanding the renewable energy infrastructure in Vojvodina. Currently, the region hosts several wind farms and solar power plants, which contribute to the diversification of its energy portfolio. Despite these advancements, the energy sector in Vojvodina remains heavily reliant on traditional fossil fuels [3]. The need for modernization and expansion of renewable energy infrastructure is pressing. Investments in new technologies and the upgrading of existing facilities are essential steps towards enhancing the capacity and efficiency of renewable energy sources.

Exploring the current state of renewable energy infrastructure in Vojvodina reveals both the progress made and the areas requiring further development to achieve a sustainable energy future [4].

The economic and environmental benefits of transitioning to renewable energy in Vojvodina are substantial. Economically, renewable energy projects can lead to job creation, particularly in rural areas, and can foster energy independence, reducing reliance on imported fossil fuels [5]. The long-term cost savings associated with renewable energy, due to lower operational and maintenance costs compared to conventional energy sources, are also significant. Environmentally, the shift to renewable energy can result in a substantial reduction in greenhouse gas emissions and other pollutants. This reduction contributes to improved air quality and public health, aligning with global efforts to combat climate change [6]. Analyzing the potential economic impacts and environmental benefits of renewable energy in Vojvodina highlights the importance of this transition for both the local economy and the broader ecological landscape.

The policy framework and implementation challenges are critical factors influencing the development of renewable energy in Vojvodina. National and regional policies, regulatory frameworks, and incentives play a pivotal role in shaping the growth of the renewable energy sector. Various policies support renewable energy development, including subsidies, tax incentives, and regulatory mandates. However, the implementation of these policies faces several challenges [7]. Bureaucratic hurdles, funding limitations, and resistance from established traditional energy sectors are among the primary obstacles. These challenges need to be addressed to create a conducive environment for renewable energy projects. Examining the policy framework and identifying the implementation challenges is essential for developing strategies to overcome these barriers and promote sustainable energy development in Vojvodina [8].

The exploration of renewable energy potential and utilization in Vojvodina, Serbia, involves a comprehensive understanding of the region's geographical and climatic conditions, the current state of its renewable energy infrastructure, the economic and environmental benefits, and the policy framework and implementation challenges. This holistic approach is necessary to realize the opportunities and address the challenges associated with renewable energy in Vojvodina. The insights gained from this exploration can inform policymakers, stakeholders, and the broader community about the steps needed to achieve a sustainable and resilient energy future for the region.

GEOGRAPHICAL AND CLIMATIC OVERVIEW OF VOJVODINA

Vojvodina, a region in the northern part of Serbia, is characterized by its unique geographical and climatic conditions, which play a crucial role in shaping its renewable energy potential. The region's landscape is predominantly flat, consisting of expansive plains that are part of the larger Pannonian Basin. This flat terrain is interspersed with several rivers, including the Danube, Tisa, and Sava, as well as numerous smaller water bodies. The presence of these water resources provides opportunities for hydropower generation, although the focus has primarily been on other renewable sources due to the limited elevation changes suitable for traditional hydropower.

The climate in Vojvodina is classified as continental, featuring hot summers and cold winters. During the summer months, temperatures can soar, providing ideal conditions for solar energy generation [9]. The region experiences a high number of sunny days annually, making solar power a viable and promising option. The long daylight hours in summer further enhance the potential for harnessing solar energy. Conversely, the winter months bring cold temperatures and occasional snowfall, which can impact the efficiency of solar panels but also presents challenges that can be mitigated through technological advancements and hybrid systems.

Wind energy is another significant renewable resource in Vojvodina [10]. The region’s flat terrain and geographical positioning create favorable conditions for consistent wind patterns, particularly in certain areas known for stronger and more reliable winds. The construction of wind farms has already begun, capitalizing on these conditions to generate electricity. The integration of wind energy into the regional grid has demonstrated the feasibility and benefits of diversifying the energy mix. However, further expansion is necessary to fully exploit the wind energy potential and contribute to the region's energy independence and sustainability goals.

Biomass energy is also a pertinent option given Vojvodina's extensive agricultural activities [11]. The region is a major agricultural hub, producing significant quantities of crop residues and other organic waste that can be converted into bioenergy. Utilizing these agricultural by-products for energy production not only provides a renewable source of power but also offers a sustainable solution for managing agricultural waste. This dual benefit aligns with the principles of circular economy and sustainable agricultural practices.

CURRENT STATE OF RENEWABLE ENERGY INFRASTRUCTURE

In recent years, efforts to develop the renewable energy infrastructure in Vojvodina have gained momentum. The region hosts several wind farms and solar power plants, marking a shift towards a more diversified energy portfolio. However, despite these advancements, Vojvodina's energy sector remains heavily dependent on fossil fuels. This reliance underscores the need for continued investment in renewable energy technologies and infrastructure to reduce carbon emissions and enhance energy security [12].

The existing renewable energy infrastructure in Vojvodina includes notable projects such as wind farms that harness the region's wind potential and solar power plants that capitalize on the high solar irradiance. These projects have not only contributed to the regional energy supply but have also served as pilot initiatives demonstrating the viability of renewable energy in the local context. However, the current capacity and efficiency of these installations are limited compared to the region's overall energy demand, indicating a significant opportunity for growth.

