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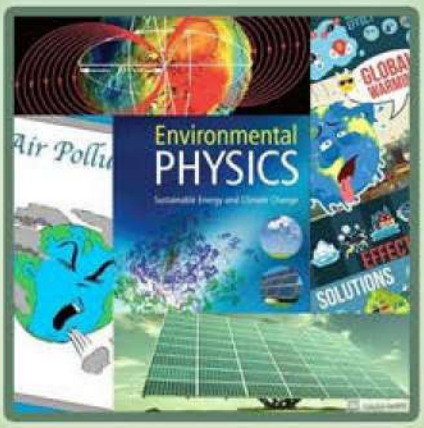

IV International Conference on Physical Aspects of Environment

ICPAE 2025

PROCEEDINGS

Zrenjanin, Serbia, August 29-30, 2025.

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

IV International Conference on Physical Aspects of Environment ICPAE2025

Proceedings

Zrenjanin, 29 – 30th, August 2025.

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INTRODUCTION

IV International Conference on Physical Aspects of Environment (ICPAE2025), held on August 29–30, 2025, was organised by the Technical Faculty "Mihajlo Pupin" 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 Timişoara, Amirkabir University of Technology (Tehran, Iran), Donghua University (Shanghai, China), and Wuhan Textile University (Wuhan, China).

The paper presentations at the Conference were moderated by Vasilije Petrović, Ph.D, Professor; Ljubiša Nešić, Ph.D, Professor; Jasna Tolmač, Ph.D, Assistant Professor; Darko Radovančević, Ph.D, Assistant Professor.

The Conference included 42 submitted papers, of which 5 were presented as plenary lectures, and the remaining were allocated to brief oral sessions. Among the submissions, 14 papers had first authors from China, Iran, Sweden, Romania, Bulgaria, North Macedonia, Montenegro, Bosnia and Herzegovina, Croatia, Slovenia, and Ethiopia, and 28 papers had first authors from Serbia. One paper had a co-author from the United Kingdom.

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, 29 - 30th August 2025.

Conference participants are from the following countries:

United Kingdom

Bosnia and Herzegovina

Romania

North Macedonia

Serbia

Croatia

Iran

Bulgaria

Ethiopia

Montenegro

China

Slovenia

Sweden

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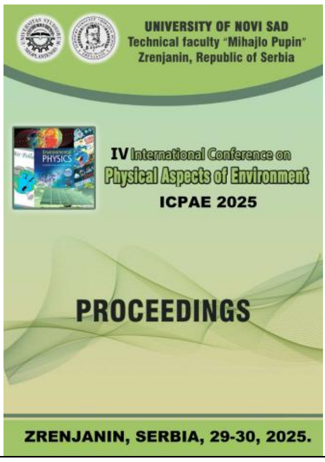

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August 29-30th, 2025, Zrenjanin, Serbia

INVITED LECTURES

Conference Proceedings
ICPAE 2025, August 29–30, Zrenjanin, Serbia
Technical Faculty "Mihajlo Pupin", Zrenjanin & Faculty of Sciences and Mathematics, Niš

From Planck's Quantum to a Sustainable Future

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Abstract. This lecture provides a concise overview of the emergence of quantum mechanics, one of the most significant scientific revolutions of the 20th century, which has permanently transformed our understanding of the world. Special emphasis is placed on the significance of the International Year of Quantum Science and Technology 2025, as well as on the fundamental ideas that have shaped modern science and ushered in a new era in technology and civilizational development. The lecture traces the crisis of classical physics and the challenges at the beginning of the 20th century, which led to radically new concepts in understanding nature: from Planck's hypothesis and the photoelectric effect, through Bohr's model and de Broglie's hypothesis, to Heisenberg's matrix mechanics and Schrodinger's wave mechanics. Particular attention is given to how these ideas today form the basis for the development of quantum technologies that contribute to environmental protection and a sustainable future: quantum materials and superconductors improve energy efficiency; quantum computers and quantum chemistry aid in understanding climatic and chemical processes; quantum sensors enable precise environmental monitoring, while quantum biology reveals how nature exploits quantum effects to optimize life processes. In this way, quantum mechanics connects fundamental scientific concepts with the challenges of energy, ecology, and sustainable development, demonstrating that the concepts which shaped modern science now provide the foundation for technological solutions for the future.

Keywords: Planck's hypothesis, quantum theory, quantum mechanics, wave–particle duality, quantum biology, quantum technologies, sustainable development, environmental protection

Conference Proceedings
ICPAE 2025, August 29–30, Zrenjanin, Serbia
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Horizontal Mixing of Air Parcels at High Altitudes

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Abstract. Air parcels can be moved both vertically and horizontally. Vertical movement, caused by temperature differences in the near-surface atmosphere, is considered highly important for the generation of winds. In addition to winds, which represent large-scale movement of air parcels, small-scale motions that mix air parcels of different temperatures are also considered. In this work, the effects of this process, occurring in the upper layers of the troposphere, will be analyzed.

Keywords: air parcel motion, temperature, atmosphere, horizontal mixing

Conference Proceedings
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Circular Economy in the Textile Industry

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Abstract. This paper examines the textile industry as one of the largest global industries, currently generating approximately 40 million tons of textile waste annually. Due to this substantial environmental impact, increasing attention is being directed toward the development of a circular economy within the textile sector. Today, circular economy in textiles is evolving beyond a narrow focus on waste management. From the perspective of circularity, a systemic approach is increasingly adopted one that aims to extend the life cycle of materials, preserve product quality, and contribute to addressing the triple planetary crisis: climate change, biodiversity loss, and pollution. The European Environment Agency (EEA) is actively engaged in advancing the circular economy in the textile domain. In this context, the Circular Economy Measurement Lab (CML) has been established. The role of this Lab is to complement existing monitoring frameworks by providing additional data and insights into the growth of circular economy practices, including those emerging from new sources and different analytical perspectives. The Lab collects a wide range of indicator data and organizes it into three distinct sets of metrics. The development of the CML textile module is based on the selection of metrics derived from available data sources, reports, and expert knowledge. The categorization of metrics within the textile module mirrors the structure of the general CML framework and includes the following metric categories: enabling framework, business, consumption, and materials and waste.

Keywords: textile industry, European Environment Agency, circular economy

INTRODUCTION

The textile industry, viewed on a global scale, is currently among the largest industries. It supplies the market with clothing, footwear, carpets, curtains, furniture, technical textiles, and more. Today, the textile industry employs millions of workers worldwide. In addition to its global relevance, the textile industry also holds a significant position within the European manufacturing sector. Currently, this industry generates approximately 40 million tons of textile waste annually on a global level. Most of this waste is either landfilled or incinerated.

On the other hand, the technological processes involved in textile production consume vast quantities of water, land, and raw materials. In terms of water consumption and the use of primary raw materials, clothing, footwear, and household textiles represent the fourth largest category in the EU, following food, housing, and transport. This group of products causes the second-largest pressure on land use, after food, and also contributes substantially to chemical pollution and water contamination including plastic microfibers released during washing as well as a range of negative social impacts [1-9].

Today, textiles are increasingly referred to as an environmental threat. According to the European Environment Agency (EEA), the consumption of clothing, footwear, and household textiles in the European Union results in the annual use of approximately 1.3 tonnes of raw materials and over 100 cubic meters of water per capita. The Agency has emphasized that significant changes are required in the textile sector to transition toward a circular economy, aiming to reduce greenhouse gas emissions, encourage resource reuse, and protect natural ecosystems [10].

The severity of this issue is further highlighted by recent research conducted by scientists from the University of Cambridge, published in The Lancet Planetary Health. The study, which included data from approximately 30 million individuals worldwide, revealed a strong correlation between air pollution and increased risk of dementia, including Alzheimer's disease. Currently, dementia affects more than 57 million people globally, and projections suggest that this number could almost triple to 152.8 million by 2050. The systematic review, which included data from North America, Europe, Asia, and Australia, clearly demonstrated a significant association between dementia and exposure to PM2.5 particles, nitrogen dioxide (NO_2), and black carbon (soot) [11].

In response, serious efforts are being made to shift from a linear textile economy to a closed-loop recycling system [1]. This transition primarily involves eco-design and the reuse of clothing and textiles, which could help mitigate the environmental and climate-related impacts of textile production and consumption [6–7]. For example, EU member states are now required to collect and separately sort textile waste, ensuring that collected materials do not end up in incinerators or landfills.

According to the EEA, circular economy models in the textile sector such as clothing rental, sharing, take-back schemes, and resale should be promoted through policies addressing material selection and design, production and distribution, usage and reuse, as well as collection and recycling. This includes policies related to sustainable production and products, eco-design and durability standards, green public procurement, safe and sustainable materials, waste prevention, extended producer responsibility (EPR), labelling, and product standards [10].

Some EU countries have already implemented extended producer responsibility schemes, holding brands and retailers accountable for post-consumer textile waste and requiring them to make financial contributions to the collection, recycling, and reuse of their products.

TEXTILE INDUSTRY

The textile industry today is one of the most important industries, involving millions of manufacturers and billions of consumers worldwide. In Europe alone, the textile sector employs around 1.5 million workers. For many years now, clothing prices have been steadily decreasing, so for example, in Europe, an average of about 26 kilograms of textiles is consumed per person annually. The textile market is highly globalized. Millions of producers and billions of consumers worldwide are part of so-called linear value chains. These chains from raw material production to the manufacturing of finished textile products, transportation, consumption, and waste include little or no reuse or recycling of textile materials. Facts show that since 1975, global textile fiber production has tripled. Of the total amount of textile fibers today, 60% are synthetic. Polyester is currently the most common fiber used in the textile industry and on the global textile market. More than 70 million barrels of oil are used annually for the production of polyester. Another major group consists of natural fibers, whose production primarily requires land and water as resources, both of which are consumed in large quantities.

All of this has negative environmental consequences because textile production involves resource consumption, climate change, and pollutant emissions. Therefore, the textile industry in the EU is ranked as the fourth highest sector in terms of pressure on the use of primary raw materials and water. The only sectors ranked higher are food, housing, and transportation.

Textile products are diverse, which makes it difficult to accurately determine their environmental impact. Some estimates suggest that globally, the textile industry accounts for between 2% and 10% of environmental impact. It is estimated that in the EU, the impact caused by textile consumption ranges from 4% to 6%. Reports from 2015 indicate that the global textile and clothing industry was responsible for consuming 79 billion cubic meters of water and generating 92 million tons of waste. The same estimates project that by 2030, under the business-as-usual scenario, these numbers will increase by at least 50%.

In 2020, on average, the production of clothing and footwear per EU citizen required 9 cubic meters of water, 400 square meters of land, and 391 kilograms of raw materials [2].

These data clearly show that the textile industry is a major consumer of water. It is estimated that in 2015 the global textile industry consumed 79 billion cubic meters of water, whereas the total water consumption of the entire EU economy in 2017 amounted to 266 billion cubic meters. For example, producing one cotton T-shirt requires 2,700 liters of potable water, which is the amount consumed by one person in 2.5 years. It is estimated that textile finishing processes mainly dyeing and finishing are responsible for 20% of global water pollution [2].

CIRCULAR ECONOMY

Today, the circular economy is developing as a concept that goes beyond mere waste management. From the perspective of the circular economy, there is an increasing emphasis on a systemic approach that prolongs the use of materials, maintains higher quality, and contributes to addressing the triple planetary crisis of climate change, biodiversity loss, and pollution [10].

The circular economy has become part of broader transitions, which include, and will continue to include, significant changes in lifestyles, particularly with regard to consumption and production patterns. The primary expectation from the circular economy is to mitigate the negative environmental impacts of existing supply chains through systemic changes within the economic system. When viewed as part of these broader transitions, the circular economy aims to improve human well-being while respecting ecological boundaries and addressing existing injustices associated with environmental degradation and climate change [10].

ACTIVITIES OF THE EUROPEAN ENVIRONMENT AGENCY IN THE FIELD OF TEXTILES

The European Environment Agency (EEA) is actively engaged in the textile sector within the framework of the circular economy. Intensive activities began in 2019 with the submission of the foundational report on textiles and the environment in the circular economy. This was followed by new reports, conferences, and various activities. The outcomes of these efforts include reports such as the 2022 publication on Design for the Circular Economy and Microplastics from Textile Consumption in Europe, as well as meetings and reports from 2023, and documents concerning bio-textiles and the export of used textiles. Further gatherings took place in 2024, resulting in reports on the quantities and disposal of unsold and returned textiles, as well as textile waste management in Europe. Additionally, a 2025 conference focused on the topic "Textile Value Chain in Numbers – Additives Changing Trends" was held. This 2025 report complements another publication titled "Textiles and the Environment: The Role of Digital Technologies in the European Circular Economy."

All these activities aim to assess the current situation in preparation for the transition to a circular textile economy within the European Union. Accordingly, the EEA report-writing committees have defined appropriate indicators. These indicators are intended to simplify complex systems by focusing on relevant aspects for which data is available. Environmental indicators serve as tools to raise public awareness about environmental issues and support policy-making by providing information on environmental challenges, measuring their severity, prioritizing issues, and monitoring political responses [4].

In this context, the Circular Economy Measurement Laboratory (CML) was established. The Laboratory's task is to complement other frameworks for monitoring the circular economy by providing additional information on the circular economy from new sources and diverse perspectives. The Laboratory collects diverse indicator data and groups it into three distinct metric sets:

1. Indicators: Established datasets at the EU level with sufficient time series, such as datasets provided by Eurostat;

2. Signals: Less reliable or fully reliable data that may include scientific studies, surveys, national datasets, etc.;

3. Potentials: Data that would be highly informative and crucial for measuring circularity but currently lack sufficient data for trend formation or assessment of the current state. These are often presented as individual data points [10].

Figure 1. illustrates the logic and structure used within the CML framework.

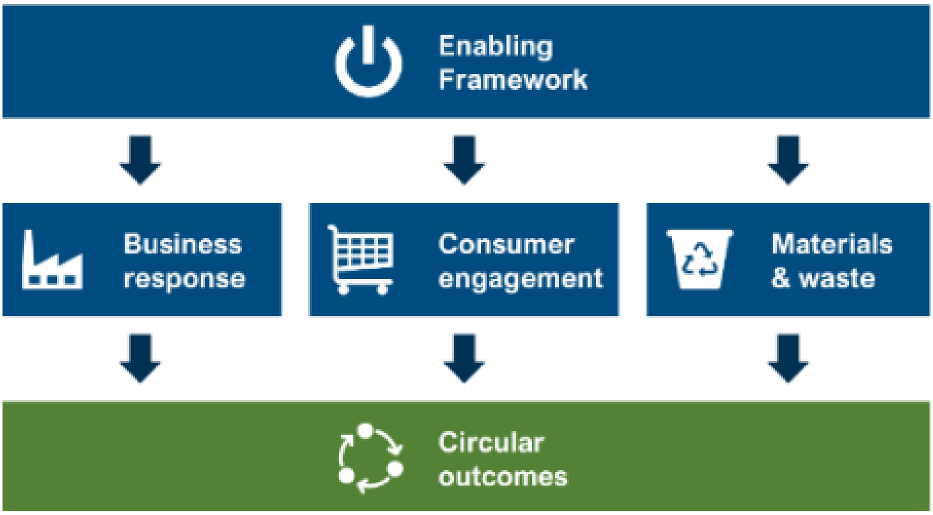

Figure 1. Illustration of the logic and structure used in the CML [10]

Circularity metrics used in the Circular Economy Measurement Laboratory (CML) are grouped into four categories [10]:

1. Framework – representing the political and economic momentum in Europe, including the potential growth of funding for circular economy projects. This is because the development and expansion of the circular economy require a framework that includes essential enabling factors such as policy, innovation, and financing.
2. Business – indicating signs of adoption of circular approaches within European business models. The development of a circular economy necessitates the transformation of companies' operational models to provide goods and services with reduced resource consumption.
3. Consumption – reflecting the readiness of consumers and producers to embrace the circular economy in the products and services they consume or produce. Consumption patterns play a crucial role in the transition to a circular economy, which is linked to the sustainable choices made by organizations and individuals when purchasing and using products and services.
4. Materials and Waste – illustrating trends in waste generation and management, as well as measures to reduce the use of primary raw materials through prolonged product use.

The European Environment Agency (EEA) does not have official indicators for textiles; however, the CML Textile module serves as a method for measuring the circular economy of textiles in Europe. The Textile module provides circular economy information for textiles while acknowledging challenges in data reliability.

Figure 2. presents the CML metrics for the Textile module implemented within the EEA's circular economy framework [10].

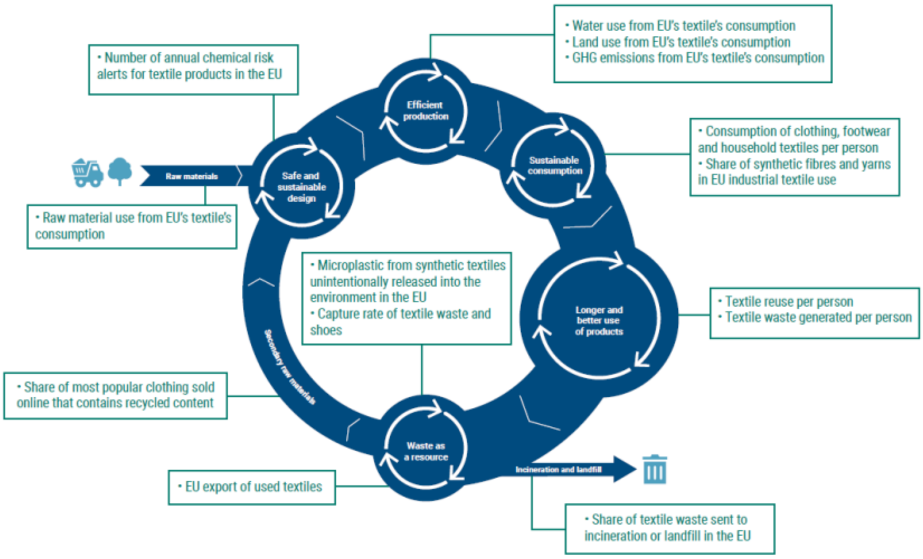

Figure 2. CML Textile Module Metrics Implemented in the EEA Circular Economy Concept [10]

The development process of the CML Textile Module is based on the selection of metrics according to available data, reports, and expertise. The division of metrics within the Textile Module follows the same structure as the general CML framework. The following categories of metrics are used:

1. Enabling framework
2. Business
3. Consumption
4. Materials and waste

Metrics for the "Enabling Framework" category include:
- Quality of textile recycling in Europe

Metrics for the "Business" category include:
- Export of used textiles from the EU

Metrics for the "Consumption" category include:
- Consumption of clothing, footwear, and home textiles
- Share of synthetic fibers and yarns in the production of technical textiles in the EU
- Microplastics unintentionally released into the environment from synthetic textile materials in the EU
- Textile reuse per capita per year
- Average garment lifetime measured by the number of wears

Metrics for the "Materials and Waste" category include:
- Raw material use for textile consumption in the EU
- Water consumption for textiles in the EU
- Land use for textile consumption in the EU

- Greenhouse gas emissions from textile consumption in the EU
- Number of annual chemical risk warnings for textile products in the EU
- Share of best-selling products containing recycled material
- Textile waste generated per capita annually in the EU
- Collection rate of textile and footwear industry waste in the EU
- Share of textile waste incinerated or landfilled in the EU

Two metrics, namely "quality of textile recycling in Europe" and "average garment lifetime measured by number of wears," were developed as part of this project. However, these metrics have proven to be too unreliable and have therefore not yet been included in the CML Textile Module.

CONCLUSION

The textile industry is currently one of the largest industries worldwide. It supplies the market with clothing, footwear, carpets, curtains, furniture, technical textiles, and more. Apart from its global significance, the textile industry also holds an important position within the European manufacturing sector. However, this industry generates approximately 40 million tons of textile waste annually on a global scale. Consequently, the textile industry ranks as the fourth most resource-intensive sector in the EU in terms of primary raw material and water consumption, following the food, housing, and transport industries. For this reason, considerable attention is being devoted to the development of a circular economy within the textile sector. Today, the circular economy in textiles is evolving as a concept that goes beyond mere waste management. From the perspective of the circular economy, a systemic approach is increasingly being adopted that prolongs the use of materials, maintains higher quality, and contributes to solutions addressing the triple planetary crises of climate change, biodiversity loss, and pollution. In this field, the European Environment Agency (EEA) is actively engaged in initiatives related to textiles within the circular economy framework.To support these efforts, the Circularity Measurement Lab (CML) has been established. The primary task of this Lab is to complement other circular economy monitoring frameworks by providing additional insights into circular economy developments from new sources and various perspectives. The Lab collects diverse data on indicators and organizes them into three distinct metric sets. The development process of the CML textile module is based on the selection of metrics derived from available data, reports, and expertise. The structure of the textile module metrics follows the same framework as the general CML, utilizing the following categories: enabling framework, business, consumption, and materials and waste.

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Waste Practices in Vojvodina's Apparel Industry

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Abstract. This study analyzes waste management practices in apparel manufacturing within the AP of Vojvodina (Serbia), which is the largest segment of the textile industry. Analysis of the results received shows clear contrasts: big companies implement sustainable systems and work with authorized operators who recycle textile waste. Also, these companies mainly use digital technology in the pre-production stages. At the same time, smaller (micro and little) firms often lack formal policies, relying on municipal disposal with limited reuse or recycling. Main barriers include low environmental awareness, poor information access, weak transparency, limited digitalization, and a shortage of recycling operators. Based on the results the study recommends technology-based measures - mandatory waste tracking, digital training, equipment subsidies, expanded recycling infrastructure, and education reforms - to drive a shift toward circular production, improve sustainability, and strengthen regional innovation capacity.

Keywords: textile waste, apparel manufacturing, waste practice, recycling, textile industry

INTRODUCTION

Textile production is steadily rising due to increasing living standards and population growth. However, this growth is closely linked to overconsumption and fast waste generation, mainly through the fast fashion model [1-4]. This model focuses on rapid trend cycles and mass overproduction, leading to shorter clothing lifespans and more textile waste [5]. In response, the slow fashion movement has gained popularity, promoting sustainable practices such as durable materials, fewer seasonal trends, higher quality, local manufacturing, and supply chain transparency [6].

Textile consumption has significant environmental impacts. In the European Union (EU), the average person buys 19 kg of textiles annually, generating about 6.94 million tonnes of waste, most of which ends up in landfills [7-9]. Serbia follows global patterns, with around ≈12 kg per capita, much of which is discarded soon after purchase [10]. Projections suggest global waste will rise from 1.3 to 2.2 billion tonnes annually by 2025, with textiles accounting for about 1.5% [11]. Recycling textiles could save up to 80% of energy compared to virgin production [12].