Investments in new technologies and the modernization of existing facilities are critical steps towards enhancing the capacity and efficiency of renewable energy sources in Vojvodina. The integration of advanced technologies, such as smart grids and energy storage systems, can optimize the performance of renewable energy installations and ensure a stable and reliable energy supply. Additionally, upgrading current facilities to improve their efficiency and output can significantly boost the overall contribution of renewable energy to the regional grid.

Challenges in expanding the renewable energy infrastructure include financial constraints, regulatory hurdles, and the need for skilled labor. Securing funding for large-scale renewable energy projects can be difficult, particularly in a region with competing priorities and limited resources. Regulatory frameworks must be streamlined to facilitate the approval and implementation of renewable energy projects. Furthermore, developing a skilled workforce capable of designing, installing, and maintaining renewable energy systems is essential for sustaining long-term growth in this sector.

The journey towards a sustainable energy future in Vojvodina involves a comprehensive approach that addresses the region's unique geographical and climatic conditions, current infrastructure, and the challenges associated with expanding renewable energy sources. Embracing renewable energy not only contributes to environmental sustainability but also promotes economic growth and energy security. As Vojvodina continues to develop its renewable energy potential, it sets an example for other regions with similar geographical and climatic profiles, demonstrating the transformative power of renewable energy in achieving a sustainable future.

SUGGESTIONS AND GUIDELINES

Developing and implementing strategies to enhance renewable energy potential and utilization in Vojvodina, Serbia, involves concerted efforts from governments, enterprises, and individuals. These strategies need to address economic, environmental, and social dimensions to ensure sustainable growth and energy security. The following suggestions and guidelines outline actionable steps that can drive the renewable energy transition in the region:

- Develop and Implement Comprehensive Renewable Energy Policies: Governments should create clear and supportive policies that incentivize renewable energy investments, including subsidies and tax breaks. These policies must streamline approval processes to reduce bureaucratic delays and encourage private sector participation.
- Invest in Renewable Energy Infrastructure: Public and private sectors should allocate funds for the construction and upgrading of renewable energy facilities, such as wind farms and solar power plants. This investment can significantly increase energy production capacity and improve efficiency, reducing reliance on fossil fuels.
- Enhance Educational and Training Programs: Educational institutions should develop specialized programs focused on renewable energy technologies and sustainable practices. Training a skilled workforce ensures the long-term growth and maintenance of the renewable energy sector.
- Promote Research and Development: Governments and enterprises should invest in R&D to advance renewable energy technologies and improve their efficiency. Innovations in energy storage, grid management, and hybrid systems can address challenges like variability in solar and wind energy production.
- Facilitate Public-Private Partnerships: Collaboration between governments, private companies, and research institutions can drive large-scale renewable energy projects. Public-private partnerships can leverage combined resources and expertise to overcome financial and technical barriers.
- Increase Public Awareness and Engagement: Governments and NGOs should launch campaigns to educate the public about the benefits of renewable energy

and sustainable practices. Engaging communities in renewable energy projects can foster local support and participation, ensuring alignment with regional needs.

- Support Agricultural Integration: Encourage farmers to use agricultural residues and organic waste for biomass energy production, providing an additional revenue stream. Governments can offer incentives and technical support to facilitate the integration of renewable energy into agricultural practices.
- Implement Smart Grid Technologies: Investing in smart grids can enhance the management and distribution of renewable energy, improving reliability and efficiency. Smart grids enable better integration of various renewable energy sources and optimize energy usage patterns.
- Encourage Local Manufacturing of Renewable Energy: Components Developing local manufacturing capabilities for renewable energy components, such as solar panels and wind turbines, can reduce costs and create jobs. Governments can support this through subsidies and by fostering an environment conducive to industrial growth.
- Ensure Financial Support and Access to Capital: Provide financial mechanisms such as low-interest loans, grants, and risk guarantees to support renewable energy projects. Access to capital is crucial for overcoming initial investment barriers and ensuring project viability.

These strategies and actions, when effectively implemented, can significantly enhance the renewable energy landscape in Vojvodina. By leveraging the region's geographical and climatic advantages, fostering innovation, and promoting sustainable practices, Vojvodina can achieve a more resilient and sustainable energy future. The collaboration of governments, enterprises, and individuals is essential in driving this transition, ensuring that the benefits of renewable energy are realized across economic, environmental, and social spheres.

CONCLUSION

The exploration of renewable energy potential and utilization in Vojvodina, Serbia, highlights the region's significant opportunities and challenges. Vojvodina's geographical and climatic conditions are well-suited for various forms of renewable energy, including solar, wind, and biomass. The region's flat terrain, ample sunlight, consistent wind patterns, and agricultural activity provide a robust foundation for developing a diverse renewable energy portfolio. Understanding these local characteristics is essential for tailoring renewable energy strategies that maximize efficiency and sustainability.

Despite the promising potential, Vojvodina's current renewable energy infrastructure remains underdeveloped, with a heavy reliance on fossil fuels. Existing projects, such as wind farms and solar power plants, demonstrate the feasibility of renewable energy but also highlight the need for further investment and expansion. Enhancing the capacity and efficiency of renewable energy installations through modernization and the adoption of advanced technologies is crucial. Addressing financial constraints, regulatory hurdles, and the need for a skilled workforce are key to accelerating this development.