The apparel sector is the largest in textile manufacturing, representing about 42% of production. Studies show that only 65% of raw materials end up in final products, with up to 35% becoming pre-consumer waste, especially during cutting [2, 14-17]. Post-consumer textile waste refers to textile products discarded by end-users after use or at the end of their life cycle, including clothing, bedding, furniture, footwear, and other items [18]. Post-consumer textile waste can be categorized as: *usage-related waste, recyclable* and *reusable textiles*. Usage-related waste means items that are worn out, damaged, outdated, or otherwise unusable; it includes household, office, and institutional textiles. Recyclable and reusable textiles are items suitable for cleaning, donation, resale on second-hand markets, or processing into new products (e.g., construction or automotive materials). Approximately 90% of post-consumer textile waste ends up in landfills or is incinerated, with only 10% recycled [19, 20]. This highlights the urgent need for more substantial legislative and market incentives to improve recycling and reuse [2]. In Serbia, such waste is considered municipal under the Waste Management Law [21], but it can also be classified explicitly according to the European Waste Catalogue (EWC) [22]. EU legislation provides guidelines for reducing environmental impact and promoting recycling and reuse. EU directives set targets for reducing landfill disposal and increasing recycling rates [23, 24]. The 2018 Circular Economy Plastics Strategy also recommends integrating post-consumer textiles into circular material flows. To mitigate environmental impacts, initiatives in Serbia and EU member states should include: developing collection systems for post-consumer textiles, promoting recycling technologies, and implementing Extended Producer Responsibility (EPR) schemes.

Effective management of post-consumer textile waste can significantly reduce environmental harm, enhance recycling efficiency, and support the transition to sustainable, circular economies. The textile waste management hierarchy creates a framework of prioritized strategies aimed at reducing environmental impacts while supporting sustainable development goals [2]. Its implementation proceeds in a sequential manner:

- *Prevention* – incorporating design and production methods that reduce waste generation from the start.
- *Reuse* – prolonging product life through resale, donation, or functional repurposing.
- *Recycling and upcycling* – reclaiming fibers or transforming textile waste into higher-value products, thus maintaining material usefulness.
- *Energy recovery* – converting non-recyclable waste into energy, decreasing dependence on virgin fuels.
- *Disposal* – the final option, involving safe incineration or landfilling under controlled conditions.

By emphasizing prevention, material efficiency, and continuous resource circulation, this hierarchy enacts the principles of a circular economy, strengthening both environmental sustainability and resource management.

The purpose of this study is to examine current waste management practices in apparel manufacturing in the Autonomous Province of Vojvodina, Serbia. The research focuses on the production process, with particular attention to textile waste generated during cutting operations, which represent the most significant share of pre-consumer waste and highlight production design optimization as a key factor [16, 23]. In collaboration with local apparel manufacturers, the study identifies the main types of pre-consumer waste, evaluates existing waste management practices, and defines the current state, existing gaps, and future perspectives. Furthermore, the research analyzes key barriers and proposes technology-driven solutions aimed at improving waste prevention at the design and production stages, as well as enhancing reuse, recycling, upcycling, energy recovery, and appropriate disposal pathways. By advancing these circular practices, the study seeks to strengthen sustainability, competitiveness, and innovation within the regional apparel industry.

MATERIALS AND METHODS

The research was carried out in several primary stages, outlined in Figure 1. During the period from September 2024 to March 2025, a total of 120 responses from apparel manufacturers situated in the AP of Vojvodina were collected and analyzed.

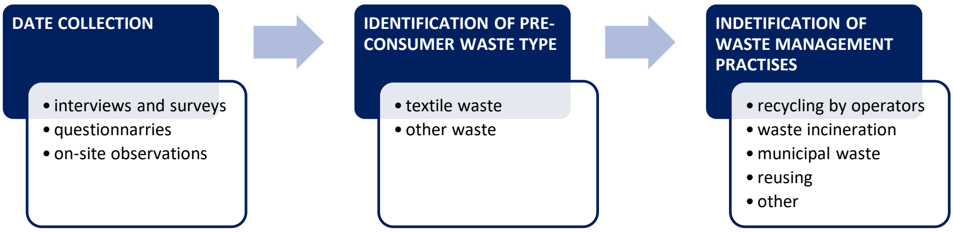


Figure 1. The primary research phases

Data collection

Accurate data collection forms the fundamental basis for comprehending waste generation and management. This process involves the systematic accumulation of both qualitative and quantitative information from various sources, including structured surveys and interviews conducted with management and waste management personnel. Standardized questionnaires are designed to record pertinent quantitative data and qualitative insights. Additionally, direct on-site observations of production processes and waste handling practices are conducted to enhance understanding.

Identification of pre-consumer waste type

In the textile industry, waste is generally classified into two main categories. Textile waste includes production residues such as fabric offcuts, yarn remnants, defective products, and worn-out textiles at the end of their lifecycle. Other waste refers to non-textile materials generated during operations, including packaging waste (plastics, cardboard, pallets), chemical residues (dyes, solvents, finishing agents), mixed municipal waste (office and cafeteria waste), as well as hazardous substances requiring special treatment.

Identification of waste management practices

Waste management in the apparel manufacturing includes recycling, incineration, municipal waste handling, reusing, and other methods like composting or innovative recovery. Recycling recovers raw materials and reduces landfill waste. Incineration treats non-reusable waste, sometimes with energy recovery. Municipal waste covers general waste from facilities. Reusing extends the material lifecycle and minimizes waste. Other practices include hazardous waste treatment and new recovery tech.

RESULTS AND DISCUSSION

Regional company structure

As of April 2025, data from the Serbian Chamber of Commerce and the Business Registers Agency indicate Serbia has 1.565 active apparel manufacturers. Most are located in Belgrade, Central Serbia, and the AP of Vojvodina. Resilient textile hubs such as Leskovac, Loznica, Užice, and Subotica continue to be vital centers in the domestic apparel industry. In Vojvodina alone, there are 120 apparel companies, making up approximately 7.7% of the national total.

The data illustrated in Figure 2 depicts the distribution of firms within Vojvodina (encompassing Banat, Bačka, and Srem) according to their size, as determined by the number of employees. Companies are classified into micro (up to 10 employees), little (10 to 50 employees), middle (50 to 250 employees), and big (exceeding 250 employees). The total sample comprises 120 entity companies.

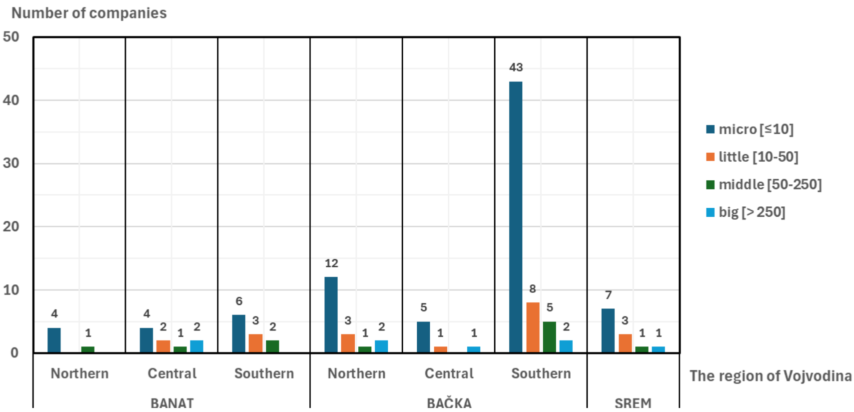


Figure 2. The regional distribution of the company's structure in AP Vojvodina

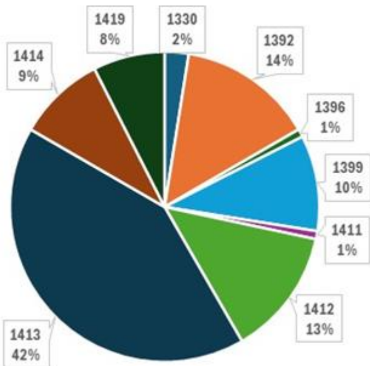
Analysis of received dates showed that micro-enterprises dominate the regional structure, accounting for 81 firms (67.5%) of the total. The highest concentration of micro companies is observed in Southern Bačka (43 firms), followed by Northern Bačka (12 firms), Srem (7 firms), and Southern Banat (6 firms). This strong presence indicates that the regional economy is driven mainly by small-scale entrepreneurial activity, consistent with broader trends in transitional economies where micro-enterprises form the backbone of employment. Little enterprises represent 20 firms (16.7%), with the most significant number located in Southern Bačka (8 firms). While little companies in number compared to micro-enterprises, this category indicates the gradual scaling-up of business activities in specific subregions, particularly in Bačka. Middle-sized enterprises are relatively scarce, totaling 11 firms (9.2%). Their presence is most notable in Southern Bačka (5 firms). This distribution suggests limited mid-scale industrial or service activities, reflecting structural challenges in sustaining medium-level business growth in the region. Big enterprises are the least represented, comprising only eight firms (6.7%). They are concentrated in Bačka (5 firms) and Banat (3 firms). Their relatively low presence underscores the weak industrial base and limited attraction of large-scale investment in the province.

When comparing across regions, Southern Bačka stands out, hosting 58 firms in total (48.3%), of which the overwhelming majority are micro-enterprises. This indicates a regional economic hub with highly fragmented firm structures. Banat follows with 25 firms (20.8%), more evenly distributed across firm sizes, whereas Srem accounts for 12 firms (10%), maintaining a moderate presence across all categories.

Overall, the analysis highlights a highly fragmented enterprise structure dominated by micro firms, with limited scaling toward middle and big enterprises. This distribution reflects both the entrepreneurial dynamism and the structural weaknesses of the regional economy, characterized by underdeveloped mid-sized business sectors and insufficient presence of large enterprises that typically drive innovation and broader regional development.

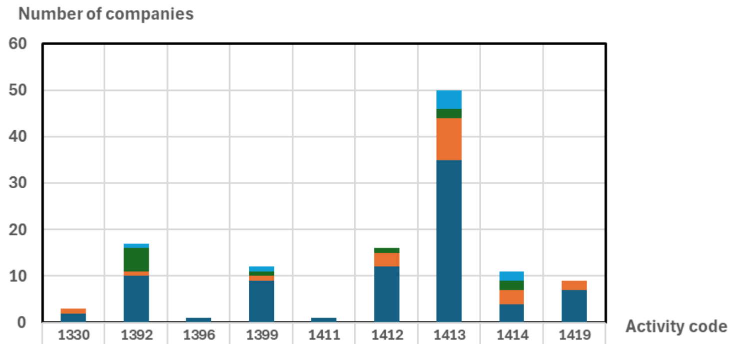
Company structure organized by activity code and size

Figure 3 details the company activity code and company size within apparel manufacturing in the AP Vojvodina.



1330 - Finishing textiles
1392 - Production of finished textile products, except for clothes
1396 - Manufacture of other technical and industrial textiles
1399 - Production of other textile items
1411 - Manufacture of leather clothes
1412 - Manufacture of workwear
1413 - Manufacture of other wearing apparel
1414 - Manufacture of underwear
1419 - Manufacture of other wearing apparel and accessories

a)



	1330	1392	1396	1399	1411	1412	1413	1414	1419
big [>250]	0	1	0	1	0	0	4	2	0
middle [50-250]	0	5	0	1	0	1	2	2	0
little [10-50]	1	1	0	1	0	3	9	3	2
micro [<10]	2	10	1	9	1	12	35	4	7

b)

Figure 3. The distribution of the company's structure by activity code (a) and company size (b)

Analysis of the distribution of companies by activity code showed that the largest group of companies is involved in the manufacture of other wearing apparel (activity 1413), with 50 companies, making up 41.7% of the total (Figure 3). Production of finished textile products except clothing (1392) follows with 17 companies (14.2%), and manufacture of workwear (1412) has 16 companies (13.3%). Other notable activities include the production of other textile items (1399) with 12 companies (10%), the manufacture of underwear (1414) with 11 companies (9.2%), and the manufacture of other wearing apparel and accessories (1419) with 9 companies (8.0%). Minor activities, each with fewer than 3% of companies, include finishing textiles (1330), manufacture of leather clothing (1411), and manufacture of technical textiles (1396). The dominance of micro-enterprises may limit the sector's ability to scale, invest in technology, or implement sustainable practices. The concentration in general apparel suggests market saturation, while specialized segments like workwear and technical textiles offer potential growth opportunities. Limited activity in finishing and technical textiles indicates room for modernization and the development of higher value-added products. Overall, the textile industry is mainly made up of small enterprises focused on general clothing, with specialized and high-value segments underrepresented. Strengthening innovation, sustainability, and scaling capacity could improve sector competitiveness and resilience.

Company structure based on waste disposal methods

Table 1 presents the company structure grouped by the different waste disposal methods.

The total number of analyzed companies is 120, categorized by different activity codes and company sizes. Waste management practices among these companies are grouped into the following groups (Table 1, Figure 4):

- RO – recycling through certified operators,
- CM – contract manufacturing (outsourced production),
- MW – disposal as municipal waste (directly),
- RU-MW – reuse combined with municipal waste disposal,
- DW– do not work or is currently not operational,
- WI – waste incineration,
- ND – no data available.

Out of the 120 analyzed companies in the field of apparel manufacturing, only eight companies – primarily big companies – send their waste for processing by authorized operators (RO group), representing just 6.7% of the total sample (Table 1, Figure 4). This marks a positive shift toward sustainable and responsible waste management.

Contract manufacturing (CM) is a business model used by nine companies (7.5%), mostly micro and little companies, where waste is returned to clients, typically foreign companies. This model reduces local responsibility for waste management and is commonly observed under activity code 1413 (manufacture of other wearing apparel).

A total of 46 companies (38.3%) treat all their waste as municipal waste, either through direct disposal or after prior reuse in the production of other products (MW and RU-MW groups). Direct municipal waste disposal (MW group) is practiced by 33 companies (27.5%), indicating that most companies still rely on conventional disposal channels rather than sustainable alternatives. Reusing and disposing of created textile waste as municipal waste (RU-MW group) is carried out by 13 companies (10.8%), indicating a degree of circularity.

Table 1. Company structure according to the grouping of waste disposal methods

Activity code	Size of companies	Grouping of waste disposal methods							Total	
		RO	CW	MW	RU-MW	DW	WI	ND	firms	%
1330	micro	-	-	2	-	-	-	-	2	1.7
	little	-	-	-	-	-	-	1	1	0.8
1392	micro	1	-	4	1	-	-	4	10	8.3
	little	-	-	-	1	-	-	-	1	0.8
	middle	1	1	-	1	-	-	2	5	4.2
	big	1	-	-	-	-	-	-	1	0.8
1396	micro	-	-	-	-	-	-	1	1	0.8
1399	micro	1	-	2	3	-	-	3	9	7.5
	little	-	1	-	-	-	-		1	0.8
	middle	-	-	1	-	-	-	-	1	0.8
	big	1	-	-	-	-	-	-	1	0.8
1411	micro	-	-	-	-	-	-	1	1	0.8
1412	micro	-	-	4	1	-	-	7	12	10.0
	little	-	-	1	2	-	-	-	3	2.5
	middle	-	-	1	-	-	-	-	1	0.8
1413	micro	-	2	12	2	4	2	13	35	29.2
	little	1	1	1	1	-	1	4	9	7.5
	middle	-	1	-	-	-	-	1	2	1.7
	big	2	-	-	-	-	-	2	4	3.3
1414	micro	-	-	1	1	-	-	2	4	3.3
	little	-	-	-	-	-	-	3	3	2.5
	middle	-	-	1	-	-	-	1	2	1.7
	big	-	1	-	-	-	-	1	2	1.7
1419	micro	-	1	2	-	-	-	4	7	5.8
	little	-	1	1	-	-	-	0	2	1.7
Total	companies	8	9	33	13	4	3	50	120	-
	%	6.7	7.5	27.5	10.8	3.3	2.5	41.7	-	100.0

RO - recycling by operators, CM - contract manufacturing (outsourced production), MW - municipal waste (directly), RU-MW - reuse and municipal waste, DW - do not work, WI - waste incineration, ND - no data

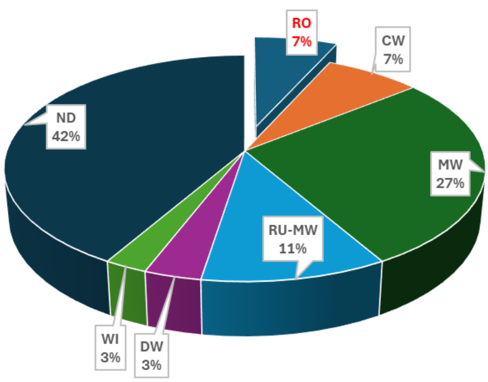


Figure 4. A distribution of waste disposal methods in textile companies

Companies currently not operating (DW group) account for 4 (3.3%), which may reflect seasonal business cycles, temporary inactivity, closures, or reduced market demand.

Waste incineration (WI) is reported only marginally and used by only three companies (2.5%). Although this may be a legitimate method for some waste, incineration without proper control and equipment poses significant environmental risks.

The group with no available data (ND) forms the largest individual group (50 companies or 41.7%), which represents a significant gap in reporting or recording practices. Again, it is dominated by micro-companies, which may point to underdeveloped or informal waste handling systems. Most of these companies believe that the amount of waste they generate is too small to be suitable for further processing. Typically, textile waste is collected weekly in quantities ranging from one to two bags, which is about 20 kg of unsorted textile waste, sometimes combining with other production waste, and is disposed of through the municipal waste system. This method of handling contributes to the misconception that the volume of waste is too insignificant to warrant inclusion in extended recycling or processing systems.

The activity code 1413 – Manufacture of other outerwear demonstrates the highest complexity, with 50 companies and the presence of nearly all waste management models, ranging from recycling and contract manufacturing to incineration.

Codes 1392 (made-up textile products), 1399 (production of other textile products), and 1412 (workwear manufacturing) also show high activity levels and diverse waste management strategies, often involving combinations of recycling, reuse, and municipal disposal approaches.

Micro-enterprises (Table 1) represent the majority of the sample, and they most frequently report municipal waste disposal (e.g., activity codes 1392, 1412, 1413). Their reliance on ND is also high, indicating limited formal waste management systems. Little companies exhibit slightly more diversity in waste handling, including reuse (RU-MW) and occasional reliance on operators for recycling. However, ND is also present in this group. Middle-sized companies show some engagement in structured recycling (RO) and mixed practices, yet the numbers remain modest compared to ND or MW reliance. Big companies are few but demonstrate the use of both recycling by operators and basic municipal waste disposal, suggesting somewhat more structured practices than smaller firms.

Activity code 1413 (likely garment manufacturing based on classification) has the highest representation (50 companies) and demonstrates the widest variety of disposal practices, including recycling, SW, MW, RU-MW, WI, and ND. However, ND (13 firms) and MW (12 firms) dominate, pointing to inconsistent management. Activity codes 1392 and 1412 also report relatively high engagement, yet again with MW as the primary method and considerable missing data. Other activity codes (e.g., 1330, 1396, 1411, 1414, 1419) represent fewer companies but display similar reliance on municipal waste and ND.

Around 18% of middle and big companies in Vojvodina currently apply digital technologies in the apparel sector. Digital tools used in pre-production stages, such as design, product development, and material procurement, have streamlined workflows, reduced human error, and improved resource efficiency. A key outcome is waste reduction: while traditional pattern-making and cutting generate 30–35% of material loss, companies using digital tools report only 8–10%, three to four times lower than the industry average. These results demonstrate the potential of digital technologies to strengthen both operational efficiency and sustainability.

CONCLUSION

The analysis of apparel manufacturing in the AP of Vojvodina reveals a highly fragmented industry, dominated by micro-enterprises (67.5% of the total), with limited presentation of middle and big firms. Southern Bačka emerges as the most concentrated regional hub, highlighting the role of small-scale entrepreneurship in sustaining local economic activity. Activity-wise, the sector is primarily oriented toward general apparel production (activity code 1413), while specialized segments such as workwear and technical textiles remain underdeveloped, indicating potential for market diversification and higher value-added production.

Waste management practices in the region demonstrate a precise size and activity-dependent pattern. Big companies are the most likely to engage in formal recycling. At the same time, micro and little enterprises predominantly rely on municipal waste disposal, with a substantial portion of companies (41.7%) lacking data on waste handling. This underscores gaps in formal waste management systems and the limited integration of circular economy principles in small-scale operations.

Overall, the findings suggest that while Vojvodina's apparel industry benefits from entrepreneurial dynamism, structural limitations - particularly the scarcity of mid- to big-scale enterprises and the dominance of conventional waste disposal - restrict its capacity for technological advancement, sustainable practices, and broader regional competitiveness. Strategic support for scaling, innovation, and sustainable waste management could enhance sector resilience and alignment with circular economy goals.

In addition to mapping current practices, the research explores the potential of digital technologies, such as computer-aided design (CAD) systems, 3D prototyping, and digital product lifecycle management tools, to enhance material efficiency and minimize waste at the design and pre-production stages.

To enhance the competitiveness of Vojvodina's apparel industry, several strategic measures are recommended:

- It is essential to improve data reliability through the implementation of standardized reporting and monitoring systems, particularly for micro and little enterprises.
- Facilitating access to finance, technology, and skills development is key to support scaling efforts.
- Targeted education and training programs focusing on prevention and sustainable production, waste management, and circular economy principles should be developed to strengthen workforce capacity.
- Promoting circular economy practices, such as prevention, which should be improved through the use of suitable digital technology, recycling, reuse, and certified waste processing, should be supported by technical guidance and incentives.
- Additional research is necessary to quantify environmental impacts, assess material flows, and evaluate the feasibility of circular models within a context dominated by micro-enterprises.

The findings of this research are useful for developing the apparel industry in this region, particularly in advancing sustainable practices, enhancing resource efficiency, and supporting the transition toward circular economy models.

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Milankovitch Cycles and Climate Change

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Abstract. Milankovitch cycles provide a fundamental theoretical basis for understanding long-term climate variability during the Quaternary, particularly in relation to the cyclic alternation of glacial and interglacial periods. The theory was formulated by Milutin Milankovitch in the early 20th century, based on the idea that variations in the parameters of Earth's orbit and rotation — eccentricity, axial tilt, and precession — influence the amount of solar radiation reaching Earth's surface, especially at high latitudes. This paper presents an overview of the main components of the theory and its historical development, as well as the confirmations derived from modern paleoclimatic research, including sediment and ice core analyses. Special attention is given to the role of Milankovitch's theory in contemporary climate models and to the distinction between natural (astronomical) and anthropogenic influences on climate. The aim of the paper is to emphasize the significance of Milankovitch's vision within a broader scientific and educational context, and to highlight the importance of understanding "cosmic rhythms" in the analysis of climate change.

Keywords: Milankovitch cycles, climate change, ice ages, insolation, paleoclimate

INTRODUCTION

Climate change represents one of the key challenges of contemporary society. Although current attention is largely focused on the consequences of anthropogenic greenhouse gas emissions, Earth's long-term climatic history demonstrates that significant variations in temperature and ice sheet extent occurred even prior to the industrial era.

The first attempts to link climatic oscillations with astronomical factors date back to the 19th century (e.g., James Croll, 1875), but these efforts were limited by the lack of precise astronomical calculations and paleoclimatic evidence.

Milutin Milankovitch (1879–1958) formulated a mathematical model that related variations in Earth's orbital and rotational parameters to changes in the space-time distribution of solar radiation (insolation). By combining knowledge from astronomy, mathematics, and geophysics, Milankovitch calculated variations in insolation over the past 600 000 years and predicted periodic climatic oscillations.

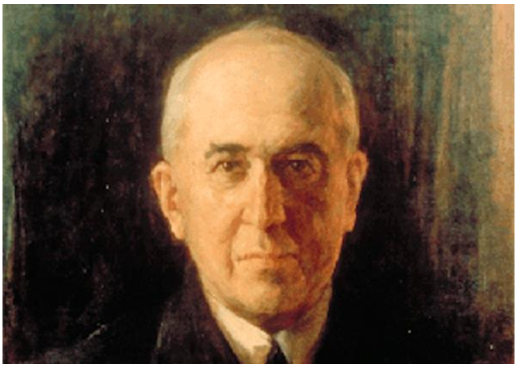

Figure 1. Milutin Milankovitch
(source: https://elementarium.cpn.rs/naucne-vesti/osuncavanje/?script=lat)

The publication of his seminal work, **Canon of Insolation and the Ice-Age Problem** [1], during World War II went largely unnoticed by the international scientific community. It was not until 1976 that Hays, Imbrie, and Shackleton, through their paper *Variations in the Earth's Orbit: Pacemaker of the Ice Ages* [2], provided empirical confirmation of Milankovitch's theory by analyzing the isotopic composition of marine sediments, demonstrating a clear correlation between orbital cycles and global temperature changes.

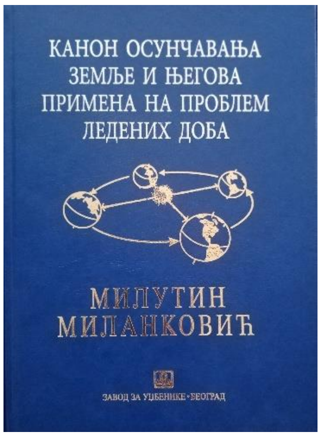

Figure 2. Canon of Insolation and the Ice-Age Problem — original book cover in Serbian

ASTRONOMICAL CYCLES

Variations in Earth's orbit and rotation are the result of gravitational influences exerted by the Sun, the Moon, and other planets, particularly Jupiter and Saturn. Building upon earlier work by astronomers such as Le Verrier, Stockwell, and Poincaré, Milankovitch incorporated three principal orbital parameters into his model:

Eccentricity: Eccentricity describes the deviation of Earth's orbital path from a perfect circle. Its value varies between approximately 0,005 and 0,058, with dominant periods of about 100 000 and 400 000 years. Higher eccentricity results in greater differences in solar radiation between perihelion and aphelion.

Axial tilt (obliquity): The tilt of Earth's rotational axis relative to the perpendicular of the ecliptic plane oscillates between 22,1° and 24,5° over a period of ~41 000 years. Larger tilt angles amplify seasonal differences in insolation, especially at higher latitudes.

Precession: Precession encompasses both the circular motion of Earth's rotational axis with a period of ~25 772 years (axial precession) and the rotation of the line of apsides — the perihelion-aphelion axis — with a period of ~112 000 years (apsidal precession). The combined effect produces a precessional cycle expressed in two dominant modes, with periods of ~19 000 and ~23 000 years*.

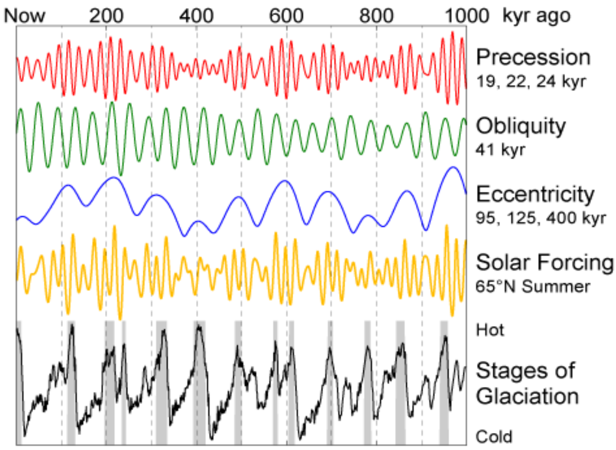

Figure 3. Milankovitch cycles
(source: https://commons.wikimedia.org/wiki/Milankovitch_cycles)

According to Milankovitch's theory, cycles in these astronomical parameters of Earth's rotation and revolution modulate the amount of solar radiation (insolation) received at the surface, thereby driving the alternation of glacial and interglacial periods during the Quaternary (the last 2,6 million years), in agreement with paleoclimatic evidence.

*In a strictly mechanical sense, this phenomenon involves both axial and apsidal precession. In climatological and orbital-mechanical calculations, including Milankovitch's Canon of Insolation [1], the so-called precession parameter or precession index is used, representing a quantitative measure of the combined effect of axial and apsidal precession.

PALEOCLIMATIC EVIDENCE AND CONFIRMATION OF THE THEORY

The key confirmation of Milankovitch's theory was provided in 1976 through the seminal work of Hays, Imbrie, and Shackleton [2], who demonstrated, by analyzing deep-sea sediment cores, that variations in ocean temperatures and glaciation records coincide with insolation cycles defined by orbital parameters. These findings opened a new chapter in paleoclimatology, as they provided solid empirical evidence linking orbital dynamics to long-term climatic changes. Since then, numerous independent data sources have confirmed this relationship, with different paleoclimatic reconstruction methods producing mutually consistent results. The most significant lines of empirical evidence include:

Isotopic records: $\delta^{18}O$ values in foraminiferal microfossils from marine sediments, which express the ratio of the number of ^{18}O atoms to ^{16}O atoms in a sample relative to a standard†, serve as a reliable indicator of changes in temperature and ice-sheet volume. Higher $\delta^{18}O$ values typically indicate colder periods with larger ice sheets, whereas lower values reflect warmer interglacial conditions. Analyses of these records enable the reconstruction of climate variability over the past several million years with a resolution of a few thousand years (Figure 4).

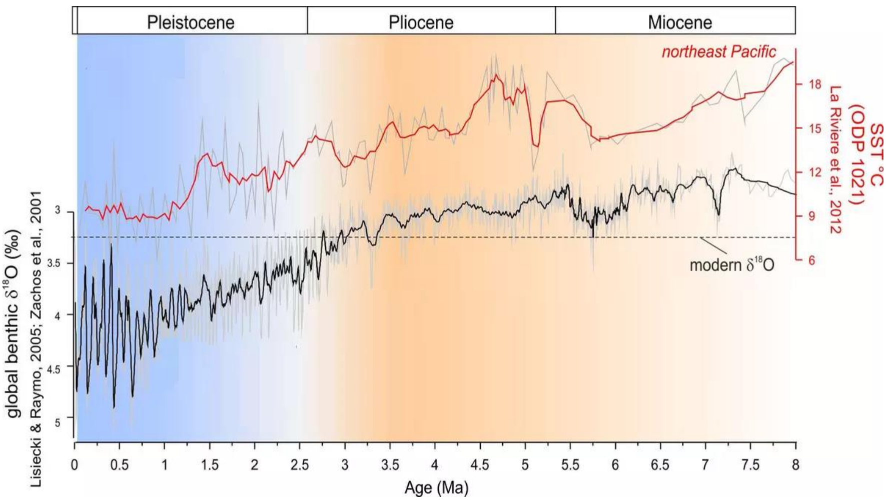

Figure 4. The oxygen isotope record and global sea surface temperature (source: https://serc.carleton.edu/eslabs/climatedetectives/6e.html)

† $\delta^{18}O = \left(\frac{\left(\frac{N(^{18}O)}{N(^{16}O)}\right)_{sample}}{\left(\frac{N(^{18}O)}{N(^{16}O)}\right)_{standard}} - 1\right) \times 1000$ ‰, where $\left(\frac{N(^{18}O)}{N(^{16}O)}\right)_{sample}$ represents the ratio of the number of ^{18}O atoms to ^{16}O atoms in the sample, and $\left(\frac{N(^{18}O)}{N(^{16}O)}\right)_{standard}$ is the same ratio in the VSMOW (Vienna Standard Mean Ocean Water) standard.

Ice cores: Drilling through ice sheets in Antarctica (e.g., Vostok, EPICA Dome C) and Greenland has yielded layered records extending back as far as 800 000 years. Each layer of ice preserves a "frozen snapshot" of the atmosphere at the time of its formation, including trapped gas bubbles (CO_2, CH_4, N_2O) and the isotopic composition of water, which allows past temperatures to be determined (Figures 5 and 6). Changes in greenhouse gas concentrations and temperature closely follow Milankovitch cycles, confirming the strong coupling between orbital geometry and the climate system.

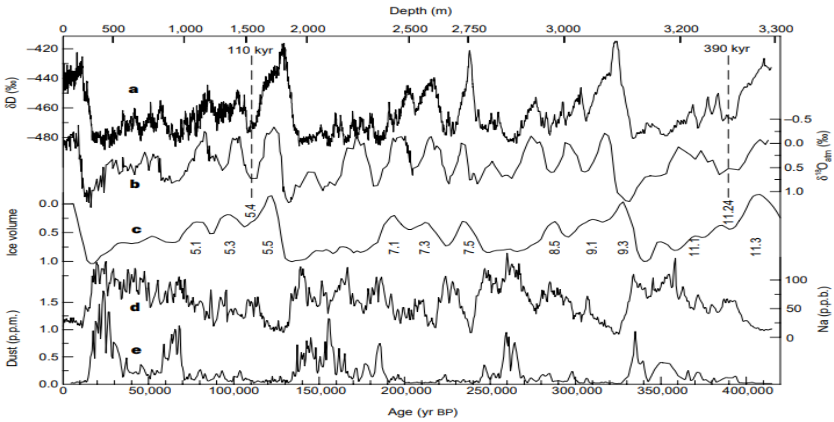

Figure 5. Vostok time series and ice volume (source: Ref. [3])

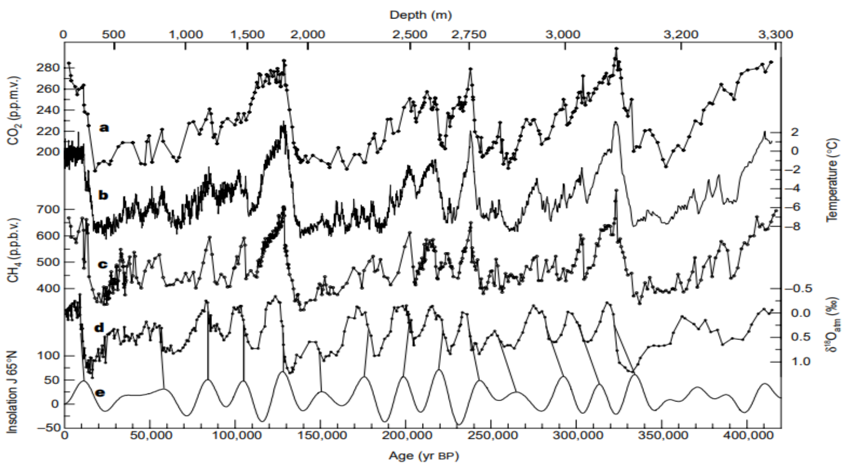

Figure 6. Vostok time series and insolation (source: Ref. [3])

Sedimentological evidence: Lacustrine and marine sediments sometimes reveal alternating layers of different composition, known as *varves* (annual sedimentary layers), which reflect seasonal changes in deposition. In long-term records, the patterns of these layers correspond to variations in insolation and paleoclimatic oscillations driven by astronomical cycles.

Graphical representations of paleoclimatic data frequently include spectral analysis, through which dominant periodicities in climate records can be identified. In many cases, these periods correspond to timescales of approximately 100 000, 41 000, and 23 000 years, directly matching the fundamental components of Milankovitch cycles, related to variations in eccentricity, axial tilt, and precession, respectively. Such concordance — confirmed across geographically distant sites and by independent methods — constitutes strong evidence for the validity of Milankovitch's theory and underscores its fundamental importance for understanding Quaternary climate.

MILANKOVITCH'S THEORY IN CONTEMPORARY CLIMATE MODELS

High-resolution climate models now incorporate orbital parameters to study paleoclimate dynamics. Simulations using **General Circulation Models (GCMs)** show that Milankovitch orbital variations alone cannot trigger glaciation [4], highlighting the need for **additional feedbacks**, such as changes in ice-sheet albedo, greenhouse gas concentrations, and ocean circulation, to reproduce the full range of glacial-interglacial climatic changes [5].

CONCLUSION

Milankovitch's theory provides an invaluable framework for understanding long-term natural climate variations. Its confirmation in the second half of the 20th century demonstrates how a fundamental scientific vision can precede widespread acceptance by decades. In the era of accelerated anthropogenic climate change, it is crucial to distinguish natural "cosmic rhythms" from human influence in order to accurately predict the future dynamics of the climate system. Understanding Milankovitch cycles is not merely a scientific curiosity — it constitutes essential knowledge that shapes our ability to interpret the climatic past and to make informed decisions for the future.

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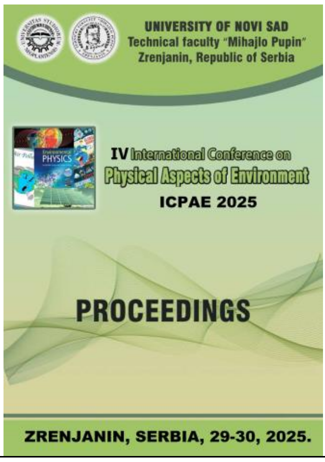

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Changing the Planet Earth Through Sustainable Materials

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Abstract. Sustainable materials are designed with the aim of reducing the use of non-renewable resources, promoting recycling, and enabling biodegradability, which makes them particularly relevant to both the academic community and the industrial sector. Research in this field is of essential importance for accelerating the transition toward a circular economy and significantly reducing the negative impacts on the environment. This paper provides an analysis of contemporary scientific literature, identifying the current state and projected trends within categories of materials related to sustainability: sustainable materials, green materials, biomaterials, environmentally friendly materials, alternative materials, recycled materials, as well as material recovery from complex products.

Keywords: sustainable materials, recyclable materials, green materials, biodegradable materials, eco-friendly materials

INTRODUCTION

Sustainable materials play a pivotal role in the transition toward a more environmentally responsible society by contributing to environmental protection, the conservation of natural resources, and the improvement of overall quality of life. Their application across various industries such as construction, automotive, fashion, food, electronics, and packaging reflects a growing awareness of the need to reduce negative environmental impacts. Although there is no unified framework for evaluating sustainable materials, current practices indicate significant progress in their development and application.

This paper analyzes research areas relevant to the assessment of sustainable materials, including environmental impact, performance and durability, economic viability, health and safety, social sustainability, as well as implementation and practical use.

In addition to sustainable, recyclable, green, biodegradable, and environmentally friendly materials, particular emphasis is placed on the development of advanced materials through nanotechnology, 3D printing, and sustainable composites. The paper offers a comprehensive overview of seven key categories of materials associated with sustainability from green and bio-based materials to recycled and alternative solutions. Based on the analysis, it can be concluded that sustainable development requires an approach that extends product lifespan, improves production efficiency, and enhances recycling and reuse strategies.

Green Composite Materials

Natural fibers and resins, as well as various fiber-reinforcement methods, represent alternative solutions to synthetic fibers, given their lower cost, biodegradability, and widespread availability. The use of these materials enables the effective replacement of synthetic polymer composites. These materials may be defined as polymer-based materials that incorporate natural fibers such as bamboo, coconut fibers, flax, and hemp. Natural fibers are typically classified into three categories: animal-based fibers (e.g., silk and wool), plant-based fibers (e.g., seed, fruit, and leaf fibers), and mineral-based fibers, such as asbestos. These biocomposites can be applied in industries such as electronics, furniture manufacturing, and sports equipment.

Green composites, also known as environmentally friendly materials, are emerging as a promising area of research due to their renewable, recyclable, and biodegradable nature. They can be produced in various forms, including polymer-based composites reinforced with natural fibers such as hemp or flax, as well as cement-based composites utilizing novel binders like geopolymers and recycled aggregates. The mechanical properties of green composites particularly those reinforced with bamboo fibers indicate their potential for application across diverse industrial sectors.

The integration of biodegradable polymers derived from natural resources further enhances the environmental sustainability of green composites. Although these materials demonstrate considerable potential, it is essential to carefully align their use with the specific requirements of individual industries.

Green composites composed of natural fibers and biodegradable polymers have shown significant promise in industries such as automotive manufacturing and construction. Research in this field highlights the ecological benefits of using fibers such as bamboo, flax, and hemp, primarily due to their recyclability and reduced reliance on synthetic materials.

Biomaterials and Bioinspired Materials – Their Applications and Research Directions

Biomaterials and bioinspired materials, often developed based on biological systems and processes, are increasingly attracting the attention of both researchers and industry due to their wide range of applications, sustainability, and potential for innovation.

A significant number of studies indicate that biomaterials, characterized by high biocompatibility and low toxicity, are utilized in the production of medical devices, food packaging, and drug delivery systems. In this context, bioinspired nanomaterials are particularly notable for their ability to enable controlled release of active substances while maintaining biodegradability.

Furthermore, various research efforts highlight a growing interest in bio-based nanostructures that mimic natural resilience and flexibility, offering enhanced performance in biomedical applications. This innovation in the field of nano-biomaterials opens new pathways for applications in regenerative medicine, bioengineering, and the development of functional bio-devices.

Particularly noteworthy are biomimetic materials, which are inspired by natural structures and functions. The increasing demand for bio-based alternatives clearly indicates that biomaterials will play a key role in the future development of sustainable and functional solutions in medicine and various industrial sectors.

Environmentally Friendly and Recycled Materials – Their Role in Sustainable Development and Advanced Industries

These materials have traditionally been predominantly applied in the textile industry, furniture manufacturing, as well as in construction and decorative applications, significantly contributing to the reduction of environmental impact.

Recycled materials further enhance sustainability by enabling the reduction of the exploitation of non-renewable resources, emissions of harmful substances into the environment, water consumption, and the volume of waste disposed of in landfills. The most commonly recycled textile materials include cotton and its composites with polyester, which can be processed using chemical, biochemical, or mechanical methods. However, certain materials, such as recycled paper, require additional control measures due to the presence of chemicals that may affect safety.

Despite the clear advantages, the recycling process continues to face a range of technical and social challenges.

Figure 1. A schematic representation of the circular recycling flow
(source: https://www.stylesocietymarketplace.com/pages/sustainability)

Alternative Materials - Future Trends and Sustainable Material Development

The use of alternative materials represents a growing trend across numerous industries, with an increasing emphasis on environmental sustainability and innovation. These materials include recycled raw materials, biodegradable composites, natural resources, and geopolymers, which are increasingly applied in fields such as construction, packaging manufacturing, design, the textile industry, and tool production.

Particular importance is attributed to the development of advanced recycling methods for cotton and polyester composites, including chemical, biochemical, and mechanical processes that enable the reuse of textile waste to reduce environmental impact. In construction, there is growing research into the use of natural materials such as wood, hemp, and cellulose, which are utilized in modern energy- efficient buildings.

In the context of packaging, there is a growing use of biodegradable biopolymers, addressing the issue of conventional plastic waste. The integration of recycled materials into standard construction components highlights the potential for improving environmental sustainability in infrastructure.

Innovations are manifested through the development of lightweight, waterproof, and high-strength materials obtained by processing plastic and rubber waste in combination with mineral fillers, opening new prospects for their application in the construction industry. Simultaneously, there is an increasing use of recycled materials in art and interior design, particularly in the production of furniture and decorative household elements. Strategies promoting the circular economy and energy conservation through innovative recycling approaches represent a key aspect of contemporary efforts to mitigate negative environmental impacts.

Research in furniture design and educational materials also indicates an expanding use of alternative materials, including paper, cardboard, glass, metal, and natural fiber composites.

The circular economy and material development emphasize the importance of coordinated efforts in the development and commercialization of sustainable materials. The focus lies on resource redistribution through recycling and reuse, as well as waste reduction throughout all stages of the product life cycle.

Polymer composites reinforced with natural fibers are lightweight, biodegradable, mechanically reliable materials suitable for engineering applications. Challenges include variable fiber quality, thermal stability, and water absorption capacity. Advanced solutions involve hybridization with synthetic fibers, chemical treatments, and the development of numerical models to simulate performance.

Figure 2. Biodegradable materials
(source: https://maidsbytrade.com/portland-recycling/)

The analysis of additive manufacturing in the context of sustainability highlights its ability to produce complex geometries while reducing waste. Potential applications span across aerospace, robotics, and medicine. Additionally, this includes the procurement of sustainable materials, product circularity and recycling, as well as the development of biodegradable and biologically derived polymers.

Sustainable applied materials offer solutions to multiple challenges faced by contemporary society, from waste reduction and resource conservation to the creation of materials with advanced functional properties. Their integration in the early stages of design, combined with circular economy strategies and advanced technologies (such as 3D printing and smart composites), forms the foundation for achieving a sustainable and innovative future.

CONCLUSION

The research on sustainable materials discussed in this study highlights their increasing importance in the context of environmental responsibility, economic efficiency, and technological advancement. These materials, derived from renewable or recycled sources, contribute to reducing the negative environmental impact through lower emissions of harmful substances, preservation of natural resources, and recyclability.

The analysis of available literature has enabled the identification of key topics, challenges, and directions for further development, with particular emphasis on the need for lifecycle integration, economic assessments, and interdisciplinary collaboration. The future development of sustainable materials in fields such as composites, the textile industry, nanotechnology, and biodegradable polymers represents a crucial component in the transition towards a more sustainable society, a healthier environment, and a circular economy.

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Assessment of the Impact of Global Warming and Climate Change on the Quality of Durum Wheat

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Abstract. The aim of this paper is to examine the impact of climate change on the quality characteristics of durum wheat genotypes grown during two productions years. The paper presents short-term forecasts of climate changes in the world and in Serbia, as well as various uncertain climate scenarios with long-term forecasts, projections, and their impact on the technological quality of durum wheat.

Keywords: climate change, durum wheat, technological quality

INTRODUCTION

Durum wheat is the most suitable raw material for pasta production. Cultivation of durum wheat in Serbia is not at an enviable level due to the low yield compared to bread wheat as well as special requirements regarding agrotechnical measures and climatic conditions. It was found that climate change affects indicators of technological quality of wheat, such as hectoliter weight, grain hardness [1], protein content [2], SDS sedimentation and kernel vitreousness [3]. The fight against climate change should be a priority with the application of adequate agricultural value measures, as well as the creation of genotypes resistant to climate change [4]. Serbia has achieved significant progress by passing the Law on Climate Change ("Official Gazette of RS", No. 26/2021) [5].

In 1988, the World Meteorological Organization (WMO) established the Intergovernmental Panel on Climate Change (IPCC) and even then pointed out the importance of climate change, as well as the need to monitor daily meteorological elements and phenomena, because they provide a description of the future climate and its impact on agriculture. IPCC has projected a global warming trend of 0.3−1.7 °C by 2100 [6]. Overview of past climate changes in Serbia, as well as climate projections for the 21st century are in the First National Communication of the Republic of Serbia [7]. Projections according to regional climate models predict that will increase the average annual temperature level of 2,4°C by the end of this century up to 2,8°C according to the optimistic scenario (A1B1), that is, from 3,4°C to 3,8°C according to pessimistic scenario (A2). According to the same model, the precipitation trend is expected to be negative until the end of this century. According to scenario A1B1 precipitation will decrease in the interval from -15% to 0% on an annual level, and according to scenario A2, it will decrease from -15% to -5% on an annual level.