The economic and environmental benefits of transitioning to renewable energy in Vojvodina are substantial. Economically, renewable energy projects can create jobs, promote energy independence, and lead to long-term cost savings. Environmentally, the reduction of greenhouse gas emissions and pollutants can improve air quality and public health. Biomass energy from agricultural residues offers a sustainable waste management solution, aligning with circular economy principles. Public awareness and community involvement are vital in fostering support for renewable energy initiatives.

Effective policy frameworks and supportive regulatory environments are critical for the successful implementation of renewable energy projects. Streamlining approval processes, securing funding, and facilitating public-private partnerships can drive the growth of the renewable energy sector. Educational and training programs are essential for developing a skilled workforce to support this growth. Public outreach and education campaigns can enhance community engagement and acceptance, ensuring that renewable energy initiatives align with local needs and values.

The transition to renewable energy in Vojvodina requires a comprehensive and collaborative approach involving governments, enterprises, and individuals. By leveraging the region's natural resources, fostering innovation, and promoting sustainable practices, Vojvodina can achieve a more resilient and sustainable energy future. The strategies and actions outlined provide a roadmap for overcoming challenges and realizing the benefits of renewable energy, contributing to the region's economic development and environmental sustainability.

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Long-Term Radon Level Measurement at TFZR

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Abstract. One of the most important parameters of indoor air quality is radon concentration. Radon is a radioactive gas with no smell, color, or taste that can enter dwellings and pose serious health risks to humans when its concentrations are high in closed spaces. At the Technical Faculty "Mihajlo Pupin" in Zrenjanin, after conducting some short-term radon level tests, we performed long-term (six-month long) measurements of radon concentration using CR39 detectors. The obtained results are presented and discussed.

Keywords: indoor radon, CR39

INTRODUCTION

Air quality is important aspect of living and working environment as it strongly affects human wellbeing. Indoodr air quality depends also on the concentration of radon in the air, because radon is a radioactive gas specially dangerous for human health when its concentrations are large [1].

Radon [2] is present everywhere on the Earth, in soil and water, as it originates from uranium and thorium decay chain .All radon isotpoes are radioactive and radon ^{222}Rn is the most important radon isotope in nature. Radon progenies are also radioactive. Radon can emanate from the ground into the open air. Its concentration varies from place to place on the Earth as uranium and thorium distribution is not uniform. Radon can also enter houses through cracks and holes in the earth or more rarely it can be present in dwellings because of the gas, water or building materials. In some closed spaces radon concentrations can be quite high, when its effect on human health can be compared to those of smoking a tree pack of cigarettes per day. It was found that radon effects are worse for smoking then for non-smoking population.

Though radon can not be noticed by senses (it is odorless, tasteless, colorless), its concentration in the air can be measured by detectors. Checking radon level in public and working quarters is crucial. At Technical Faculty "Mihajlo Pupin" Zrenjanin, first we did some short-term radon level tests by using Airthings detectors (analysis described in [3]). Then, by using CR39 detectors, we started long-term (six-months long) radon ^{222}Rn concentration measurements, described in this paper. We wanted tto see if it is safe to stay and work at TFZR, for both students and emplyees who are studying and working there.

DETECTORS

Radon concentration measurement can be realized in different ways, by passive or active methods, by measuring it directly or via its daughters. Measurements can last from few days to one year. Used techniques are very diverse and include those based on track detectors, active continuous detectors, charcoal detectors, electrets [4].

Track detectors are most often made of plastic (like in case of detectors we used), but are rarely also made from glass or inorganic crystals. When heavy particle with charge arrives on detector surface, it leaves narrow track. These so called “latent” tracks are viewed after treating detectors with appropriate chemicals (process called etching). Then tracks are counted by using optical microscope. Density of tracks is connected to radon concnetration. Track detectors are usually exposed for few months.

In order to measure ^{222}Rn concentration in the air at TFZR, we used FIDO track detectors [5] (presented on Figure 1), produced by Niton srl. These are passive CR39 kind of detectors (Solid State Nuclear Detectors). FIDO track detectors are made of plastic polymers and have cylindrical shape with height of about 2 cm and diameter of about 4 cm. Inside detector exist small diffusion chamber, made of conductive material. FIDO track detectors are reccommended to be exposed to the air from two to six months. After six months measurements at TFZR, we closed them and sent them to certified Niton Laboratory for analysis, There they are first treated with sodium hydroxide and then analyzed with microscopes and appropriate software which elaborate radon tracks.

Figure 1. Photo of FIDO track detector.

MEASUREMENTS

Radon concentration changes during the day and it also fluctuates with different seasons, because weather instability, temperature, humidity and preassure changes affects it [6]. Limits on radon level given in our legislation are on annual level. Longer we measure the radon, more reailable result we obtain. First we did two-days long radon concentration screening measurements at TFZR [3] to eastablish if a Faculty building has a potential for high exposure to its occupants. Then, with FIDO track detectors, we performed six-months long radon level measurements, in order to obtain even more precise results. The measurements started on 3rd January 2024. and lasted until July 2024. We choose 6 rooms at TFZR where previous two-day long radon level tests give largest values. These rooms in the ground floor and first floor were in normal use throughout measurement period. We placed detectors on a table, far from windows, walls, doors and heating system. Measured concentrations are given in Table 1 below. Estimated errors for these measurements are also presented.