MATERIALS AND METHODS

The genetic material used in this research included 14 genotypes of durum wheat, winter and facultative type, obtained from the Gene Bank of the Maize Institute in Zemun Polje. The durum wheat lines were produced in the same locality (Zemun Polje (ZP) (44°52′ N; 20°19′ E) and 88 m above sea level, during two production years (2012 and 2013). All tests were carried out within the accredited laboratories of the Scientific Institute for Food Technologies FINS in Novi Sad. Chemical-technological analyzes were performed on each sample of durum wheat and included the following tests:

Hectolitre mass, protein content, moisture content of durum wheat, moisture content of durum semolina were determined using a NIR device ((Infratec 1241 Grain Analyzer (Foss Analytical AB, Hillerod, Denmark)). Sodium dodecyl sulfate (SDS) sedimentation of durum semolina was determined according to ICC method 151 [8]. To determine the mass of 1000 grains, a grain counting machine with a photo cell was used, and the mass was measured on an analytical balance. Visual evaluation of the appearance of the grain cross-section, i.e. the appearance of the endosperm structure, was determined by counting 50 grains twice and cutting them with a farinatome or by hand in the middle with a razor blade or scalpel (ICC method 129) [8],. Instrumental measurement of grain texture (hardness) of durum wheat lines was performed using the Texture analyzer TA.XT.plus (Stable Micro System, U.K.) Hardness is determined as the force required to break (crack) a grain of wheat, and is expressed in newtons (N). Measurements were made using a piercing attachment. The values of this indicator are expressed as the mean value of 15 measurements on one sample.

Data on the climatic conditions that prevailed during the vegetation period May-June on the experimental fields were obtained from the Republic Hydrometeorological Service of Serbia (RHSS) [9], The climatic conditions of Zemun Polje and Surčina, where the climatic data were measured, can be defined as a special southwestern variety of semiarid climate with a pronounced continental character. Transitional seasons are characterized by changeable weather with autumn being warmer than spring. Summer is characterized by stable weather conditions and occasional shorter rainfall of a local character. The month with the most precipitation is June and the least is February. In winter, the weather conditions are influenced by cyclone activity from the Atlantic Ocean and the Mediterranean Sea, as well as the winter so-called Siberian cyclone.

According to the RHSS report, agrometeorological conditions in the production year 2011/2012, during June, influenced the faster flow of the initial stages of winter grain ripening, due to very warm weather with significantly less precipitation (only 32% of the multi-year average). Maximum air temperatures were usually around 30°C, but on some days over 35°C were recorded. The warm and mostly dry weather did not adversely affect the general condition of the winter crops, because the durum wheat grain was already well watered before the onset of high temperatures, so it lost moisture faster under these conditions. Due to the occurrence of high air temperatures, the final stages of ripening of winter grains passed faster than usual, so the harvest started ten days earlier.

Climatic conditions in 2012/2013 show a cooling in the second half of May, which lasted until the first decade of June and somewhat slowed down the stages of development (flowering, fertilization, formation and filling of grains). Heavy rains, bad weather and stormy winds caused the crops to lie down. At the beginning of the second decade of June, the weather conditions stabilized, there was an increase in air temperatures, which enabled the drying of the soil and the beginning of the final stages of ripening of winter grains. From the middle of the month, the maximum air temperatures were usually around 30°C, but on some days, over 35°C was recorded. The warm weather with occasional heavy downpours did not adversely affect the condition of the winter crops, because the wheat grain was already well watered before the onset of high temperatures, so it lost moisture faster under these conditions. Due to high air temperatures, the final stages of ripening and drying of winter grains passed faster than usual, so the harvest started a few days earlier than planned.

RESULTS AND DISCUSSION

The obtained results of the analysis of the most important physical and chemical indicators of the quality of the tested samples of durum wheat genotypes showed that the average protein content, yield of semolina and hectoliter weight were significantly higher in 2012. (Table 1)

Table 1. Physical and chemical quality parameters of durum wheat genotypes in two production years (2012 and 2013)

	Average		Minimum		Maximum	
	2012	2013	2012	2013	2012	2013
Hectoliter mass (kg/hl)	82,83	80,58	79,30	77,85	84,90	82,30
1000-grain weight (g)	45,17	43,06	39,28	35,83	54,15	51,76
Hardness (N)	13629,60	14590,07	10645,99	12788,64	16315,06	17298,97
Vitreousness (%)	92,57	92,43	80,00	83,00	98,00	98,00
Protein content (%)	15,01	13,75	12,90	12,10	17,90	16,10
Yield of semolina (%)	67,10	64,96	68,00	61,00	76,80	70,60
SDS sedimentation (ml)	21,79	20,57	15,00	15,00	30,00	28,00

Within the research, a significant positive correlation was established for the following quality indicators: protein content and vitreousness ((Figure 1.), vitreousness and grain hardness (Figure 2.), hectoliter mass and yield of semolina ((Figure 3)., as well as protein content and SDS sedimentation, which is in agreement with the results obtained by other authors [10, 11,12].

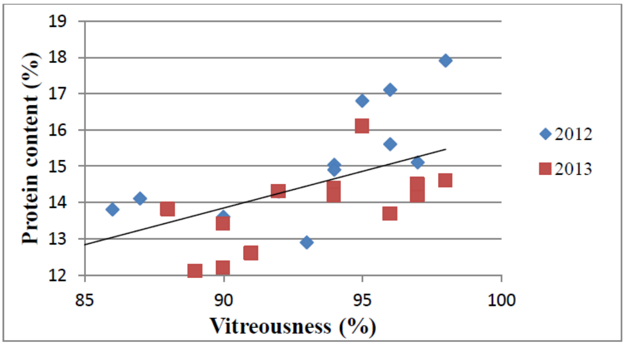

Figure 1. Correlation of protein content and vitreousness for 2012 and 2013.

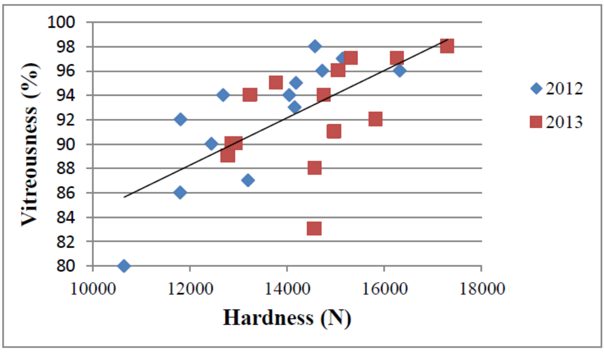

Figure 2. Correlation of vitreousness and hardness for 2012 and 2013.

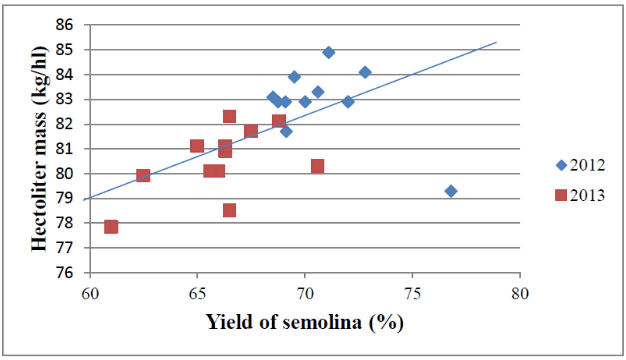

Figure 3. Correlation of hectoliter mass and yield of semolina for 2012 and 2013.

CONCLUSION

In agriculture, the climate is often a limiting factor due to the manifestation of the extremes of some factor, and agrotechnical measures can only mitigate the negative climate impacts on wheat. The modern cultivation strategy is the creation of genetically improved lines of durum wheat, adapted to global climate changes, resistant to stress, with high yield and good technological quality. All examined genotypes of durum wheat showed a very broad adaptability to different climatic conditions that prevailed in the two production years in the same locality, and at the same time achieved good technological quality of grain for the needs of the pasta industry

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The Importance of Biomaterials in Medicine

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Abstract. Biomaterials represent a key component of modern medical technology, with broad applications in orthopedics, dentistry, cardiovascular medicine, and regenerative medicine. Their ability to interact with biological tissues makes them suitable for the replacement, restoration, or enhancement of the function of damaged structures within the body. This paper provides a systematic overview of various types of biomaterials metals, polymers, ceramics, and composites as well as their applications in clinical practice. Particular attention is given to challenges such as biocompatibility, longevity, regulatory frameworks, and ethical considerations. The paper offers insight into contemporary technologies and future directions in the field of biomaterials, with the aim of improving therapeutic approaches and patients' quality of life.

Keywords: biomaterials, biocompatibility, medical devices, regenerative medicine, sustainable materials

INTRODUCTION

The development of biomaterials represents one of the most dynamic fields of contemporary biomedicine. As natural or synthetic substances intended to interact with biological systems in order to replace, support, or enhance the function of tissues and organs, biomaterials play a key role in the development of modern therapeutic strategies.

Although their use dates back to ancient attempts at reconstructive surgery, contemporary research is focused on designing materials with high biocompatibility, controlled biodegradability, and functional performance. Of particular importance are new-generation polymers, which enable the modulation of physicochemical properties, targeted drug delivery, and the stimulation of regenerative processes.

Biomaterials are obtained from natural sources (e.g., collagen, hyaluronic acid) or synthetic origins, and their clinical application requires strict evaluation of parameters such as biocompatibility, mechanical strength, and integration with living tissues.

In medical practice, they are used in orthopedics, dentistry, cardiovascular surgery, regenerative medicine, and tissue engineering, where they form the basis of implantable devices, prosthetics, stents, and controlled drug release systems [1].

In the context of accelerating technological advancement and interdisciplinary collaboration, biomaterials are becoming a key factor in the development of personalized medicine, aimed at increasing therapeutic efficacy, reducing postoperative complications, and improving patients' quality of life.

Biomaterials have wide application in modern medicine, encompassing areas such as orthopedics, dentistry, cardiovascular medicine, ophthalmology, regenerative medicine, and tissue engineering. Their functionality is based on specific physicochemical and biological properties tailored to various clinical requirements.

The key properties of biomaterials include biocompatibility, mechanical stability, controlled degradability, and the ability to integrate with biological tissues, all of which are optimized according to therapeutic objectives. In orthopedics, they are used in implants that support bone system regeneration, while in dentistry, biomaterials are applied for implants and restorations with both aesthetic and functional outcomes. Cardiovascular medicine relies on biomaterials in the production of stents, with a focus on inertness and the minimization of immune reactions [2].

Regenerative medicine and tissue engineering use biomaterials as three-dimensional scaffolds that promote cell adhesion, proliferation, and maturation, providing opportunities for the treatment of damaged tissues and organs for which existing therapies have proven inadequate.

Although significant progress has been made, challenges such as achieving long-term biocompatibility, material safety, and compliance with regulatory requirements still persist. Ethical and societal aspects also require special attention, particularly in the field of regenerative therapies.

The aim of this paper is to provide a systematic overview of biomaterials, classified by type (metals, polymers, ceramics, composites), with an analysis of their properties, clinical applications, advantages, and limitations. It will also focus on modern technologies such as nanotechnology, bioprinting, and surface functionalization, as well as on the regulatory and ethical aspects of their use. The paper aims to highlight the importance of biomaterials in improving therapeutic methods and to guide future multidisciplinary development.

BIOMATERIALS IN MEDICINE

Biomaterials are of natural or synthetic origin and are specifically designed to interact with biological systems for diagnostic, therapeutic, or reconstructive purposes. A fundamental requirement for their application is biocompatibility, i.e., the ability to avoid eliciting immunological, inflammatory, or other adverse reactions upon contact with tissues and bodily fluids [3].

In addition to biological inertness, biomaterials must meet certain mechanical and chemical criteria, including appropriate strength, elasticity, and chemical stability. In specific applications particularly in regenerative medicine controlled biodegradability of the material is also essential. In this context, biocompatibility refers to the material's ability to function within a living organism over a defined period without inducing toxic effects. Diverse applications of biomaterials in medicine are shown in Figure 1.

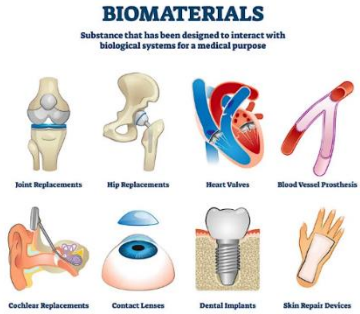


Figure 1. Diverse applications of Biomaterials in Medicine [4]

DEVELOPMENT OF BIOMATERIALS

The use of biomaterials in medicine has a long history dating back to ancient civilizations. Archaeological findings confirm that the Egyptians and the Maya used natural materials such as shells and bones for dental repairs and cranial reconstruction, representing early forms of medical intervention.

The modern development of biomaterials began in the 19th century, with advances in surgical techniques and the introduction of sterilization, which enabled the clinical use of materials such as rubber, paraffin, and wax. In the first half of the 20th century, progress in chemistry and metallurgy led to the use of stainless steel, cobalt-based alloys, and synthetic polymers (polyethylene, polypropylene), laying the foundation for modern implants [5].

Of particular importance was the introduction of titanium and its alloys in the 1950s, which, due to their mechanical strength and chemical stability, found widespread application in orthopedics and dentistry. In parallel, biodegradable polymers such as polylactic acid (PLA) and polyglycolic acid (PGA) were developed, enabling the production of medical devices that are resorbed by the body, thereby reducing the need for additional surgical interventions.

A chronological overview of the key stages in the development of biomaterials is presented in Figure 2, which illustrates the evolution of materials used in medical applications over time [5,6].

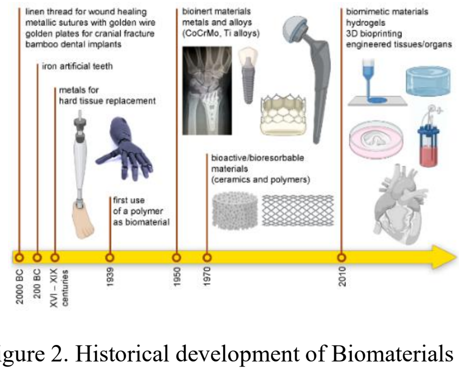


Figure 2. Historical development of Biomaterials [5]

First Generation of Biomaterials

First-generation biomaterials are bioinert materials designed to avoid harmful biological reactions upon implantation. Their primary role was to provide mechanical support without active interaction with the surrounding tissue. These materials did not promote regeneration or integrate with host cells but rather formed a passive barrier between the implant and the organism.

This group includes metals and alloys, which have been widely used in orthopedics and dental prosthetics due to their high mechanical strength, corrosion and wear resistance, and good yet passive biocompatibility. While they provided functional tissue replacement, the lack of biological integration prompted the development of more advanced biomaterials [7].

Titanium and its alloys represent a transitional material between bioinert and bioactive biomaterials. Due to their low specific weight, high mechanical strength, corrosion resistance, and good biocompatibility, titanium is extensively used in orthopedics, dentistry, and cardiovascular medicine. Surface modifications of titanium significantly enhance osteointegration, enabling a stable bond between the implant and bone tissue, which is crucial for the long-term success of implants [5,6].

Second Generation Biomaterials – Bioactive and Bioresorbable Materials

Unlike the bioinert materials of the first generation, the second generation of biomaterials encompasses bioactive and bioresorbable materials that, in addition to biocompatibility, actively participate in biological processes following implantation. Their key advantage lies in their ability to stimulate tissue regeneration and enable functional integration with the host organism.

Bioactive materials form a chemical bond with living tissues, promoting strong attachment to bone. In contrast, bioresorbable materials gradually degrade within the body, eliminating the need for surgical removal after their therapeutic function is complete [8].

The most significant representatives of this generation include:

- Ceramics (e.g., bioactive glass, hydroxyapatite), which are used in bone tissue regeneration;
- Polymers (e.g., polylactic acid and polyglycolic acid), employed in the production of resorbable sutures, drug delivery carriers, and temporary implants.

The second generation of biomaterials marks the transition from passive to biologically active materials, thereby laying the foundation for the further development of regenerative medicine and tissue engineering [5,6].

Third Generation Biomaterials

The third generation of biomaterials represents a significant advancement in biomedical engineering, focused on the development of biomimetic materials that replicate the structure and function of natural biological systems. Unlike previous generations, these materials are not only biocompatible and bioactive but also actively participate in biological processes, enabling advanced therapeutic approaches in regenerative medicine and tissue engineering.

Biomimetic materials imitate the extracellular matrix, providing support for cellular growth, differentiation, and organization. Their application is particularly prominent in controlled drug delivery systems and regenerative therapies.

Additive manufacturing (3D printing) has enabled the production of personalized structures with complex geometries using various materials, significantly enhancing the functionality and clinical application of implants and prosthetic components.

The highest level of application of this generation is observed in tissue and organ engineering, where biomaterials are combined with cells and bioactive molecules to create functional three-dimensional tissues. These materials are biodegradable and serve as temporary scaffolds for regeneration, eliminating the need for material removal [9].

In addition to mechanical support, these systems include signaling factors that stimulate cellular proliferation and integration of new tissue with surrounding structures. Such technologies are applied in the regeneration of skin, cartilage, bone, liver, and cardiovascular tissues.

The evolution of biomaterials, from passive structures to intelligent functional systems, reflects continuous technological and scientific progress toward precise, personalized, and regenerative medicine [5,6].

THE IMPORTANCE OF BIOMATERIALS FOR CONTEMPORARY MEDICINE

In orthopedics, biomaterials are used for the fabrication of implants such as artificial joints and plates. Titanium and cobalt-chromium alloys are known for their high mechanical strength, corrosion resistance, and long-term biocompatibility. High-density polyethylene is utilized for joint surfaces, reducing friction and prolonging the lifespan of implants.

In dentistry, biomaterials are present in dental implants, crowns, bridges, and dentures. Titanium and zirconium dioxide are distinguished by excellent biocompatibility and wear resistance, while polymers and composite materials allow for aesthetically acceptable and functional restorations.

In cardiovascular medicine, these materials are employed in the production of stents, artificial heart valves, blood vessels, and patches. Requirements include high biocompatibility, resistance to thrombosis, and mechanical flexibility. Stainless steel and nitinol provide the necessary elasticity and shape memory, offering chemical inertness and good tolerance in contact with blood [1].

In regenerative medicine and tissue engineering, biomaterials serve as biodegradable scaffolds that support cell growth and differentiation, enabling the formation of new tissue. Polymers such as PLA and PGA gradually degrade into harmless products, reducing the need for additional surgical interventions. This approach offers personalized therapies for the regeneration of bone, cartilage, nerve, and cardiac tissues.

ETHICAL ASPECTS OF BIOMATERIALS APPLICATION IN MEDICINE

The development and clinical application of biomaterials bring numerous benefits to modern medicine but simultaneously raise important ethical issues that require careful regulation. The fundamental principle is the protection of patient safety and rights, as well as environmental preservation. The most important ethical aspects include:

1. **Patient Safety** – Biomaterials must undergo rigorous testing on animal models and clinical trials to ensure their safety, avoid adverse reactions, and confirm their efficacy.
2. **Regulation and Standardization** – The production and use of biomaterials are subject to strict regulations and international standards (such as FDA and ISO), covering safety, biocompatibility, and ethical approval of clinical studies.
3. **Accessibility of Therapies** – The high cost and technological complexity may limit therapy availability, especially in less developed regions. Ethics demands efforts toward fair distribution and the development of affordable solutions for all patients, regardless of social status.
4. **Informed Consent** – The use of biomaterials must be based on clearly obtained informed consent, where patients are fully informed about all risks, benefits, and alternatives, without pressure or manipulation.

Biomaterials form the foundation of modern therapies and significantly improve quality of life, but their application must be grounded in ethical principles that ensure safety, effectiveness, and fairness in treatment. Ongoing development of biomaterials opens new possibilities for even better clinical outcomes and wider access to innovative treatments [10].

EMBEDDED SYSTEMS WITH BIOMATERIALS

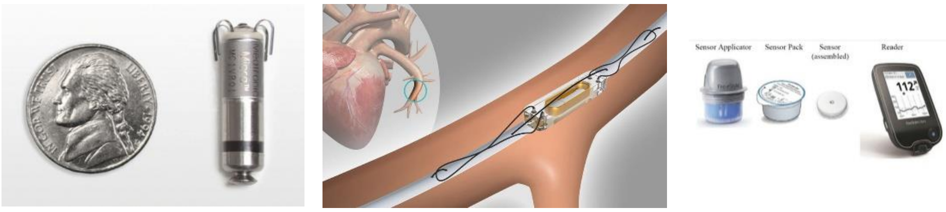
Embedded systems with biomaterials represent an interdisciplinary field that integrates biocompatible materials, electronic embedded systems, information technology, and computer science with the aim of developing smart medical and technological solutions. The core of this concept lies in the integration of materials that can safely interface with the human body and miniature electronic components capable of collecting, processing, and transmitting information from the biological environment. Such systems enable precise health monitoring and targeted medical intervention [6].

The biomaterials used in these systems must be biocompatible, non-toxic, and capable of functioning within the body over extended periods. Examples include natural materials such as collagen, hyaluronic acid, and alginates, as well as synthetic polymers like polyethylene glycol and polylactic acid. Embedded systems, on the other hand, comprise sensors, microprocessors, memory units, and wireless communication modules, which are integrated into or onto the biomaterial to create a unified functional device. Some well-known examples of embedded systems with biomaterials include:

- **Micra** – the world's smallest implantable pacemaker, without leads or wires, which is directly implanted into the heart. Thanks to biocompatible materials and miniaturized electronics, the device is more durable and safer than traditional pacemakers. Micra uses a remote monitoring system (CareLink) that allows doctors to monitor the device's function and the patient's condition online without frequent hospital visits. Data is automatically sent to the cloud via a home monitor. This system significantly reduces the risk of complications and improves the quality of life for patients with heart rhythm disorders.
- **CardioMEMS** – an implantable sensor for measuring pressure in the pulmonary artery. Data is wirelessly transmitted daily to a database that doctors can access

online and use to adjust therapy accordingly. This system enables early detection of worsening heart failure, often without the need for hospital admission.

- **FreeStyle Libre** – a continuous glucose monitoring (CGM) system that allows wireless data transmission via the LibreLink app. Using the LibreView platform, patients and doctors can access real-time data online. Alternative apps (e.g., xDrip+, Nightscout) are also available for advanced monitoring and data sharing.



[11] [12] [13]

Figure 3. Embedded systems with biomaterials: (a) Micra, (b) CardioMEMS, and (c) FreeStyle Libre

Although the potential is enormous, there are also challenges — including ensuring long-term stability, preventing immune reactions, and developing flexible electronics that can behave naturally within or on the body. Nonetheless, embedded systems with biomaterials are increasingly finding applications in personalized medicine, rehabilitation, regenerative therapy, and diagnostics, making them one of the most advanced fields in modern biomedical technology.