Table 1. Radon concentration values measure at TFZR with CR39 detectors during six-months period (winter and spring 2024.).

Room	Radon concentration (Bq/m^3)
Office 5 (D) (Ground floor)	187 (30)
Office 5 (PD) (Ground floor)	79 (16)
Office 1 (Ground floor)	64 (14)
Office 2 (Ground floor)	53 (12)
Office 22 (First floor)	41 (10)
Office 23 (First floor)	31 (9)

The maximum radon concentration value measured at TFZR is 187 Bq/m^3 and the minimum measured radon concentration value is 31 Bq/m^3. Higher floors have smaller radon concentration values then lower floors, as expected.

CONCLUSION

Radon represent true danger for living being health, so its concentration in closed spaces must be regularly checked. There are different threshhold for the maximum radon concentration level in closed spaces. The most severe recommendations are given by World Health Organization [1], which recommands less than 100 Bq/m^3 for residential buildings and at most value of 300 Bq/m^3 for the national reference level. In the European Union regulations [7] radon concentration in work and living quarters should be less than 300 Bq/m^3. In Serbian legislation [8] intervention level for working quarters is 1000 Bq/m3, while 400 Bq/m3 is limit for old and 200 Bq/m3 for new buildings. All these concentrations are on annual level. Limits in our National legislation should be changed and harmonised with limits in the European Union.

Six-months long measurements, during winter and spring 2024., shows that radon concentrations at TFZR are at acceptable level, and that there is no risk of high radon concetrations there. Measurements last long enough to be said that obtained results are realiable. There is no reason for any space remedies at TFZR. Regular ventilations are always good to be practiced, as they significantly reduce radon level in the room.

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Enhancing Safety and Environmental Protection through Effective Maintenance and Diagnostics of Blowout Preventers

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Abstract. Drilling operations pose significant risks due to high-pressure conditions and unpredictable subsurface environments, which can lead to catastrophic events if not properly managed. The control of pressure during drilling is typically regulated by the drilling fluid, but encountering high-pressure gas or fluids can result in dangerous blowouts if the pressure exceeds the safety limits of the well's control systems. The Blowout Preventer (BOP) system is critical for maintaining well safety by managing fluid pressure, sealing, and fluid transfer. However, failures of BOP systems, such as the Deepwater Horizon disaster in 2010, highlight the necessity for reliable safety measures. This paper reviews the evolution of drilling technology, from early water wells to modern oil and gas operations, emphasizing the role of BOP systems in preventing blowouts. It explores the basic components and functions of BOPs, including annular and ram preventers, and assesses their performance and reliability. Advanced analytical methods, such as Failure Modes and Effects Analysis (FMEA) and Bayesian Networks, are discussed for evaluating BOP effectiveness. Additionally, the paper addresses the challenges in maintaining and enhancing BOP components, particularly focusing on the durability of annular seals and innovations in preventer design. The study underscores the importance of continuous improvements in safety equipment to mitigate risks, protect human lives, and safeguard the environment.

Keywords: blowout preventer (bop), well safety, annular preventers, ram preventers, performance and reliability, fmea, bayesian networks, preventer design, environmental protection

INTRODUCTION

Drilling involves penetrating various rock layers, with pressure controlled by the drilling fluid; however, encountering gas or liquids under high pressure can cause an eruption if it exceeds the pressure of the fluid column [1]. Oil and gas drilling carries significant risks due to high pressures and unpredictable conditions in subsurface reservoirs, where inaccurate data and improper use of the fluid, inadequate wellhead equipment, improper casing, and high drilling rates can lead to dangerous pressure imbalances and blowouts [2]. The Blowout Preventer (BOP) system maintains well safety by containing fluids, regulating volumes, sealing, and managing fluid transmission; however, its reliability is crucial due to increasingly challenging drilling conditions [3]. The 2010 Deepwater Horizon platform disaster occurred because the BOP failed to cut the drill pipe and seal the well due to the unfavorable position of the pipe near the inner wall of the well, beyond the reach of the annular preventer [4]. This incident has driven the industry to focus on improving reliability and safety [3]. Safety equipment serves as a secondary mechanism for well control, managing high pressures and blowouts when the hydrostatic pressure of the drilling fluid is insufficient [5]. Therefore, the BOP serves as a critical safety measure predominantly used during exploration, development, and operations in oil and gas fields [5, 6]. Its absence, deterioration, or failure allows an initial incident to escalate into a major disaster with catastrophic consequences [6]. The development of effective maintenance and diagnostic methods for safety equipment becomes crucial to minimizing risks in oil and gas drilling. Increased attention to prevention and rapid detection of potential failures contributes to greater operational safety, protection of human lives, and environmental preservation. By introducing new technologies and approaches, the industry can enhance safety standards and responsibility towards natural resources.

MATERIAL AND METHODS

Overview of Drilling Development Throughout History

Water drilling began in France in 1126, while in the 13th century, the Chinese already had 10,000 saltwater wells using a percussion rope system. Depths reached over 500 meters. Oil and Gas: The first oil well was drilled in 1859 by Colonel Edwin Drake in Titusville, Pennsylvania, using a percussion drilling system with a chisel, reaching a depth of 23 meters. The drilling technology revolution occurred in 1901 with the development of the rotary system in Texas, which allowed for more efficient drilling in loose formations. Electric logging was introduced in 1929 by the Schlumberger brothers, enhancing well exploration. Turbo drills have been extensively used in the former USSR since 1943 for drilling deep oil and gas wells [7].

Basic Characteristics of a Well

Wells are vertical passages through the Earth's crust with the following basic components (Figure 1.) [8]:

- Entrance (1)
- Bottom (2)
- Wall (3)
- Wellbore (4)
- Length (L)
- Diameter (d)
- Depth (H)

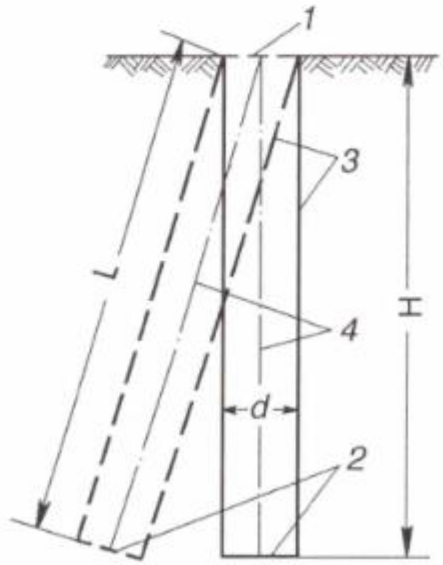

Figure 1. Basic Characteristics of a Well [8]

Blowout

A blowout refers to the uncontrolled release of fluids from a formation, such as crude oil and natural gas, through a wellbore, which can be triggered by high formation pressures, low density of the drilling fluid, inadequate height of the fluid column, or other factors. The response to a blowout typically involves using a blowout preventer to seal the well and adding higher-density drilling fluid to balance the pressure in the formation [9-11].

Safety Equipment and Its Basic Components

Safety equipment includes a complex pressure control system installed on the wellhead during drilling or completion operations [12]. This equipment encompasses [7, 8]:

- Blowout preventer assembly
- Wellhead
- Valves
- API flangesAPI

Safety Mechanism (Blowout Preventer Assembly)

Blowout preventers are crucial for preventing the ingress of formation fluids into the annular space between the casing and the drill string [7, 8, 11, 13, 14].

Blowout preventers are classified according to their size, working pressure, and sealing mechanism, including [7]:

- Ram Preventers: Close off the space around the drill string or the full profile of the wellbore [1, 8, 11, 15].
- Annular Preventers: Close off the space between the outer diameter of the drill string and the inner diameter of the casing [7, 8, 12].

Operation of Ram Preventers: Activated by hydraulic pressure which moves the pistons, closing the rams and rubber seals [8].

Operation of Annular Preventers: Activated by hydraulic pressure, with rubber that expands and tightly seals around the drill string or the full profile of the wellbore [7, 8].

Performance Assessment and Improvement of Safety Equipment

Subsea BOP systems are the subject of numerous studies focusing on their reliability, revealing that despite improvements, BOPs remain a critical risk factor during drilling. Failures in BOP systems can lead to severe consequences, including financial losses and environmental disasters. Therefore, it is important to analyze the reliability of these systems using historical data [12, 17].

Studies employ methods such as Failure Modes and Effects Analysis (FMEA) and Fault Tree Analysis (FTA) to assess the reliability of BOPs [16-19], while Markov models and Petri nets are used for more advanced analyses [17, 18, 20, 21]. Additionally, Bayesian Networks (BN) and Dynamic Bayesian Networks (DBN) are increasingly important for predictive analysis due to their ability to manage uncertainties [17, 21, 22].

The wear of annular and ram preventers presents a key challenge in the oil and gas industry, given the extreme conditions under which they operate. Regular maintenance and improvements in materials and design of these devices are crucial for ensuring long-term efficiency and safety. The implementation of new technologies, such as advanced elastomers and improved engineering solutions, enhances resistance to wear and extends the operational life of annular preventers, reducing the risk of failures and ensuring continuity of operations.

The annular sealing element in the BOP system, made from a flexible material with solid components, wears out quickly due to its design. Initial wear occurs in a narrow strip of material near the top, and as wear progresses, this strip expands, increasing friction and pulling [23]. Areas of stress in the rubber core, especially at the ends and points of contact with the ram, are particularly affected [24-26]. The sealing efficiency depends on the friction coefficient, the pressure of the sealing fluid, and the degree of compression of the rubber, and it functions as a dynamic seal when raising or lowering the pipe [27-29].

Traditional annular preventers use metal inserts within the elastomeric material for sealing, but high pressure can damage the elastomeric material. A new patent introduces an innovative design that replaces metal inserts with flexible non-metallic composite bodies, improving the stress condition of the seal and extending its lifespan, making the preventer more efficient and durable [30].