CONCLUSION

Biomaterials represent a fundamental segment of modern medical practice, enabling the development of innovative therapeutic approaches and significantly improving patients' quality of life. Their diverse application in orthopedics, dentistry, cardiovascular medicine, and regenerative medicine confirms their essential contribution to modern medical technologies. Although numerous challenges related to biocompatibility, safety, and regulation exist, ongoing research efforts and technological advancements open new possibilities for developing advanced biomaterials with enhanced properties that also contribute positively to the environment. Besides technical aspects, it is crucial to adequately address the ethical and social dimensions of their use to ensure broad accessibility and safety for all patients. Therefore, an interdisciplinary approach in the development and application of biomaterials is key to achieving sustainable and effective solutions in contemporary medicine.

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Biodegradable Textile Materials as a Sustainable Alternative to Synthetic Fibers

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Abstract. The textile industry is taking the lead in polluting our environment year after year. The increasing number of inhabitants on the planet and the need for clothing, as well as the negative consequences of fast fashion, are shifting the focus of manufacturers from environmental protection and the preservation of water resources and ecosystems to pure profit and the race for personal wealth. The desire of owners of large production plants for profit dominates the need to preserve nature. Also, in addition to the pollution of surface water courses, groundwater, standing water, as well as soil and air, a large textile factory also requires a large amount of energy in order for production to take place. The aim of this paper is to present new biodegradable fibers and natural fibers, as well as to highlight all their advantages and offers as an alternative to chemical fibers, the decomposition of which takes over 200 years.

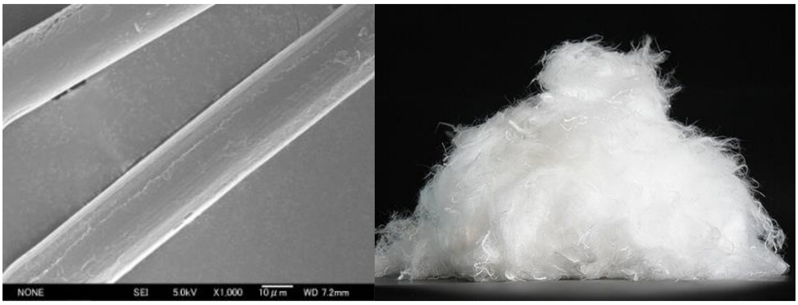
Keywords: biodegradable fibers, PLA fibers, PHA fibers, regenerated cellulose, natural fibers

INTRODUCTION

The textile industry is one of the fastest-growing and most polluting sectors of the global economy. The dominance of synthetic fibers such as polyester, nylon, and acrylic has provided numerous functional and economic advantages, but has also led to significant ecological challenges. These include microplastic release during washing, persistence in the environment, and high energy demand during production. The need for environmentally friendly alternatives is becoming urgent, particularly in the context of circular economy principles and sustainable development goals [1].

PLA FIBERS

Polylactic acid (PLA) fibers, derived from renewable resources such as corn starch and sugarcane, are among the most promising biodegradable fibers. PLA exhibits good mechanical properties, low flammability, and a biodegradation process that significantly reduces environmental impact compared to petroleum-based synthetics. However, its thermal stability and cost remain limiting factors [2].



a) b)

Figure 1. PLA fibres under the microscope [3] and as staple fibres [4]

Properties of PLA Fiber

Mechanical Properties

PLA fibers have a breaking strength ranging from 3.2 to 4.9 cN/dtex, surpassing that of natural cotton fibers. Their dry-state breaking elongation rate is comparable to nylon and wool, and it increases in the wet state, indicating high strength and good extensibility.

Biodegradability

Under normal temperature and humidity, PLA fibers and their products remain stable. In natural environments with specific conditions, microorganisms can completely degrade PLA into carbon dioxide and water. In industrial composting conditions (58°C, 98% humidity, and microbial presence), PLA products can decompose within 3-6 months. eSUN's PLA fibers have received certifications from DIN (Germany) and BPI (USA) for compostability and degradability.

Biocompatibility and Hypoallergenic Nature

Derived from lactic acid, an endogenous substance in the human body, PLA fibers have a pH value similar to human skin. This gives them excellent biocompatibility, skin affinity, and non-allergenic properties, making them suitable for biomedical applications.

Antibacterial and Anti-mite Properties

The weak acidity of lactic acid on the surface of PLA fibers imparts natural antibacterial properties, effectively inhibiting the growth of mites, mold, and odors.

Wearability

Drape: PLA fibers have a low initial modulus and small drape coefficient, providing good draping properties. Moisture Absorption and Breathability: While PLA fibers have poor moisture absorption, they offer good breathability. Crease Recovery: With an elastic recovery rate of up to 93% when stretched by 5%, PLA fiber fabrics exhibit good crease recovery. Abrasion Resistance and Pilling: PLA fibers have slightly better abrasion resistance than polyester, though fabrics may experience pilling. Thermal Insulation: Lightweight PLA fibers can quickly dry after getting wet. In winter, they offer better thermal insulation than cotton and polyester; in summer, they provide excellent moisture permeability and quick-drying properties.

Other Properties

UV Resistance: The molecular structure of PLA fibers contains numerous C—C and C—H bonds, which do not absorb light with wavelengths less than 290nm, granting them good UV resistance.

Self-extinguishing and Low Smoke: PLA fibers are not easily flammable, self-extinguish upon removal from fire, and emit no black smoke or toxic gases, ensuring safety during use.

Applications of PLA Fiber

Sanitary Materials

PLA non-woven fabrics have smooth surfaces, do not absorb moisture, and offer better fluidity, dryness, biocompatibility, and non-allergenicity. They are suitable for sanitary napkins, diapers, makeup remover pads, wet wipes, face towels, and other disposable sanitary products. Due to their biodegradability, PLA fibers help address the “white pollution” problem caused by disposable medical and sanitary products.

Apparel Fabrics

PLA fibers possess physical properties similar to polyester materials, can be shaped, have good strength and dimensional stability, and do not irritate the skin. They are easy to wash and dry and can be functionalized during spinning by adding other materials to achieve moisture absorption, UV protection, and other features. Applications include:

Sports and Leisure Clothing: DTY low-elastic yarn knitted fabrics for polo shirts, T-shirts, etc.

Underwear: Interwoven or blended fabrics that retain better shape and safety.

Children’s Clothing: Non-allergenic, skin-friendly, and flame-retardant properties are essential for modern children’s clothing.

Home Textiles and Toy Fillings

Fillings for Quilts and Pillows: Hollow PLA short fibers can be used in pure form or blended with other fibers, replacing existing polyester-related fillers.

Bedding Fabrics: Interwoven or blended fabrics that are skin-friendly, non-irritating, non-allergenic, and offer better dimensional stability than all-cotton fabrics.

Medical Supplies

PLA fibers are used in masks, protective clothing, medical gauze, bandages, sheets, and high-end antibacterial products due to their biocompatibility and biodegradability.

Other Applications

PLA fibers find applications in packaging materials, agricultural cloths, sand barriers, filter bundles, decorative board adhesives, and more [4].

PHA FIBERS

Polyhydroxyalkanoates (PHA) are biopolymers produced by bacterial fermentation of organic substrates. They are fully biodegradable in natural environments and demonstrate promising potential for textile use. Their high cost of production and relatively limited availability are the main barriers for large-scale application [5].

a) b)

Figure 2. PHA fibres under the microscope [6] and as staple fibres [7]

PHAs are a class of natural materials that exist in nature for over millions of years. These materials are both bio-based and biodegradable, similar to other natural materials such as cellulose, proteins and starch. PHAs are produced by an extensive variety of microorganisms through bacterial fermentation. During fermentation, bacteria convert different types of feedstock into a product. In this case, the microbes produce PHA, a natural polymer. This natural process can be mimicked in an industrial setting. During the last 20-30 years, dozens of initiatives from all over the world have been started to make PHA materials useful for durable and structural applications as a sustainable alternative to chemically synthesised polymers. 10 years ago, the main feedstock sources were corn, sugar and vegetable oils. Today, many PHA producing start-ups are working with innovative technologies that use waste water streams, plastic waste, renewable methane as well as carbon dioxide as feedstock.

Properties

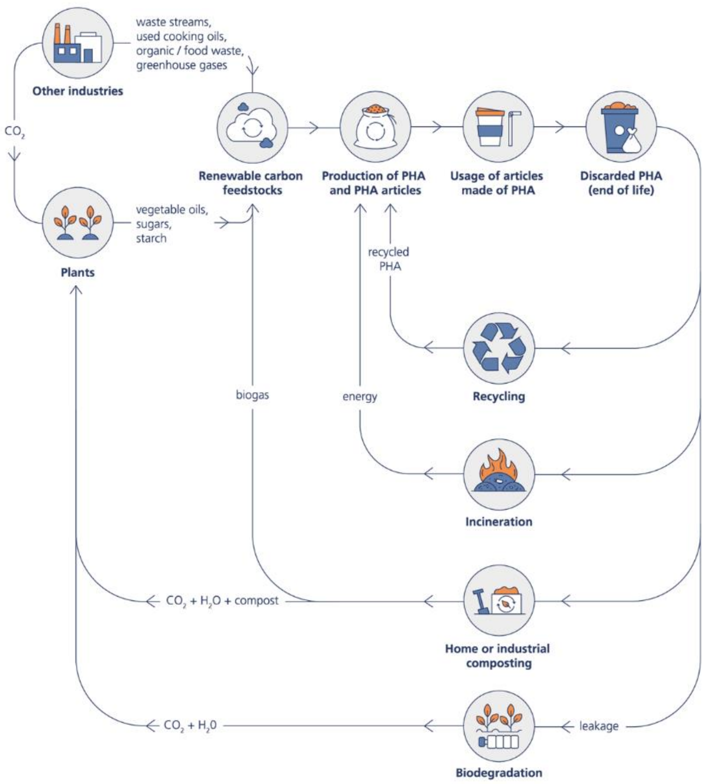
Today, 9 different PHA families are produced developed in the short, medium and long-chain length composition. PHA products range from amorphous to highly crystalline. They go from high-strength, hard and brittle to low-strength, soft and elastic. The chemical composition of PHAs can be formed and adjusted depending on which monomers are used and in which composition. PHAs have a potentially large design space and resulting application options as a wide variety of different polymers can be co-polymerised and blended. [8]

Applications

The versatility of the PHA family accommodates a wide range of market applications, due to their biocompatibility, biodegradability and green credentials. Depending on type and grade, PHAs can be used for injection moulding, extrusion, thermoforming, foam, non-wovens, fibers, 3D-printing, paper and fertiliser coating, glues, adhesives, as additive for reinforcement or plasticisation or as building block for thermosets in paints and foams. The main markets where PHAs have already achieved some degree of penetration are packaging, food service, agriculture and medical products.

End-of-Life

PHA can be reused. It can be recycled back to the polymer for new applications. It can be recycled back to raw materials to be used as renewable feedstock. It can be recycled to the environment through industrial or home composting. It can be recycled through incineration creating renewable energy. And lastly, it can be recycled to nutrients for living organisms through full biodegradation. [8]



Picture 3. PHAs usage cycle [8]

REGENERATED CELLULOSE FIBERS (TENCEL, MODAL, LYOCELL)

Regenerated cellulose fibers such as Tencel and Modal are derived from wood pulp using environmentally responsible production processes. These fibers are soft, strong, and fully biodegradable, making them an excellent alternative for apparel and household textiles. Tencel production in particular uses a closed-loop process with over 99% solvent recovery, minimizing environmental impact [9].

NATURAL FIBERS: BAMBOO, HEMP, AND OTHERS

Bamboo, hemp, and similar plant-based fibers are traditional yet highly relevant in the context of sustainability. They require less water and pesticides compared to cotton, while offering strength, breathability, and biodegradability. Nevertheless, the processing methods for bamboo often involve chemicals that can reduce the overall ecological benefits, unless more sustainable technologies are applied [10].

This paper is based on a comprehensive literature review of peer-reviewed articles, industrial reports, and recent scientific studies published between 2010 and 2025. The selected sources focus on mechanical performance, biodegradability, and life-cycle assessment of biodegradable textile fibers. The aim is to identify advantages, limitations, and perspectives of these materials in comparison to conventional synthetic fibers [11].

RESULTS AND DISCUSSION

Studies consistently demonstrate that biodegradable fibers can significantly reduce the ecological footprint of textiles. PLA and PHA show great promise as polymer-based alternatives to polyester and nylon, though scaling production remains a challenge due to cost factors. Regenerated cellulose fibers like Tencel offer immediate, commercially viable alternatives with proven ecological advantages. Traditional plant-based fibers, especially hemp, present strong sustainability credentials but are limited by processing requirements and slower adoption in mainstream markets.The integration of biodegradable fibers into global textile supply chains requires not only technological improvements but also systemic changes in consumer behavior, governmental regulation, and industry practices. Furthermore, durability and performance in various applications remain critical issues to be addressed, as sustainability must be balanced with functionality and cost-effectiveness [12].

CONCLUSION

The transition to biodegradable textile materials in the future will be a challenge for manufacturers. It will probably affect the price of the finished product, especially in the beginning. The transition from synthetic to natural and biodegradable fibers will not be an easy or cheap process, but the preservation of the environment, which is already heavily polluted with microplastics and textile waste made of mostly chemical fibers, is a task and a mission that has no alternative if we want to preserve the health of the human population as well as the flora and fauna. It is necessary to raise the awareness of a larger number of the population about the importance of preserving a healthy ecosystem. It is necessary to define and apply appropriate standards that production facilities must meet in every part of the planet and not only in developed countries. It is necessary to limit the production of finished products that are made from predominantly chemical fibers. It is necessary to involve science in order to obtain high-quality finished products from biodegradable fibers, as well as to switch production facilities to full production exclusively of this type of fibers, i.e. fibers that quickly decompose in nature without negative effects on the ecosystem. Also, it is necessary to change the global policy and conditions for the use of biodegradable fibers in all countries, especially where large production facilities are located.

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Bridging Theory and Practice: The Role of Service-Learning in Design Education in Private Universities in Taiwan

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Abstract. This study addresses the persistent theory-practice gap in design education at Taiwan's private universities amid declining enrollment and rapid industry changes. Employing a mixed-methods approach, it combines quantitative surveys (N=327 undergraduates from three institutions) with qualitative interviews (N=15) to examine Service-Learning's impact on design skills, academic performance, social responsibility, and intercultural communication. Hypotheses posited positive associations (effect sizes ~0.27-0.52). Statistical analyses (descriptive statistics, regression modeling) and thematic coding revealed significant improvements in all outcomes for SL participants, with medium effect sizes (e.g., Cohen's d=0.52 for design skills). However, challenges such as time management (affecting 60%) and cultural mismatches moderate effects. Findings underscore SL's potential to enhance experiential learning in globalized design contexts, informing curriculum reforms in resource-constrained settings.

Keywords: Service-Learning, Design Education, Private Universities, Theory-Practice Integration, Student Engagement, Experiential Learning, Taiwan Higher Education

INTRODUCTION

Design education in higher education often emphasizes theoretical knowledge, limiting practical application and contributing to a persistent theory-practice gap [1,2]. In Taiwan, the design sector is rapidly evolving due to technological advancements, digital innovation, and globalization, underscoring the need for curricula that integrate real-world experiences [3]. Private universities, which comprise about three-quarters of Taiwan's 160 higher education institutions (77 private as of 2025), are well-positioned to address this, given their focus on vocational training and diverse student populations [4]. Design programs, offered in approximately around 40 universities, span fields like graphic, industrial, multimedia, fashion design and other programs to meet industry demands.

Service-Learning (SL) serves as a promising pedagogical approach, combining community service with academic content to enable students to apply design principles in authentic settings [5,6]. SL activities, such as creating visual materials for non-profits or sustainable solutions for communities, foster skills in problem-solving, teamwork, and ethical decision-making [7]. In Taiwan, SL adoption aligns with national policies like the 2018 University Social Responsibility (USR) program, which promotes civic engagement and career readiness; by 2023, over 70% of universities integrated SL, with participation rates of 40-50% in some institutions [8]. However, research on SL's specific impacts in design programs at private universities remains limited, with studies showing general positive outcomes but lacking design-specific insights in resource-constrained contexts [9, 10].

This study examines SL's role in bridging the theory-practice gap in design education at Taiwan's private universities. Key research questions include: (1) How does SL participation affect design skills? (2) What is its impact on academic performance and social responsibility? (3) How does it influence intercultural communication? Hypotheses predict positive associations, with expected effect sizes of 0.27-0.52 based on meta-analyses.

The study's significance lies in its focus on private universities, which enroll ~70% of vocational students amid challenges like a 10% enrollment decline since 2018 due to low birth rates and industry shifts. By employing a mixed-methods approach—quantitative surveys (N=327) and qualitative interviews (N=15) from three institutions—this research provides evidence for curriculum reforms in globalized design contexts. Grounded in experiential learning theory, SL facilitates knowledge construction through reflection and application. Identified gaps, such as limited empirical data on design-specific SL in Taiwan, motivate this investigation.

LITERATURE REVIEW

Definition and Development of Service-Learning

Service-Learning (SL) refers to an instructional strategy that combines community service with defined learning goals and reflection. It began in the United States in the 1960s as part of civic education movements and has since adapted to different educational systems worldwide, with over 1,000 institutions in the US alone incorporating SL by 2020 [11]. In higher education, SL differs from general volunteering by tying service to academic objectives, benefiting both learners and recipients through reciprocal partnerships.

The development of SL draws from experiential learning ideas, including those of John Dewey, who advocated learning through experience and reflection to foster democratic citizenship [1]. Current models, such as Kolb's experiential learning cycle, include reflection to help students process their involvement, transforming experiences into knowledge [2]. In Asia, SL has been implemented since the 2000s, incorporating regional values like community focus and harmony, with Taiwan adopting it through policies like the USR programme, which has funded hundreds of projects since 2018 [3, 4].

Service-Learning in Design Education

In design education, SL allows students to use concepts such as colour theory, user-centred design, or sustainable practices in real-world projects. For instance, students may create packaging solutions for community needs, blending principles with user input to address social issues like environmental sustainability. Studies suggest that SL supports creativity by presenting varied challenges, with participants reporting 20-30% increases in innovative thinking. It also aids in developing skills for user-focused design through stakeholder interactions, fostering empathy and iterative processes essential in professional design.

Research indicates that SL in design courses can lead to better project outputs and career preparation, with meta-analyses showing effect sizes of 0.43 for academic outcomes in creative fields. Participants in SL have reported increased ability to manage client requirements, with qualitative studies highlighting gains in portfolio quality and employability. Potential issues include coordinating academic and service elements, which may require additional support like faculty training or community partnerships, as seen in Taiwanese design SL projects where time management challenges affected 60% of students.

Service-Learning in Taiwan's Higher Education

Taiwan has incorporated SL through initiatives like the University Social Responsibility programme, to promote SL across institutions. Private universities also have used SL to stand out in a competitive market with declining enrollment due to low birth rates. In design areas, projects often address cultural topics, such as materials for indigenous groups or intergenerational design initiatives, with over 20 pilot studies since 2019 focusing on design-thinking SL.

Studies in Taiwan point to SL's links with student interest and civic knowledge, with surveys of 157 undergraduates showing significant gains in global perspectives. A survey of undergraduates, for example, found associations between SL and higher social responsibility, with participation rates in technical universities reaching 40%. Research on design education specifically is less common, with broader fields more represented, but recent work on DevOps-based SL in IS courses highlights applicability to design.

Effects on Key Outcomes

SL positively influences several key outcomes. It enhances design skills by promoting practical abilities through iterative engagement with community feedback, with meta-analyses reporting moderate effect sizes around 0.43 for cognitive outcomes; Taiwanese design SL projects further show creativity improvements, with effect sizes near 0.52. In terms of academic performance, SL’s application of theory in real-world contexts is linked to better grades and higher student retention, as demonstrated by studies in Taiwan reporting an effect size of 0.52 for learning effectiveness. SL also fosters social responsibility by increasing awareness of societal roles aligned with Taiwan’s community-oriented culture, resulting in gains in empathy and ethical considerations, with effect sizes of approximately 0.35 for civic engagement. Finally, considering the globally connected design field, SL’s diverse participant interactions enhance intercultural communication skills, supporting international collaboration, with effect sizes around 0.27 for social skills.

Challenges and Limitations of Service-Learning

Despite its advantages, SL faces challenges in higher education, particularly in Taiwan. Studies highlight issues such as students' lack of interest due to prior negative experiences or misunderstandings, time management constraints affecting up to 60% of participants, and disruptions from external factors like the COVID-19 pandemic, which led to hybrid models but reduced engagement. Cultural mismatches arise as SL's Western origins may not fully align with Taiwan's collectivist norms, potentially causing implementation barriers and uneven participation. Furthermore, some research notes potential negative outcomes, including frustration, burnout, or diluted academic focus in group projects.

METHODOLOGY

Research Design

A mixed-method approach was selected to gather quantitative patterns and qualitative details. Surveys provided data on impacts, while case studies added explanatory depth. This combination strengthens the study's reliability by triangulating data sources. The design follows a convergent parallel strategy, where quantitative and qualitative data were collected simultaneously and integrated during interpretation to provide a comprehensive view of SL's role in design education. The quantitative component targeted measurable outcomes like skills and performance, while qualitative focused on lived experiences, ensuring targeted investigation of research questions.

Participants and Sampling

The study included 327 undergraduate students from design programmes at three private universities in Taiwan: University A, University B, and University C. The three universities were selected for diversity, representing 20% of private design program providers. Criteria were enrolment in a design course and age above 18. Convenience sampling with stratification by university was used, involving university email distribution to approximately 1,500 students, yielding a 22% response rate. The group was 55% female, average age 21.3 years, with 58% having SL experience of at least one semester.

Quotas ensured balance (University A: 120, B: 110, C: 97). Non-response checks compared early and late submissions, finding no major differences. Sample size was determined via power analysis using Python's statsmodels, assuming a medium effect size ($f^2=0.15$), alpha=0.05, power=0.8, and 3 predictors, yielding a minimum of 76; the 327 is justified by resource constraints and aligns with Taiwan SL studies (e.g., 84-157 samples).

Data Collection

Quantitative Survey

A quantitative survey was developed using established measures to assess SL impacts in design education. The questionnaire covered demographics (age, gender, study year), SL participation (yes/no, duration), design skills (measured via a 10-item Likert scale, 1=strongly disagree to 5=strongly agree, adapted from the Design Self-Efficacy Scale, Cronbach's α=0.85), academic performance (self-reported GPA on a 4.0 scale), social responsibility (8-item scale from the Civic Attitudes Measure, α=0.82), and intercultural communication (12-item scale from the Intercultural Effectiveness Scale, α=0.88). After piloting with 30 students, minor revisions were made. Data collection occurred online via Google Forms over two months in 2025.

Qualitative Case Studies

Interviews were held with 15 students (5 per university), chosen for varied SL involvement. Sessions of 40-60 minutes explored projects, difficulties, and outcomes. Questions included: "How did SL influence your design process?" Transcripts were made from recordings, with saturation reached after 12 interviews.