In 2010, T3 Energy Services introduced the Shear All Ram (SAR), a new type of ram preventer capable of cutting through all sizes and types of casings and drill strings. The SAR is equipped with an automatic locking mechanism that prevents accidental opening and offers two main types of locking: wedge and multi-position ram-locks [4].

CONCLUSION

The maintenance and diagnostic strategies for Blowout Preventers (BOPs) are crucial for ensuring safety and environmental protection in drilling operations. This paper emphasizes the importance of BOP systems in preventing blowouts and highlights advancements in their design and performance assessment. Through a review of historical and contemporary technologies, the study underscores the necessity of reliable BOP components, such as annular and ram preventers, and introduces innovative solutions for enhancing their durability and effectiveness. Techniques like Failure Modes and Effects Analysis (FMEA) and Bayesian Networks play a significant role in evaluating and improving BOP reliability. The ongoing development of advanced materials and designs, such as non-metallic composite bodies and Shear All Ram preventers, reflects the industry's commitment to addressing challenges and minimizing risks associated with drilling.

Further research could explore the integration of real-time monitoring systems with BOP diagnostics, utilizing advanced sensors and machine learning algorithms to predict and prevent potential failures before they occur, thereby enhancing safety and operational efficiency in drilling operations.

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Assessment of the Environmental Gamma Dose Rate in Macedonia

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Abstract. Assessment of the environmental gamma dose rate in Macedonia was conducted in 2010, 2015, and 2020 to establish baseline data of the gamma dose rate and observe potential changes over time. For the purpose, the gamma dose rate was measured at 68 locations in 2010, and 72 location in 2015 and 2020 using a portable dosimeter positioned 1 m above the ground surface. The gamma dose rates in the country were in the range 53 - 340 nSv/h in 2010, 38 - 360 nSv/h in 2015 and 41 - 300 nSv/h in 2020. It was found that the reason for a variation in the measured values is due to the geological factors and geological formations which are different in different parts of the country.

Keywords: gamma dose rate, portable dosimeter, geological formations, Macedonia

INTRODUCTI\ON

Environmental radiation monitoring is critical to environmental science, public health, and safety. Gamma rays are of particular concern among various radiation types due to their high penetration power and potential health impacts. Gamma dose rates provide crucial information about environmental radiation levels and are essential for assessing natural background radiation and anthropogenic contributions. Understanding gamma radiation levels in some regions is crucial for several reasons: it aids in evaluating the impact of natural sources of radiation, monitoring potential contamination from human activities, and ensuring public safety.

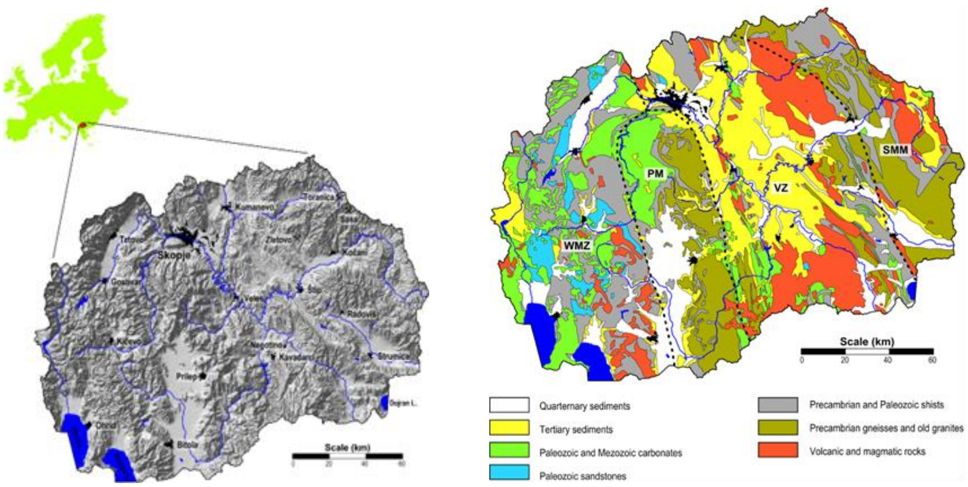
This study presents a comprehensive analysis of in situ gamma dose rate measurements taken in Macedonia across three distinct time points: 2010, 2015, and 2020. These timeframes provide a historical perspective and allow for the assessment of temporal trends in environmental gamma radiation levels.

The objective of this research is twofold: to establish a baseline of gamma dose rates in Macedonia and to assess any fluctuations that may indicate environmental or anthropogenic influences. The results of this study will contribute to the broader understanding of radiation levels in Southeast Europe and offer valuable insights for future monitoring and regulatory efforts. [1,2].

EXPERIMENTAL

Study area

Macedonia is located in Southeast Europe, occupying the central part of the Balkan Peninsula (Fig. 1a). It is a landlocked country bordered by Serbia to the north, Bulgaria to the east, Greece to the south, and Albania to the west. The country has an area of 25713 square kilometers and is characterized by a diverse topography that includes mountainous regions, valleys, and lakes. The landscape of Macedonia is predominantly mountainous, with the southwestern and eastern parts of the country featuring rugged terrain and high peaks. The climate in Macedonia varies with altitude but is generally characterized by a continental climate with hot summers and cold winters. The lowland areas experience a Mediterranean influence, particularly around the lakes and river valleys, while the mountainous regions have a more temperate climate with greater seasonal variations [3].



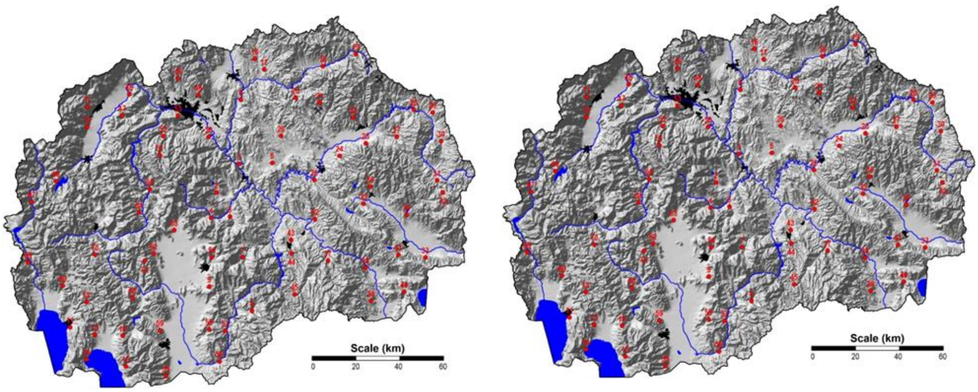
a. b.

Figure 1. Location and map of Macedonia (a), Lithological map of Macedonia (according to Geological map of SFR Yugoslavia, 1970). The areas of the principal tectonic units are separated by dashed lines: West-Macedonian zone (WMZ), Pelagonian massif (PM), Vardar zone (VZ), and Serbo-Macedonian massif (SMM)] (b)

Situated at the border of several major tectonic plates, Macedonia has developed a variety of geological structures over millions of years. The Pelagonian Massif (PM) represents the largest and most ancient geotectonic unit in the country, including much of the western and central regions. It is composed of crystalline rocks such as gneisses, schists, and granites, and dates back over 300 million years. The Vardar Zone (VZ) extends through the central and eastern parts of Macedonia and consists of a complex series of rocks, including metamorphic, sedimentary, and volcanic types. This zone formed through a series of tectonic collisions and subductions and is younger than the Pelagonian Massif. In the northeastern part of the country lies the Serbo-Macedonian Massif (SMM), which is distinguished by its metamorphic and igneous rock formations and originated during the late Paleozoic and early Mesozoic eras. The West-Macedonian Zone (WMZ), located in the western part of Macedonia Macedonia, is characterized by its metamorphic rocks, including schists and gneisses, and features numerous thrust faults and folds. This zone was formed in the Mesozoic era. A simplified lithological map of Macedonia, highlighting these principal tectonic units, is presented in Fig. 1b. [4]

Sampling and analyses

Ambient radiation dose rate has been monitored at 68 locations in 2010 (Fig. 2a) and 72 locations in 2015 and 2020 (Fig. 2b) all around the country to estimate the rate of the absorbed radiation dose that arises from the terrestrial radiation exposed to open space. The dose rates have been measured by dose rate detector ATOMTEX AT1117M with BDGK-01 probe with a dose rate range from 0.01 μSv/h to 10 Sv/h. The energy interval in which the radiation was identified was from 60 keV to 3 MeV. The measurements of radiation dose rate were conducted at a height of one meter above the ground, following the guidelines of the Scientific Committee for the Effects of Atomic Radiation of the United Nations - UNSCEAR [2].



a. b.

Figure 2. Locations of and radiation dose measurements points across Macedonia in 2010 (a) and in 2015 and 2020 (b)

RESULTS AND DISCUSSION

All data obtained from this investigation (processing, calculations, geostatistical data interpretation and visualization - (mapping) were processed using the following software:

Statistica (Stat Soft Inc.), Autodesk MAP 3D (Autodesk Inc.), QGIS (Open Source Geographic Information System) and Surfer (Golden Software Inc.).

The basic statistical parameters (mean, median, minimal and maximal content, standard deviation, percentile values, and coefficient of variation) of the data for the ambient dose rates are given in Table 1.

Table 1. Descriptive statistics. All the values in the table are given in nSv/h

Year	N	X	Md	X_{BC}	Min	Max	P_{10}	P_{90}	P_{25}	P_{75}	S	CV
2010	68	113	110	104	53	340	65	170	80	130	46	40
2015	72	110	110	102	38	360	56	158	80	142	48	43
2020	72	110	104	104	41	300	55	156	82	140	45	41

N- number of measurement locations; X - arithmetic mean; Md - median; X_{BC}- Median Box-Cox transformed values; Min - minimum; Max - maximum; P_{10}, P_{90}, $P_{25,}$ and P_{75} percentile values S - arithmetic standard deviation; CV - coefficient of variation.

According to the data shown in Table 1, it can be concluded that the ambient radiation dose rate in Macedonia ranged from 53 nSv/h to 340 nSv/h in 2010, from 38 nSv/h to 360 nSv/h in 2015 and from 41 nSv/h to 300 nSv/h in 2015. The average dose were assessed to be 113 nSv/h in 2010 and 110 nSv/h in 2015 and 2020. Notable difference are not observed in the median values for the measurements in the three surveys also. The results for the ambient dose rate measurements done in many regions in the world reveal that the mean values varied from 24 nSv/h to 160 nSv/h. The world average for the ambient radiation rate was determined at 57 nSv/h [2].