Data Analysis

Quantitative Analysis

After cleaning, 327 valid responses remained (75% rate). SPSS was used for means and standard deviations. Linear regression models examined SL effects, adjusting for gender and year. Assumptions (normality, homoscedasticity) were verified via histograms and scatterplots. Effect sizes were calculated using Cohen's d, targeting 0.2-0.5 based on meta-analyses.

Qualitative Analysis

NVivo assisted thematic coding, progressing from open to axial to selective stages (e.g., "skill application"). Two coders reviewed 20% for consistency (kappa=0.78).

Data Integration

Integration used joint displays, mapping quantitative results to qualitative themes.

RESULTS

Quantitative Findings

The sample distribution was University A (36.7%), B (33.6%), C (29.7%). SL participants (n=190) reported average duration of 4.5 months. As shown in Table 1, descriptive statistics of key variables are presented below.

Table 1. Descriptive Statistics of Key Variables (N=327)

Variable	Mean (95% CI)	Std. Dev.	Min	Max
SL Participation (0/1)	0.58 [0.53, 0.63]	0.49	0	1
Design Skills (1-5)	3.75 [3.68, 3.82]	0.66	1.75	5.00

Academic Performance (GPA)	2.90 [2.85, 2.95]	0.41	1.82	3.90
Social Responsibility (1-5)	3.80 [3.74, 3.86]	0.50	2.36	4.90
Intercultural Communication (1-5)	3.50 [3.42, 3.58]	0.74	1.43	5.00

As indicated above, the descriptive statistics indicate moderate to high levels across variables. For design skills, the mean of 3.75 suggests students generally perceive their abilities positively, with the 95% CI [3.68, 3.82] showing narrow variability, implying consistency in responses. Academic performance mean of 2.90 reflects average GPA, with SD 0.41 indicating low dispersion, perhaps due to self-reporting bias. Social responsibility mean of 3.80 points to positive attitudes, while intercultural communication at 3.50 has higher SD 0.74, suggesting greater individual differences, potentially influenced by diverse university settings.

Differences between participants and non-participants were significant (t-tests, $p<0.01$). Regression analyses confirmed positive effects. Model for design skills: $\beta=0.83$, $p<0.001$, $R^2=0.39$, Cohen's $d=0.52$. For academic performance: $\beta=0.48$, $p<0.001$, $R^2=0.38$, $d=0.43$. Social responsibility: $\beta=0.63$, $p<0.001$, $R^2=0.40$, $d=0.34$. Intercultural communication: $\beta=0.88$, $p<0.001$, $R^2=0.35$, $d=0.28$. These effect sizes indicate medium impacts, with design skills showing the strongest association, consistent with cognitive development in SL. The R^2 values (0.35-0.40) suggest the models explain substantial variance, but other factors (e.g., prior experience) may contribute.

Table 2. Regression Coefficients for SL Participation (Controlled Models)

Dependent Variable	SL Coefficient	Std. Error	t-value	p-value	R^2	Controls Included
Design Skills	0.833	0.057	14.50	0.000	0.393	Gender, Year
Academic Performance	0.484	0.034	14.10	0.000	0.379	Gender, Year
Social Responsibility	0.635	0.043	14.72	0.000	0.400	Gender, Year
Intercultural Communication	0.888	0.066	13.38	0.000	0.355	Gender, Year

As illustrated in Table 2, the regression results demonstrate that SL participation is a significant predictor across outcomes, with t-values >13 indicating strong statistical reliability. For intercultural communication, the higher $\beta=0.88$ suggests a more pronounced effect, possibly due to community diversity in projects. Subgroup analysis revealed University C had stronger intercultural effects ($\beta=0.95$, $p<0.001$) compared to A and B ($\beta=0.8$, $p=0.01$), with ANOVA confirming significant difference ($p=0.03$), likely attributable to rural settings with greater cultural exposure. Overall, the findings objectively indicate positive associations, though causality requires caution due to self-reported data. Additional correlations, such as between design skills and intercultural communication ($r=0.58$, $p<0.001$), suggest interconnected benefits, where SL fosters holistic development.

Qualitative Findings

Thematic analysis of 15 interviews revealed four key themes related to SL experiences in design education. First, students highlighted the application of theory to practice, with one from University A noting, "I redesigned a website for an NGO and saw user feedback in action." Second, skill enhancement was evident, particularly in creativity and collaboration, as a University B student shared, "Team mural project taught negotiation with diverse views." Third, students developed a stronger sense of social responsibility, with a University C student reflecting, "SL showed design's role in environmental issues." Finally, intercultural insights emerged, as one student described adapting designs for immigrant group projects to enhance cultural communication. Despite challenges like time constraints, reported by 60% of participants, the benefits were deemed significant. However, the limited sample size suggests these themes indicate patterns rather than broad generalizability.

Integration of Results

Quantitative regressions (e.g., β=0.888 for intercultural) aligned with qualitative themes, confirming SL's role. For example, a joint display shows the integration as presented in Table 3.

Table 3. Integration of Quantitative and Qualitative Findings

Outcome	Regression β (p-value)	Cohen's d	Qualitative Theme	Example Quote
Design Skills	0.833 (<0.001)	0.43	Skill Enhancement	"Team mural project taught negotiation"
Academic Performance	0.484 (<0.001)	0.35	Application of Theory	"Redesigned website with user feedback"
Social Responsibility	0.635 (<0.001)	0.35	Social Responsibility Growth	"Design's role in environmental issues"
Intercultural Communication	0.888 (<0.001)	0.27	Intercultural Insights	"Adapted designs culturally"

The integration reveals that quantitative metrics, such as the medium effect size for design skills (d=0.52), are supported by qualitative narratives on skill enhancement, where students objectively reported practical gains in creativity and problem-solving. Similarly, the lower d=0.28 for intercultural communication corresponds to themes of insights from diverse interactions, indicating consistent but moderate associations. This convergence strengthens the evidence, as qualitative quotes provide contextual explanation for statistical patterns, though the small qualitative sample limits depth. Overall, the mixed data objectively support SL's positive role, with no contradictory findings, suggesting reliable conclusions within the study's scope.

CONCLUSION

This study demonstrates the significant role of Service-Learning in connecting theory with practice within design education at Taiwan's private universities. Data from questionnaires and interviews reveal that SL participation enhances students' design skills, academic performance, social responsibility, and intercultural communication, transforming traditional curricula into experiential learning environments that prepare students for a globalised industry. To maximise benefits, institutions should integrate SL into programmes with proper planning, staff development, and community partnerships, while aligning efforts with national guidelines to secure support. Beyond design, SL's model offers promise for other disciplines, fostering the skills needed in an increasingly interconnected world. Future research could examine SL's long-term effects and variations across university types to guide educational strategies in Taiwan and similar settings.

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The Role of Air Pollution in Shaping Migration Trajectories: A Case Study of Belgrade, Serbia

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Abstract. Air pollution, as one of the major environmental issues, is closely related to population mobility process. The Republic of Serbia faces numerous air quality challenges, while its capital is one of the most air pollution affected areas of the country. In light of these circumstances, the aim of this paper is to examine the impact of air pollution on population mobility in the City of Belgrade. The research results show the diversity of possible mobility trajectories in a geospatial context, and highlight the role of air pollution in the migration process. The paper provides important insights for the consideration of future population mobility patterns and their impact on overall development.

Keywords: air pollution, migration, development, Belgrade

INTRODUCTION

Population mobility is an integral part of territorial development and as such is linked to demographic, socio-economic, political and environmental conditions [1]. Migration can have positive side effects important for the development of the place of origin. This can be seen in remittances, various types of financial support from migrants and the transfer of knowledge and skills acquired abroad. However, population mobility (emigration) from a particular area is primarily a negative component of overall development. It affects the number of the total population and influences changes in the structural characteristics of the population. As the young population participates most frequently in mobility process, the consequences of this migration are reflected in future demographic trends and labor market patterns [2,3].

Environmental issues, such as air pollution, are recognized as an increasingly important factor of population mobility. As air quality is related to quality of life, including public health, air pollution has the potential to encourage individual and/or organized migration. This pattern is particularly characteristic of urban areas, which face specific challenges in terms of air pollution. Therefore, due to air pollution, population is willing to leave their place of origin and move to known, less known or unknown regions [4]. Accordingly, air quality could encourage both internal and international migration.

The aim of this paper is to investigate the effects of air pollution on population mobility in the City of Belgrade, Serbia. The focus in this research is to examine the geospatial context of the potential migration process, i.e. to determine the direction of future migration movements. The study of the effects of air pollution migration on a global scale is a common topic. However, according to the author's knowledge, no research has been conducted in this area. The paper therefore provides an insight into the basics of the mentioned issue and discusses the possibilities of future impacts of air pollution on population migration and development.

METHODOLOGY

The research on the influence of air pollution on population migration is the result of the engagement of a group of researchers in the fields of physics and geography. As part of this research, it is planned to study this issue in Serbia from various aspects and to create a data base that will make possible to formulate appropriate measures and activities beneficial for society and the environment. In order to obtain relevant material, field research has been conducted in the City of Belgrade. Accordingly, this paper represents a part of the complex research that is still in progress.

For the purpose of this paper, we processed and analyzed data from a survey conducted in the City of Belgrade. A total of 120 participants were included in this research. In this paper, we focus on two segments:

- Air pollution and migration perceptions
- Air pollution and potential migration trajectories

Thus, we studied the characteristics of migration intention regarding air quality in the City of Belgrade, and the possible direction of future migration movements. Respondents had the opportunity to answer whether they intend to move within the borders of Serbia or abroad. Based on the respondents' intention to migrate and participate in internal or international migration, the potential impact of migration on the demographic and socio-economic development of the country was analyzed.

The research data were processed in the statistical program SPSS. The survey data were analyzed by determining the frequency and percentage share of the selected categories regarding migration intentions. Chi-Square ($\chi2$) [5] was applied to identify a statistically significant difference in terms of socio-demographic characteristics of respondents and elements of potential migration trajectories induced by air pollution.

RESULTS

Respondents' perceptions of air quality and its impact on migration represent the starting point of this paper. The majority of respondents (85%) stated that the air quality in the City of Belgrade has changed in the last five years. Almost a third of them (29.2%) indicated that air quality has worsened significantly, while 60.8% noted that air quality has gotten worse in the last five years. Air pollution was considered predominantly as one of the main factors for the migration from the area of the City of Belgrade (53.3%). The respondents who stated that air pollution does not affect migration make up 24.2%, while 21.7% of respondents are not familiar with this issue, and 0.8% of them believe that air pollution is a major factor in migration (Figure 1).

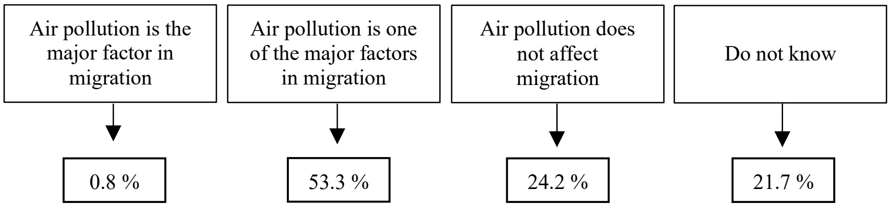

Figure 1. Respondents' perception of air pollution as a factor of migration

In accordance with these findings are evidance related to migration intentions, which suggests that air pollution is a significant potential factor in population moility. Migration intentions were found to be particularly present among population aged 30-39 and 20-29. This finding is in line with previous studies that indicated that there are differences in the population in terms migration intention due to air pollution, and that, therefore especially young people are more willing to participate in mobility than others [6]. From a geospatial point of view, the largest proportion of respondents plan to migrate abroad (25.8%) and to other parts of Serbia (outside the City of Belgrade) (25%). Those who plan to migrate to another municipality in the area of the City of Belgrade make up 15.8% of the sample, while the smallest proportion of respondents plan to migrate to another settlement in the same municipality (0.8%) (Figure 2).

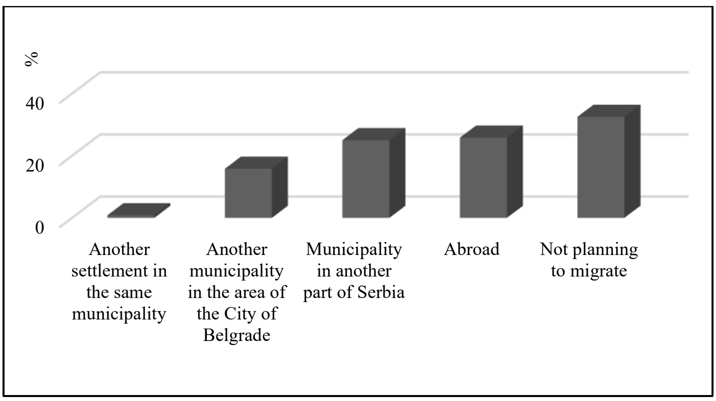

Figure 2. Geospatial aspect of potential migration caused by air pollution

Regarding socio-demographic characteristics, the results show that the migration potential is greater among women than men, both in terms of internal and international migration. Although there is a slight difference between the other socio-demographic characteristics of respondents in terms of migration to other parts of Serbia or abroad, population in the 20-29 age group, students and the unemployed most often stated that they would migrate abroad due to air pollution, while population in other age groups, the permanently employed and retired persons are more willing to migrate in other parts of Serbia. The results of the chi-square test show no statistically significant difference between respondents in terms of socio-demographic characteristics and geospatial aspects of potential migration due to air pollution, as the value of p is greater than 0.05 in all categories.

DISCUSSION

Air pollution is one of the major environmental and social issues worldwide. In the capital of Serbia, which has been one of the most affected areas in the country for years, air pollution has the potential to influence migration intentions. Our findings indicate migration potential in the City of Belgrade and shows that the younger population is more willing to participate in future migration due to air pollution. The migration opportunity is possible in the domain of both internal and international migration.

International migration has a direct impact on population dynamics, which is further emphasized by the migration of the young population. On the other hand, population mobility from the City of Belgrade to other parts of the country (internal migration) can be seen as a way to improve the demographic profile of municipalities facing unfavorable population trends. However, the question arises whether the depopulated parts of Serbia should improve the population profiles in this manner. The issue is therefore complex and requires the involvement of experts from both the environmental and social fields in order to find optimal solutions.

In addition to the economic and social factors that have been shown to be significant for emigration from Serbia in previous research [7], air pollution has been also shown to be a significant determinant of the migration process in this study. For this reason, the results suggest that this environmental aspect (air quality) should be taken into consideration when designing migration policy. Considering that air pollution can also be linked with socio-economic growth and sustainable development [8], the association between these categories has potential to be considered also in the context of regional development.

CONCLUSION

The research results underline the importance of environmental aspects in the process of population migration, and emphasize that this topic has potential to be further investigated in the future. In this paper, we have examined the influence of air quality on population migration in urban areas. One of the suggestions for future research is to examine this topic on the example of rural areas. For future research, it is important to examine the temporal aspect of future migration, as well as the attitudes of the population towards the impact of air pollution on the population migration process and the differences in the intentions of the population in the central and peripheral parts of the City of Belgrade. As mentioned earlier, this paper is a part of the wider research on the topic, and provides insight into the issues we will address in the future.

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The European Circular Economy in the Textile Sector

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Abstract. The paper emphasizes that textiles have been identified as one of the key value chains in the European Union's Circular Economy Action Plan (CEAP) of 2020. This plan serves as a fundamental starting point for the European Green Deal, within which goals have been set to reduce microplastic emissions into the environment by 30%, as well as to decrease the amount of residual municipal waste by 50% by the year 2030. In order to achieve these objectives, the Circular Economy Monitoring Framework Laboratory (CML) was established. The task of the CML's textile module is to monitor the implementation of circular economy principles within the textile sector, in alignment with the direction and goals set out in the EU Textile Strategy. This module is based on the selection of metrics derived from available data, reports, and expertise. The categorization of the textile module's metrics follows the same structure as the general CML framework and includes the following categories: (1) enabling environment, (2) business operations, (3) consumption, and (4) materials and waste. The paper presents a limited set of collected data, indicating, for instance, that the annual volume of used textile exports from the EU has remained around 1.4 million tonnes per year since 2015. In 2022, each person in the EU consumed on average approximately 19 kilograms of clothing, footwear, and household textiles amounting to about 8.5 million tonnes of total textile consumption across the EU. Furthermore, in 2021, the average amount of textiles reused per person in the EU was approximately 2.3 kilograms.

Keywords: European Environment agency, circular textile economy

INTRODUCTION

Today, the textile industry is one of the largest industries globally, encompassing millions of producers and billions of consumers worldwide. However, it is increasingly regarded as an environmental adversary, as it generates approximately 40 million tonnes of textile waste annually on a global scale. The majority of this waste is either landfilled or incinerated. In addition, the technological processes involved in textile production consume vast amounts of water, land, and raw materials. It is estimated that the global textile industry used 79 billion cubic meters of water in 2015, while the total water consumption of the entire EU economy in 2017 amounted to 266 billion cubic meters.

For instance, the production of a single cotton T-shirt requires approximately 2,700 liters of drinking water the amount one person would consume over a period of two and a half years. Furthermore, it is estimated that textile finishing processes particularly dyeing and treatment are responsible for up to 20% of global water pollution [1].

These global challenges are also strongly present within the countries of the European Union. According to the European Environment Agency (EEA), the consumption of clothing, footwear, and household textiles in the EU accounts for an average of 1.3 tonnes of raw materials and over 100 cubic meters of water per capita annually. The Agency has emphasized the urgent need for substantial transformation within the sector in the direction of a circular economy, in order to reduce greenhouse gas emissions, promote resource reuse, and protect natural ecosystems [2].

CIRCULAR ECONOMY IN THE TEXTILE SECTOR

Textiles have been identified as one of the key value chains in the European Union's Circular Economy Action Plan (CEAP). As a result, substantial efforts are being made to facilitate a sustainable transition from a linear economy towards closed-loop recycling systems. Particular emphasis is placed on high-quality recycling that would ensure a greater proportion of recycled materials in the production of new textile goods, thereby reducing the use of primary raw materials. This would, on one hand, decrease waste generation and, on the other, reduce the environmental impact associated with the extraction and processing of virgin resources.

The objective is to develop closed-loop systems in which materials are continually recycled after each stage of production or disposal of used garments so that textile materials theoretically remain in permanent circulation. For this reason, the European circular textile economy is evolving beyond the traditional concept of waste management. Today, it represents a systemic economic approach that aims to retain materials in use for longer, preserve product quality, and contribute to addressing the triple planetary crisis: climate change, biodiversity loss, and pollution [3-10].

In achieving the EU's sustainability goals, the circular economy is viewed as part of a broader socio-economic transition, involving significant changes in lifestyles, particularly in terms of consumption and production patterns. These changes primarily aim to reduce the environmental impacts of supply chains through transformations within the economic system. At the same time, such transitions strive to enhance human well-being, respect ecological boundaries, and address the injustices linked to environmental degradation and climate change.

METHODS FOR MONITORING AND MEASURING THE CIRCULAR ECONOMY

Textiles, in the context of household consumption, have been identified as one of the sectors exerting the greatest negative environmental pressures throughout their life cycle, including significant impacts on climate change. For this reason, textiles have been recognized as one of the key value chains in the European Union's Circular Economy Action Plan (CEAP) of 2020. This plan serves as the primary foundation for the European Green Deal. The obligations defined by the European Green Deal and the CEAP have been incorporated into the EU Strategy for Sustainable and Circular Textiles, which addresses textile production and consumption. The European Green Deal also contributed to the adoption of the EU Zero Pollution Action Plan in 2021, which set targets to reduce microplastic emissions into the environment by 30% and to decrease residual municipal waste by 50% by 2030 [2].

To achieve these objectives, the Circular Economy Monitoring Framework Laboratory (CML) was established. The task of the CML's textile module is to monitor the implementation of circular economy principles within the textile sector, in line with the directions and goals set out in the EU Textile Strategy. This module is based on the selection of metrics derived from available data, reports, and expertise. The classification of the textile module metrics follows the same structure as the general CML framework, organized into four categories: (1) enabling framework, (2) business operations, (3) consumption, and (4) materials and waste.

For example, the "business operations" metric analyzes the export of used textiles from the EU. Data in this sector indicate that the annual volume of used textile exports from the EU has nearly doubled since 2005. Consistently high export volumes of approximately 1.4 million tonnes per year have been recorded since 2015. The majority of these exports from the EU are destined for Africa and Asia. It is noteworthy that the fate of exported used clothing depends on product quality, type, and the saturation of the global market. Exported textiles are either reused or recycled, or they end up in landfills or illegal waste dumps. This complex trade provides a source of income for many people worldwide; however, it also exerts considerable environmental and climate pressures. Figure 1 illustrates estimates of used textile exports from the EU (EU-27 and the UK) to the rest of the world from 2005 to 2023, measured in millions of tonnes [2].

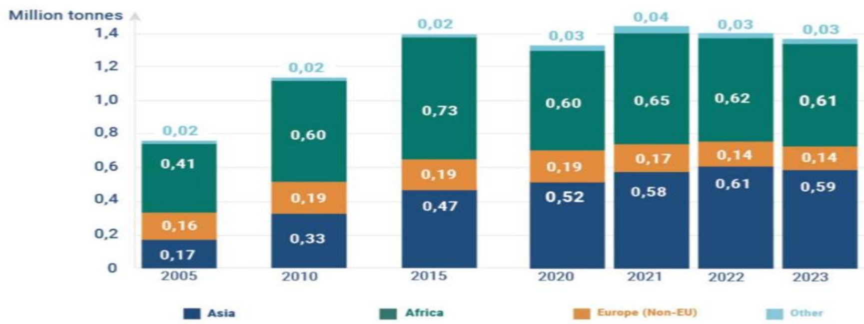

Figure 1. Export of used textiles from the EU (EU-27 and UK) to the rest of the world, 2005–2023, in million tonnes [2]

The consumption metrics analyze: the consumption of clothing, footwear, and household textiles; the share of synthetic fibers and yarns used in industrial textiles within the EU; microplastic emissions from synthetic textiles unintentionally released into the environment in the EU; the annual per capita textile reuse; and the average garment lifespan measured by the number of wears.

In 2022, the average consumption per person in the EU was approximately 19 kilograms of clothing, footwear, and household textiles. This amounts to about 8.5 million tonnes of total textile consumption in the EU. Figure 2 illustrates the consumption of clothing, footwear, and household textiles in the EU (EU-27) from 2010 to 2022, expressed in kilograms per capita [2].