Following the Box-Cox transformation of the data, bivariate statistics was used to detect the correlations or relationships between the data obtained in each of the measurement campaigns. For that objective, the Pearson correlation coefficient *r* reflecting the strength and direction of the linear dependence (correlation degree), between two random variables or sets of random variables was determined. The results from bivariate statistics are displayed in the matrix of the correlation coefficient in Table 2. The values within the range of 0.7-1.0 are considered to show a strong connection between the variables which is the case in this situation. This can be interpreted as the constant origin of the radiation on the territory of Macedonia in the studied period.

Table 2. Pearson correlation coefficient. Values are in the range 0.7-1.0 showing strong association; Box-Cox transformed values were used.

2010	1.00		
2015	0.78	1.00	
2020	0.76	0.84	1.00
	2010	2015	2020

The observed radiation dose distribution for 2010, 2015 and 2020, in Macedonia is shown in Figure 3. From the analysis of the geological map of Macedonia Fig 1b, and the results obtained for the ambient dose rate at each of the locations it was evident that the highest ambient dose rates were observed at the places where volcanic and magmatic rocks were most present in the Western-Macedonian zone (regions of Kičevo and Bitola) and in the Vardar zone of Mariovo, Kožuf, Kratovo and Radoviš region as well as smaller regions. Furthermore, regions extensively covered by Precambrian granites in the Serbian-

Macedonian massif and Pelagonian Massif have shown elevated dose rates. High ambient dose rates were measured in the Pelagonia Valley, and that can be further explained by the emission of dust from the uranium-enriched ore mine and fly ash from the thermoelectric power station near the town of Bitola [5-8].

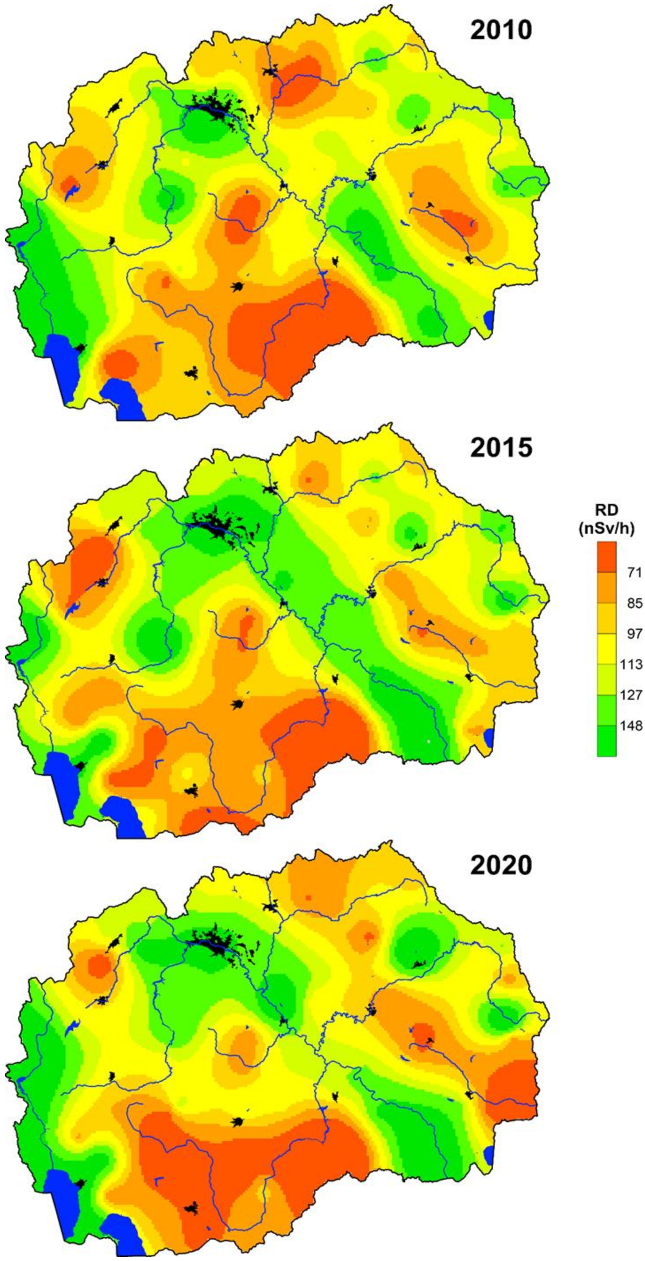


Fig 2. Spatial distribution of measured radiation dose rates in 2010, 2015 and 2020.

CONCLUSION

The results from this study show that the results obtained in the in situ environmental dose rate measurements in Macedonia made in 2010, 2015 and 2020 are strongly influenced by the geology of the country and the highest values are locations where volcanic and magmatic rocks were most present. Higher values are observed also in the Pelagonia Valley, which can be explained by the emission of dust from the uranium-enriched ore mine and fly ash from the thermoelectric power station situated near the town of Bitola

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