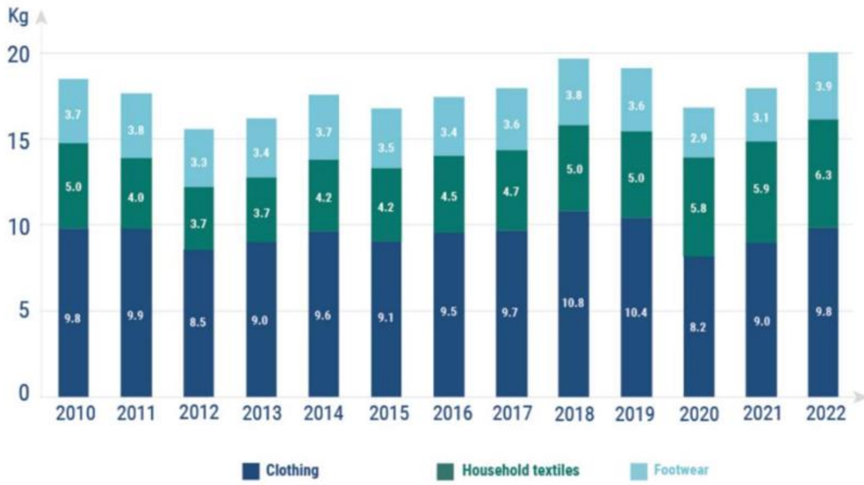

Figure 2. Consumption of clothing, footwear, and household textiles in the EU (EU-27), 2010–2022, in kilograms per capita [2]

In 2021, an average of 2.3 kilograms of textiles per person were reused in the EU. Figure 3 presents the amounts of reused textiles, expressed in kilograms per capita, for the year 2021 [2].

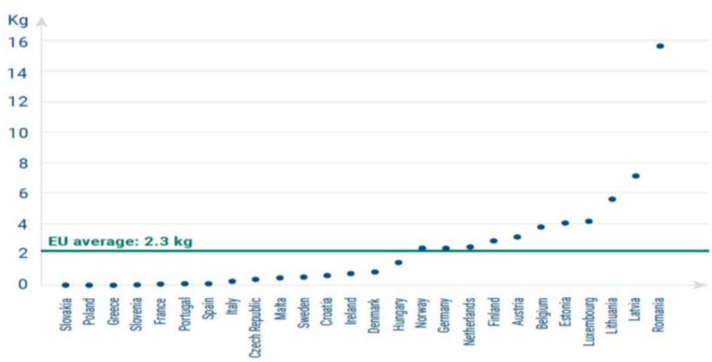

Figure 3. Amounts of Reused Textiles, in Kilograms per Capita, 2021 [2]

The metrics for "materials and waste" analyze: the use of raw materials for textile consumption in the EU; water consumption for textiles in the EU; land use related to textile consumption in the EU; greenhouse gas emissions from textile consumption in the EU; the number of annual chemical risk warnings for textile products in the EU; the share of best-selling products containing recycled materials; textile waste generated per capita annually in the EU; the collection rate of textile and footwear waste in the EU; and the proportion of textile waste that is incinerated or landfilled in the EU [2]

CONCLUSION

Today, the textile industry stands as one of the largest industries globally, yet it is often referred to as an environmental adversary due to the generation of approximately 40 million tonnes of textile waste annually worldwide. The majority of this waste is currently sent to landfills or incinerated. Consequently, textiles have been identified as a key value chain in the European Union's Circular Economy Action Plan (CEAP) of 2020, which serves as the primary foundation for the European Green Deal. The Green Deal sets ambitious targets to reduce microplastic emissions into the environment by 30% and to cut residual municipal waste by 50% by 2030.

To achieve these objectives, the Circular Economy Monitoring Laboratory (CML) was established. The CML textile module is tasked with monitoring the implementation of circular economy principles within the textile sector, aligned with the directions and goals outlined in the EU Textile Strategy. This module is based on the selection of metrics derived from available data, reports, and expertise. The textile module's metrics follow the same structure as the general CML framework, categorized into: (1) enabling framework, (2) business operations, (3) consumption, and (4) materials and waste.

The data presented indicate, for example, that the annual volume of used textile exports from the EU has been approximately 1.4 million tonnes since 2015. In 2022, the average per capita consumption of clothing, footwear, and household textiles in the EU was about 19 kilograms, totaling roughly 8.5 million tonnes of textile consumption. Furthermore, in 2021, an average of 2.3 kilograms of textiles per person were reused within the EU.

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Determination of the Amount of Cutting Waste and Its Characterization

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Abstract. The generation of cutting waste is an inevitable outcome of production processes in the clothing industry. Efficient management of cutting waste can lead to significant cost savings, resource optimization, and environmental sustainability. Although this waste can be a valuable resource, it is currently only one of the environmental pollutants. In order to implement a more efficient way of managing apparel cutting waste, a comprehensive analysis of its quality and quantity needs to be done.This paper presents an applied methodology to determine both the quantity and quality of cutting waste at the place of creation in the clothing manufacturing company. The application of this methodology will be the basis for further research to develop a more efficient way of managing cutting waste than the current one - disposal in landfills.

Keywords: textile waste, cutting waste, methodology

INTRODUCTION

The textile industry in the Republic of North Macedonia represents one of the leading manufacturing industries, with significant contributions to GDP formation, high labor absorption, and exports. This industry employs around 35,000 workers, which accounts for approximately 27% of all employees in the manufacturing sector or about 6.7% of the total number of employees in the country. The industry is export-oriented and contributes about 13% to the total Gross Domestic Product (GDP) and 27% to Macedonian exports. In terms of regional distribution, the textile industry is spread across the entire territory of the Republic of North Macedonia, with a significant concentration in the eastern part of the country. The volume of textile waste depends on production capacity. Textile waste is a significant problem, as 2 to 15 kilograms of waste per person are generated annually in Europe [1,2].

THEORETICAL PART

Most of the companies in North Macedonia are focused on garment production, consequently, the majority of textile waste is apparel cutting waste. This type of waste is a valuable resource because of its preserved physical and mechanical qualities Despite this potential, it is largely disposed of in landfills. The amount of cutting waste depends on the cutting layout, garment type, and frequency of material defects The most of the textile companies are small to medium-sized, limiting their ability to invest in recycling equipment. Studies indicate that 94.19% of clothing producers discard waste in landfills, while only 3.49% sell it to licensed recyclers, Disposal and customs clearance costs for textile waste reach €1.5 million annually [2-4].

Textile waste poses multiple challenges: it harms the environment, increases the demand for landfill space, and generates additional management costs. European waste policy focuses on preventing waste generation to minimize its impact. In line with this, the European Parliament adopted a resolution (2006/2175 INI) to promote waste recycling and reduce landfill volumes [5,6].

The most effective approach to textile waste management is an integrated treatment model guided by sustainable development principles, particularly the 7Rs: reduce, reuse, recycle, regulations, recovering, rethinking, and renovation. Recycling plays a central role, as up to 99% of textile waste can be reused. From the perspective of conserving energy and raw materials, recycling is the preferred treatment method, reducing pollution, lowering waste volumes, and saving resources [7,8].

Garment manufacturers can significantly support recycling efforts by implementing waste sorting processes, as only sorted waste can be reused. However, recent studies in North Macedonia reveal that many managers have a negative outlook on textile waste recycling. Most of the top executives show little interest in sorting waste, despite its importance for recycling.

In the past decade, several studies have been conducted on the quantity and quality of textile waste, specifically cutting waste, in the Republic of North Macedonia as a prerequisite for introducing a more efficient way of managing it [9,10]. At present, there is no standardized methodology for accurately calculating apparel cutting waste produced during the cutting process at its point of origin—within the companies themselves. This paper seeks to develop a straightforward method for determining the quantity of textile waste generated during tailoring at the production site in garment manufacturing.

EXPERIMENTAL PART

Using the knowledge from industrial practice regarding the course of cutting processes, a methodology was developed for determining the quantities of generated textile waste through several stages, directly at the place of its occurrence, as follows:

1. Determination of the total length L (m) and weight T (kg) of the imported textile material. This data is planned to be collected through the analysis of import documentation;
2. Determination of the actual cut length per bale Rlb (m), the sum of:

$$Rlb = [(Lks + Oks) \cdot N] + Ld + Ob \quad \text{(m)} \tag{1}$$

where:
$Lks -$ length of cutting marker (m);
$Oks -$ remnants (leftovers) of cut layers (m);
N – number of cut layers in the cut lay;
$Ld -$ length of material due to removed errors (defects) (m);
Ob - remnants of the ends of the bale (m).

3. Determination of the actual cut total length RL (m), as a sum of:

$$RL = \sum_{i=1}^{n} Rlb \text{ (m)} \tag{2}$$

In this phase, a cutting form (Material Cut Report) was designed, a form that serves to keep precise records of the use of the textile material, used by operators when forming cut layers. The form is shown in Table 1.

Table 1. Material cut report

Marker number	Marker name	Length of the coil Lb (m)	Marker length Lks (m)	CAD efficiency (%)	Number of layers in the cut lay N	Left-overs of cut layers Oks (m)	Defect Ld (m)	Coil left-overs Ob (m)

4. The next stage is the determination of:

(%) of cut length PLk:

$$PLk = (RL/L) \cdot 100 \text{ (\%)} \tag{3}$$

(%) of removed defects PLd:

$$PLd = (Ld/L) \cdot 100 \text{ (\%)} \tag{4}$$

(%) of the coil leftovers POb (%):

$$POb = (Ob/L) \cdot 100 \text{ (\%)} \tag{5}$$

5. Then follows the determination of:

the gross cut quantity BT (kg):

$$BT = (T/100) \cdot PRL \text{(kg)} \tag{6}$$

quantity of removed defects KLd (kg):

$$KLd = (T/100) \cdot PLd \text{ (kg)} \tag{7}$$

coil remnants (leftovers) quantity: KOb (kg):

$$KOb = (T/100) \cdot POb \text{ (kg)} \quad (8)$$

6. The next step is the determination of the net cut quantity NT (kg):

$$NT = (BT / 100) \cdot ACADef \quad (9)$$

where:
$ACADef -$ average utilization of the total number of cutting markers

$$BT = (T / 100) \cdot PLk \quad (10)$$
$$ACADef = \sum_{i=1}^{n} PCADiKSl \quad (11)$$

where:
$PCADiKSl -$ the percentage of utilization of the used cutting markers individually (this data is taken from Table 1, Material Cut Report form).

7. The determination of the inter-cutting loss KMg (kg) was calculated according to the formula 12:

$$KMg = BT - NT \text{ (kg)} \quad (12)$$

8. Calculation of the quantity Ok (kg) and the percentage of waste generated from the cutting process POk (%), is according to formulas (13) and (14), respectively:

$$Ok = KMg + Kld + KOb \text{ (kg)} \quad (13)$$
$$POk = Ok/(BT + KLd + KOb) \cdot 100(\%) \quad (14)$$

For examining the practical applicability of the methodology, a clothing manufacturing company from the Republic of North Macedonia was selected. The company has 170 employees and produces dresses, skirts, shirts, and blouses, with an average monthly capacity of 16,000 garment units. It is a successful company that, even during the COVID-19 pandemic, operated at full capacity without any lockdown. The research was conducted during the period from May 1 to May 30, 2024.

RESULTS AND DISCUSION

During the study, 9.224 garment units were produced using 3.299 kg of textile material. Only one model (M_4) used knitted fabric; the rest used woven fabric. The dominant raw materials were 100% viscose, 100% Tencel, and 100% cotton. Only one (M4) of the eight models under consideration is made from knitted fabric, requiring 492 kg of knitted material composed of 95% viscose and 5% elastane. The remaining models are made from woven fabric (2807 kg). Among the woven fabrics, the predominant raw composition is 100% viscose (4043.3 kg), followed by 3805.4 kg of 100% Tencel fabric, 1179.9 kg of 100% cotton, and 195.7 kg of other or mixed raw compositions. For the production of the first six models, both main material and lining were used, while for models M_7 and M_8, only the main material was used.

Table 2. Import data

Model	Order quantity	Imported quantity (m)	Imported quantity (kg)	Type of fabric	Raw material content
M_1	2464	2842	806	Woven	67% Lyocell, 33% Linen
		200	18	Woven	100 % cotton
M_2	1533	2042.9	613	Woven	100% Tencel
		268	43	Woven	100% cotton
M_3	1848	1762.5	541	Woven	100% Tencel
		299	14	Woven	100 % cotton
M_{4se}	573	1205	492	Knitted fabric	95% viscose, 5% elastane
		89	18	Woven	100% cotton
M_5	505	1026.8	305	Woven	100% viscose
		131.9	30	Woven	100% cotton
M_6	764	1271.5	385	Woven	100% viscose
		192	34	Woven	100% cotton
M_7	312	520	239,2	Woven	100% viscose
M_8	1225	2252	900,8	Woven	100% viscose
Sum	9224	7867	3299		

Table 3. Obtained results according to the proposed methodology

Model	NT (kg)	KLd (kg)	KOb (kg)	KMg (kg)	Ok (kg)	POk (%)
M_1	624.35	14.96	20.77	136.59	172.33	21.38
	14.16	0	0.36	3.48	3.84	21.35
M_2	503.40	3,53	4.50	101.58	109.60	17.88
	35.97	0,25	0.56	6.23	7.03	16.35
M_3	285.72	2,55	10.74	240.76	254.05	46.96
	11.96	0.04	0.15	1.85	2.04	14.58
M_4	406.75	8.26	8.35	68.65	85.25	17.33
	15.70	0.09	0.23	1.98	2.30	12.79
M_5	242.10	3,94	6.28	51.89	62.11	20.36
	25.37	0.23	0,49	3.90	4.62	15.4
M_6	300.63	5.72	4.70	65.81	76.23	19.8
	4.55	0.09	0.04	1,34	1.47	4.32
M_7	178	2.53	2.82	55.53	60.89	25.46
M_8	729.35	8.02	20.72	142.56	171.29	19.02
Sum	2874.61	50.21	80.71	745.56	1013.05	Average: 19.5

The results obtained based on the proposed methodology are shown below in Table 3. The total amount of generated waste is *POk* = 19.5%. An unusually high percentage of waste was observed in model M_3, which is attributed to the specific construction of the model and the fact that the pattern pieces were aligned in only one direction on the cutting layout.

During the research period, a total of 1013.05 kg of cutting waste was generated in one company, of which 85.25 kg was knitted fabric waste, and the rest was woven fabric waste. Regarding the raw composition, 21.3 kg was waste from 100% cotton fabric, 370.52 kg from 100% viscose fabric, 363.35 kg from 100% Tencel fabric, and the remainder was waste from fabrics and knits with various raw compositions. All the generated cutting waste was disposed of at the local landfill.

CONCLUSION

This methodology enables a quick and easy determination of the quantity as well as quality of cutting waste at the point of its generation, i.e., within the company. By applying this methodology. By applying this methodology, the necessary data for more efficient management of cutting waste are obtained. This methodology could be the subject of further research for its improvement or conversion into a software tool that would contribute to changing the way textile waste is managed, particularly cutting waste, which represents a valuable resource that can be utilized but still ends up in local landfills. Solving this problem requires the involvement of all relevant institutions: companies, municipalities, and governments.

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EnergyPLAN-Based Scenarios for Serbia's 2030 Low-Carbon Power System

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Abstract. Energy policy in Serbia emphasizes securing reliable supply, reducing dependence on imports, and improving sustainability. This study develops and analyzes two scenarios for Serbia's power system in 2030 using the EnergyPLAN simulation tool: a baseline scenario reflecting current trajectories and a flexible scenario that incorporates an additional 10 TWh of electricity generation from renewable energy sources (RES). Both scenarios demonstrate the potential to meet sustainability criteria while minimizing system costs. The results highlight the crucial role of renewable integration and energy efficiency measures in significantly reducing greenhouse gas emissions and enhancing energy security.

Keywords: Energy policy, renewable energy sources, EnergyPLAN, Serbia, energy transition, energy efficiency, greenhouse gas emissions, techno-economic optimization

INTRODUCTION

Energy has been a key driver of global economic growth, yet it remains the largest source of greenhouse gas emissions, reaching 36.8 gigatons of CO_2 in 2023—a 1.1% increase from 2022 [1]. This trend highlights the urgency of effective climate mitigation strategies. The European Union (EU) aims to cut emissions by at least 55% by 2030 and achieve climate neutrality by 2050 [2]. The Carbon Border Adjustment Mechanism (CBAM), effective 1 October 2023, imposes carbon tariffs on imports from non-EU countries, with compliance payments starting in 2026, potentially affecting Serbia's industry and electricity prices [3,4].

Serbia's energy framework, guided by the 2023 Energy Law [5] and the national "Strategy for the Development of the Energy Sector until 2025, with projections to 2030" [2], focuses on secure and sustainable supply, reduced import dependence, and lower environmental impact [6]. This paper models a flexible RES-based system using the EnergyPLAN software to simulate hourly operations, annual balances, CO_2 emissions, and cost analyses [7-9]. Two scenarios are examined: a baseline reflecting current trends and a flexible scenario adding 10 TWh from renewables, aimed at aligning with EU climate goals and national priorities [10,11].

MATERIALS AND METHODS

Serbia's energy system is based on domestic sources—coal, oil, natural gas, and renewables—supplemented by imports and supported by electricity and heat generation, coal mining, and distribution [12]. *Elektroprivreda Srbije* (EPS) operates about 7,855 MW of installed capacity, with 70% of electricity from coal-fired plants and 30% from hydropower [13–15].

Table 1 Installed electricity generation capacities in 2023 (excluding APKM) [15].

Technology	**Installed Capacity (MW)**
Hydroelectric power plants	2,941
Thermal power plants (coal)	4,429
Thermal power plants (gas, fuel oil)	526
Gas power plants	-
Nuclear power plants	-
Wind power plants (independent producers)	373
Small power plants (EPS-owned)	39
Small power plants (independent producers)	214
Total Installed Capacity	**8,522**

Modeling assumes sustainable policy is achievable, EnergyPLAN can simulate the system, and investments can minimize costs while ensuring reliability [2,3,6]. The analysis covers electricity, heat, and transport sectors, including CO_2 emissions and annual costs. Flexibility is provided via CHP, heat pumps, storage, and electric vehicles [16,17].

Input data include sectoral energy demands, installed and planned RES capacities, technical characteristics, costs, and projected imports/exports. The EnergyPLAN model structure is shown in Figure 1 [9].

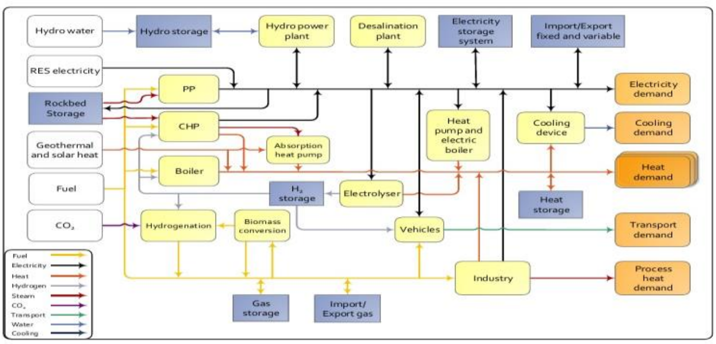

Figure 1. Principle of the EnergyPLAN model. (https://www.energyplan.eu), accessed June 25, 2025.

RESULTS

The EnergyPLAN model was employed to simulate Serbia's power system for the year 2023, generating a comprehensive assessment of its performance across key indicators (Table 2).

Table 2. Summary of EnergyPLAN simulation results for Serbia's power system in 2023.

Input energyplan_new.txt — The EnergyPLAN model 16.3

Electricity demand (TWh/year):		Flexible demand	0,00
Fixed demand	24,95	Fixed imp/exp.	0,70
Electric heating + HP	8,61	Transportation	0,00
Electric cooling	0,00	Total	34,26

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	6,23	2,98	0,09	9,30
Solar Thermal	0,00	0,00	0,00	0,00
Industrial CHP (CSHP)	0,00	0,00	0,00	0,00
Demand after solar and CSHP	6,23	2,98	0,09	9,30

Wind	0	MW	0,00	TWh/year	0,00	Grid
Photo Voltaic	0	MW	0	TWh/year	0,00	stabili-
Wave Power	0	MW	0	TWh/year	0,00	sation
River Hydro	270	MW	0,19	TWh/year	0,00	share
Hydro Power	2831	MW	9,24	TWh/year		
Geothermal/Nuclear	0	MW	0	TWh/year		

	Capacities MW-e	Capacities MJ/s	Efficiencies elec.	Efficiencies Ther	Efficiencies COP
Group 2:					
CHP	0	0	0,40	0,50	
Heat Pump	0	0			3,00
Boiler		0		0,90	
Group 3:					
CHP	0	0	0,40	0,50	
Heat Pump	0	0			3,00
Boiler		486		0,90	
Condensing	325		0,45		

Heatstorage: gr.2: 0 GWh gr.3 0 GWh
Fixed Boiler: gr.2: 0,0 Per cent gr.3: 0,0 Per cent

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0,00	0,00
Gr.2:	0,00	0,00
Gr.3:	0,00	0,00

Regulation Strategy	Technical regulation no. 1	
CEEP regulation	000000000	
Minimum Stabilisation share	0,00	
Stabilisation share of CHP	0,00	
Minimum CHP gr 3 load	0	MW
Minimum PP	0	MW
Heat Pump maximum share	1,00	
Maximum import/export	0	MW
Distr. Name :	Hour_nordpool.txt	
Addition factor	0,00	DKK/MWh
Multiplication factor	2,00	
Dependency factor	0,00	DKK/MWh pr. MW
Average Market Price	227	DKK/MWh
Gas Storage	0	GWh
Syngas capacity	0	MW
Biogas max to grid	0	MW

Fuel Price level: Basic

Elec. Storage	Capacities MW-e	Storage GWh	Efficiencies Elec.	Efficiencies Ther.
Charge 1:	0	0	0,80	
Discharge 1:	0		0,90	
Charge 2:	0	0	0,80	
Discharge 2:	0		0,90	
Electrolysers:	0	0	0,80	0,00
Rockbed Storage:	0	0	1,00	
CAES fuel ratio:		0,000		

(TWh/year)	Coal	Oil	Ngas	Biomass
Transport	0,00	23,91	0,06	0,00
Household	2,66	0,27	2,66	5,06
Industry	4,09	7,00	3,65	0,00
Various	0,00	0,00	0,00	0,00

Output

District Heating (MW):

	Demand: Distr. heating	Production: Solar	Waste CSHP	DHP	CHP	HP	ELT	Boiler	EH	Balance
January	1793	0	0	1202	0	0	0	17	0	574
February	1695	0	0	1136	0	0	0	16	0	543
March	1460	0	0	978	0	0	0	14	0	468
April	1091	0	0	731	0	0	0	11	0	350
May	715	0	0	479	0	0	0	7	0	229
June	523	0	0	350	0	0	0	5	0	168
July	425	0	0	284	0	0	0	4	0	136
August	440	0	0	295	0	0	0	4	0	141
September	620	0	0	415	0	0	0	6	0	199
October	964	0	0	646	0	0	0	9	0	309
November	1360	0	0	911	0	0	0	13	0	436
December	1643	0	0	1101	0	0	0	16	0	526
Average	1059	0	0	710	0	0	0	10	0	339
Maximum	1883	0	0	1262	0	0	0	18	0	603
Minimum	381	0	0	256	0	0	0	4	0	122
TWh/year	9,30	0,00	0,00	6,23	0,00	0,00	0,00	0,09	0,00	2,98

Electricity (MW):

	Consumption: Elec. demand	Flex.& Transp	HP	Elec-trolyser	EH	Hydro Pump	Production: Tur-bine	RES	Hy-dro	Geo-thermal	Waste CSHP	CHP	PP
January	2943	0	17	0	1643	0	0	2	1052	0	0	0	3629
February	2947	0	16	0	1552	0	0	9	1052	0	0	0	3534
March	2913	0	14	0	1338	0	0	13	1052	0	0	0	3280
April	2655	0	10	0	999	0	0	32	1052	0	0	0	2660
May	2747	0	7	0	655	0	0	36	1052	0	0	0	2401
June	2747	0	5	0	479	0	0	48	1052	0	0	0	2211
July	2528	0	4	0	389	0	0	38	1052	0	0	0	1910
August	2930	0	4	0	403	0	0	37	1052	0	0	0	2328
September	2932	0	6	0	568	0	0	23	1052	0	0	0	2510
October	2897	0	9	0	883	0	0	12	1052	0	0	0	2805
November	2988	0	13	0	1245	0	0	4	1052	0	0	0	3270
December	2862	0	16	0	1505	0	0	2	1052	0	0	0	3409
Average	[illegible]	0	10	0	970	0	0	21	1052	0	0	0	2827
Maximum	4349	0	18	0	1725	0	0	270	1052	0	0	0	4971
Minimum	[illegible]	0	4	0	349	0	0	0	1052	0	0	0	882
TWh/year	24,95	0,00	0,09	0,00	8,52	0,00	0,00	0,19	9,24	0,00	0,00	0,0[illegible]	24,83

Balance and Exchange:

	Stab-Load %	Imp MW	Exp MW	CEEP MW	EEP MW	Exchange Payment Imp (Million DKK)	Exp (Million DKK)
January	100	0	0	0	0	0	0
February	100	0	0	0	0	0	0
March	100	0	0	0	0	0	0
April	100	0	0	0	0	0	0
May	100	0	0	0	0	0	0
June	100	0	0	0	0	0	0
July	100	0	0	0	0	0	0
August	100	0	0	0	0	0	0
September	100	0	0	0	0	0	0
October	100	0	0	0	0	0	0
November	100	0	0	0	0	0	0
December	100	0	0	0	0	0	0
Average	100	0	0	0	0	Average price	
Maximum	100	0	0	0	0	(DKK/MWh)	
Minimum	100	0	0	0	0	-	-
TWh/year		0,00	0,00	0,00	0,00	0	0

FUEL BALANCE (TWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste/ HTL	CAES Elc.ly.	BioCon- version	Electro- Fuel	Wind	PV and Wind off CSP	Wave	Hydro	Solar.Th	Transp.	househ.	Industry Various	Total	Imp/Exp Corrected Imp/Exp	Net	CO2 emission (Mt): Total	Net
Coal	1,73	-	-	-	0,03	13,79	-	-	-	-	-	-	-	-	-	-	-	-	2,66	4,09	22,31	0,00	22,31	7,63	7,63
Oil	1,73	-	-	-	0,03	13,79	-	-	-	-	-	-	-	-	-	-	-	23,91	0,27	7,00	[illegible]	0,00	46,73	12,45	12,45
N.Gas	1,73	-	-	-	0,03	13,79	-	-	-	-	-	-	-	-	-	-	-	1,60	2,66	3,65	23,46	0,00	23,46	4,81	5,12
Biomass	1,73	-	-	-	0,03	13,79	-	-	-	-	-	-	-	-	-	-	-	-	5,06	-	20,61	0,00	20,61	0,00	0,00
Renewable	-	-	-	-	-	-	-	9,24	-	-	-	-	-	-	-	9,43	-	-	-	-	9,43	0,00	9,43	0,00	0,00
H2 etc.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Biofuel	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Nuclear/CCS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	[illegible]	0,00
Total	6,93	-	-	-	0,10	55,18	-	9,24	-	-	-	-	-	-	-	9,43	-	25,51	10,66	14,[illegible]	122,54	0,00	122,54	24,88	[illegible],20

14-jun-2024 [19:25]

Annual CO_2 emissions were 24.88 TWh/year, mainly from coal, while total primary energy consumption reached 122.54 TWh/year. Coal alone accounted for 22.31 TWh/year. Maximum utilized generation capacity was 4,349 MW, with thermal (mostly coal) plants producing 24.83 TWh/year.

Coal's dominance explains the high CO_2 emissions and energy use, highlighting environmental challenges. Despite adequate capacity for peak demand, integration of renewables is needed to improve sustainability.

Figure 1, Figure 2, and Figure 3 show the annual dynamics of electricity consumption and production, district heating, and fuel usage, respectively. These graphs provide visual insight into the system's seasonal behavior and the structure of energy use by source and sector.

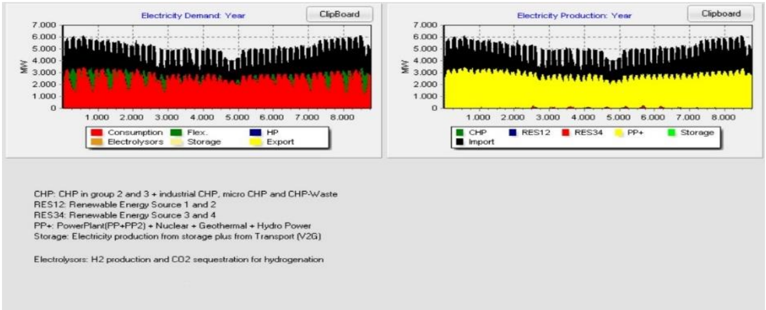

Figure 1 : Annual Electricity Demand and Production in Serbia (2023)

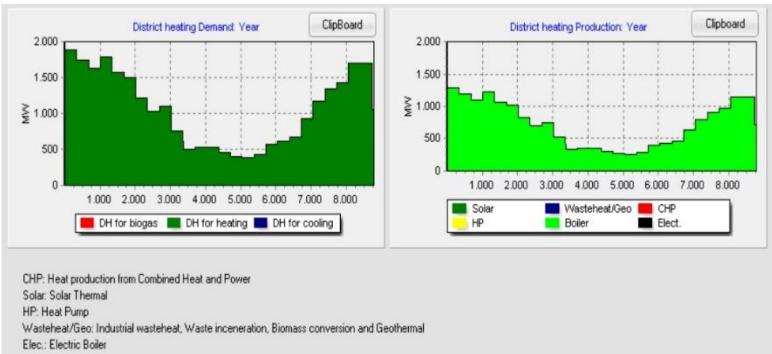

Figure 2. Annual District Heating Demand and Supply in Serbia (2023)

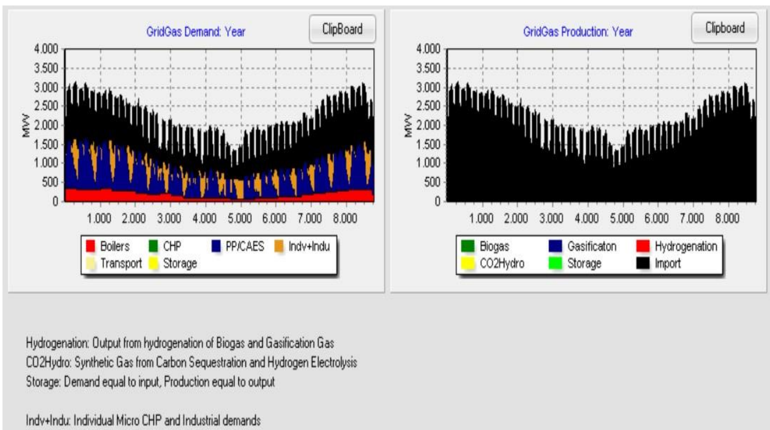

Figure 3. Fuel Consumption and Production Structure in Serbia (2023)

Analyzing sectoral energy demand trends shows a decreasing need for heating, mainly due to efficiency improvements and climate factors. In contrast, electricity demand is projected to rise significantly, driven by electrification of transport and heating sectors, highlighting electricity's growing role in Serbia's energy future. District heating systems continue to depend heavily on biomass and fossil fuel boilers, with limited adoption of advanced technologies such as CHP plants and solar thermal systems, indicating opportunities to increase renewable shares in heat supply. Fuel consumption patterns remain dominated by fossil fuels, while domestic renewable production is modest, emphasizing the need to expand renewable capacity and improve energy security through diversification and reduced import dependence.

DISCUSION

Two energy development scenarios for Serbia in 2030 were analyzed: the Baseline Scenario, based on projected balances for 2023 and 2030 [18], and the Flexible Scenario, which adds 10 TWh of renewable energy and efficiency measures aligned with EU climate goals [1,6]. In the Flexible Scenario, total primary energy demand falls from 122.54 TWh to 103.5 TWh, saving around 19 TWh across residential, heating, transport, and industrial sectors [38], contributing directly to decarbonization and sustainability targets [19,6,16].

In electricity generation, renewables could reach ~60% by 2030, led by hydropower (12.20 TWh), wind (3.95 TWh), and solar PV (2.85 TWh), while coal's share drops to ~35%, reducing both greenhouse gas emissions and fossil fuel dependence [20,21].

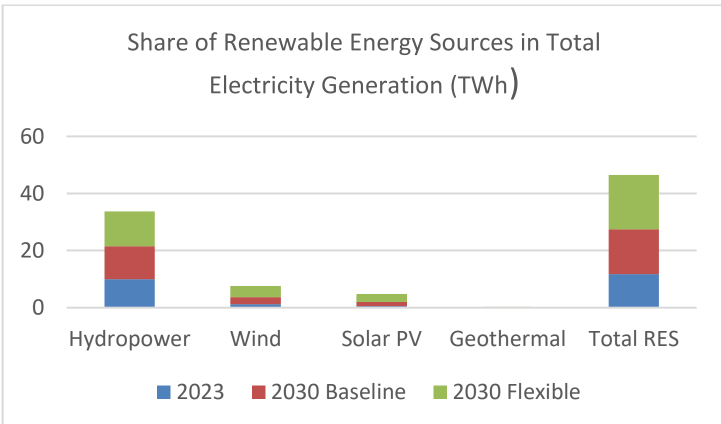

Figure 4. Share of Renewable Energy Sources in Total Electricity Generation

The chart shows the growth of hydropower, wind, solar, and geothermal shares from 2023 to 2030. A substantial increase in wind and solar generation is observed in the Flexible Scenario compared to the Baseline Scenario.

EnergyPLAN simulations confirm that increased RES deployment and efficiency measures significantly lower CO_2 emissions and fossil fuel reliance. However, the Flexible Scenario also highlights the necessity for grid modernization and enhanced system flexibility.

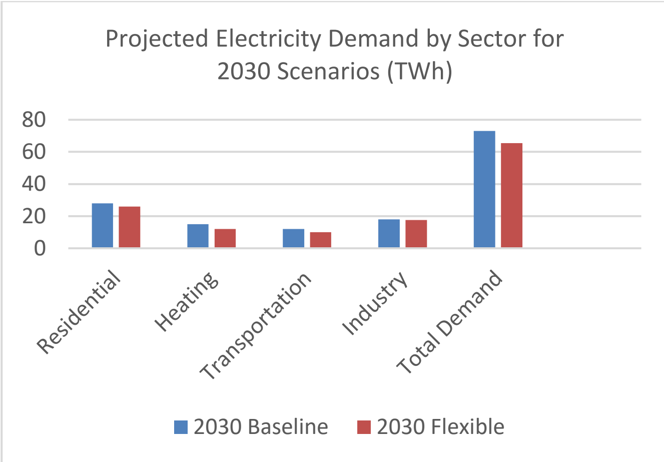

Figure 5. Electricity Demand for Different Scenarios

This figure illustrates projected electricity demand under the Baseline and Flexible Scenarios. The rise in demand is mainly due to electrification of heating and transport, with efficiency measures helping to moderate overall consumption in the Flexible Scenario.

Electrification of transport and heating, together with renewable integration, forms a cornerstone of a sustainable Serbian energy system. Seasonal demand variations and technological variability are considered to ensure alignment with EU climate and energy targets.

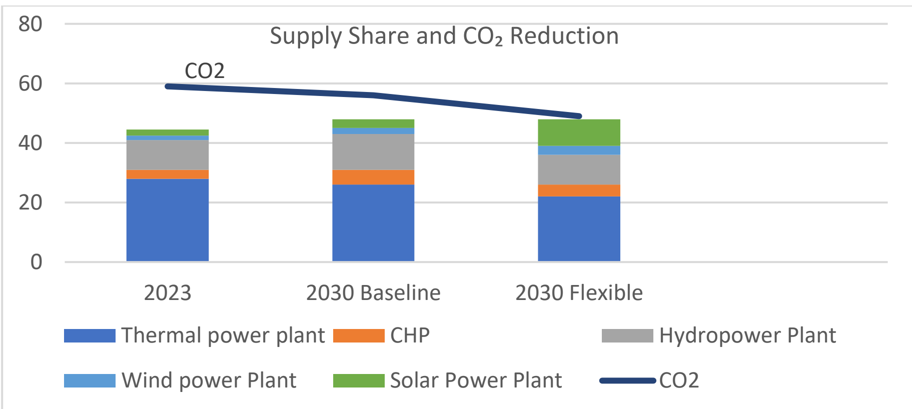

Figure 6. Supply Share and CO_2 Reduction for Different Scenarios

The chart demonstrates the reduction of coal usage and the increase in biomass and other renewables in the Flexible Scenario. Corresponding CO_2 emissions decrease significantly, emphasizing the environmental benefits of the energy transition.

Primary energy consumption patterns show a marked shift: coal dominates in the Baseline Scenario, whereas biomass and other renewables gain a larger share in the Flexible Scenario.

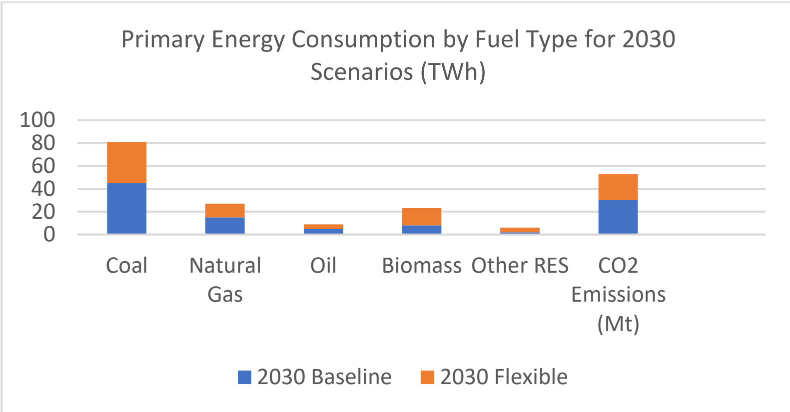

Figure 7. Primary Energy Consumption

This figure highlights Serbia's changing primary energy mix, comparing the Baseline and Flexible Scenarios. The Flexible Scenario shows a clear movement toward a more sustainable energy portfolio with increased contributions from renewable sources

CONCLUSION

This study used the EnergyPLAN tool to analyze Serbia's energy system and project two scenarios for 2030, showing that increased renewables and energy efficiency can significantly cut primary energy use (~19 TWh) and CO_2 emissions, supporting EU-aligned decarbonization goals. EnergyPLAN proved effective for assessing technological options, stability, and costs, aiding strategic planning. Ambitious renewable deployment and targeted efficiency measures can realistically reduce fossil fuel reliance and environmental impacts, fostering a sustainable and resilient energy future.

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Industry 4.0 Technologies and Sustainable Development of Domestic Enterprises

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Abstract. This paper explores the possibilities and challenges of implementing Industry 4.0 technologies in domestic companies in order to promote sustainable development. The paper is a theoretical research based on the analysis of relevant literature. The results show that the implementation of Industry 4.0 technologies can increase efficiency, reduce resource consumption and improve the competitiveness of the domestic economy. The paper proposes guidelines for gradual digital transformation, development of human resources, application of green technologies and strengthening of institutional support. It is concluded that the synergy of Industry 4.0 and the principles of sustainable development represent a realistic path towards the modernization of domestic companies and achieving a competitive advantage in the conditions of an economy in transition.

Keywords: Industry 4.0, sustainable development, domestic enterprises, transition economy

INTRODUCTION

Industry 4.0 represents the fourth industrial revolution, which combines modern digital technologies such as the Internet of Things, artificial intelligence, robotics and big data analysis with industrial processes [1]. This development of technology enables smarter production, better use of resources and greater efficiency. The benefits of the implementation of Industry 4.0 are the reduction of costs of production, products, services and transportation, and just some of the possibilities that Industry 4.0 brings are automation and efficiency, maintenance and environmental responsibility and increasing the competitiveness of companies [2].

On the other hand, sustainable development is a concept that meets the needs of the present without compromising the ability of future generations to meet their needs [3]. The application of sustainable development in all spheres of life, including business, contributes to reducing divergence in society, improving biodiversity and quality of life, as well as reducing the amount of pollution. The application of the principles of sustainable development in business is reflected in the achievement of energy efficiency of the company, the implementation of green technologies, the use of alternative energy sources, as well as corporate social responsibility [4].

The domestic market implies the market characteristics of an economy in transition, and it can be said that in domestic companies there is still not a strong enough interest in the development and application of complete digitization of business processes [5]. Orientation to Industry 4.0 technologies can provide a chance for the development of productivity and competitiveness of domestic companies, and the development of digitized companies would imply the encouragement of digitization, promotional activities, dedicated funds for the implementation and creation of a legal environment by state authorities [6]. Thus, this industrial revolution can bring smart enterprises that will reduce poverty and improve living standards, sustainable energy sources, environmental protection, social cooperation and a healthier population [7].

By reviewing and analyzing existing studies and theoretical foundations, this paper aims to emphasize the importance of business improvement in accordance with the principles of sustainable development, as well as to provide guidelines and recommendations for domestic companies that recognize the importance of this concept.

METHODOLOGY

The problem and the subject of research

Despite global trends towards digitization and sustainable development, a large number of domestic companies still do not show readiness to implement Industry 4.0 technologies and use outdated and inefficient business practices. Such a situation results in limited productivity, weaker competitiveness on the international market and slower adoption of sustainable development principles. Therefore, the research problem represents the need to investigate how Industry 4.0 technologies can improve the sustainable development of domestic enterprises, what obstacles exist in that process and what measures contribute to overcoming them.

The subject of the research includes examining the potential of the implementation of Industry 4.0 technologies in domestic companies in order to improve sustainable development. The focus is on analyzing how digital technologies can contribute to energy efficiency, environmental responsibility, resource optimization and increasing the competitiveness of the domestic economy.

Research goal

The goal of the research is to identify the opportunities and challenges of implementing Industry 4.0 technologies in domestic companies, as well as to determine how their application can contribute to the improvement of sustainable development.

Research question

Based on analyzed theories, we will try to answer the following question:

How can the application of Industry 4.0 technologies contribute to the improvement of the sustainable development of domestic companies in the conditions of an economy in transition?

Research method

This work represents a form of theoretical research, which includes a review and analysis of relevant literature and research in the field of Industry 4.0 and sustainable development. The paper reviews the existing results in order to reach universal conclusions and guidelines for application in the domestic economy.

RESULTS AND DISCUSSION

The literature indicates that the implementation of Industry 4.0 technologies can significantly contribute to the improvement of sustainable development through synergistic action on the economic, environmental and social aspects of business. The effects of doing business in accordance with Industry 4.0 technologies are automation and efficiency, as a result of which companies can increase productivity and reduce operating costs. Such improvement is reflected in the optimization of production processes, the reduction of energy and resource consumption and the increase of the company's flexibility, and these effects confirm the potential of Industry 4.0 as a driver of sustainable business models [8, 9].

By using modern monitoring tools, businesses can monitor and better manage resource consumption, thereby reducing the negative impact on the environment, which contributes to sustainability and environmental responsibility. Also, digital development allows companies to quickly react to market changes and to adapt to demands in an innovative way, thus improving the competitiveness of the domestic economy [10].

Companies with adopted digital technologies in combination with green practices record a long-term reduction in operating costs and greater market competitiveness, which is especially important to emphasize in the context of domestic companies, where costs and efficiency are key factors for market survival. The application of digital technologies contributes not only to economic sustainability, but also to the social responsibility of companies through business transparency and reducing the environmental footprint [11].

When it comes to the barriers and challenges of the digital transformation of domestic companies, one of the challenges is represented by financial limitations. Namely, domestic companies often have a problem with the lack of financial resources for investing in advanced technologies, and the lack of professional staff for the use of modern technologies represents a separate challenge in this process. Resistance to change represents a significant barrier when it comes to human resources as the carriers of sustainable development. The way of thinking and working habits within the company can slow down the complete digitization of business, especially when employees are not clear about the advantages that digitization brings. Also, the lack of experts in data analytics, management of automated systems and development of artificial intelligence is a limiting factor for rapid digital transformation. For domestic conditions, it emphasizes the need for systemic investments in education and retraining of the workforce. The mentioned challenges are an indicator of the need for synergistic action of all levels of the company in the transition to a digitalized and sustainable way of doing business [5, 12].

To overcome these challenges in an economy in transition, institutional support is important, which includes the creation of a favorable regulatory framework, tax incentives and financial incentives for digitization and green innovation. The state can play a key role in encouraging digital transformation through various programs and subsidies, and company management must recognize the importance of these changes and their implementation [13]. This includes strategic planning, employee training and developing a work environment that encourages innovation and sustainability.

The successful implementation of Industry 4.0 and sustainable development in domestic enterprises requires a coordinated approach that includes technological modernization, development of human resources through education and retraining, institutional support and a focus on sustainable practices that link economic profit with the reduction of negative impact on the environment [11, 14]. Therefore, the company's operations can be improved so that it functions socially responsibly and in accordance with the principles of integrated management systems, as well as striving to meet as many sustainable development goals as possible, such as investment in innovation and infrastructure, economic growth and quality education.

GUIDELINES AND RECOMMENDATIONS

Based on the previous analysis of the implementation of Industry 4.0 technologies in the context of sustainable development, the following guidelines and recommendations for domestic companies were defined:

- The introduction of Industry 4.0 technologies should be implemented in stages, starting with those that bring quick and measurable benefits, which will create the foundation for further automation and digitization. Businesses should develop a clear transformation plan with defined goals and timelines. This approach will reduce risks and enable easier adaptation of employees.
- Investing in continuous training of employees to work with new technologies is necessary due to the creation of competent staff that meets the modern needs of the economy.
- In parallel with digitization, it is necessary to adopt green technologies, use renewable energy sources and apply measures to reduce waste and harmful gas emissions, which will contribute to the transparency of the company, better communication with the environment and improvement of the company's overall image.
- Active monitoring and use of support programs, subsidies and tax incentives for digitization and green projects can significantly accelerate the transformation, and it is recommended to establish cooperation with domestic and international partners for networking and knowledge exchange, in accordance with trends and innovations.

CONCLUSION

This paper confirms that the application of Industry 4.0 technologies can contribute to the improvement of the sustainable development of domestic companies in the conditions of an economy in transition. By integrating digital solutions, such as automation, Internet of Things, data analytics and artificial intelligence, businesses can achieve higher levels of efficiency, reduce resource consumption, improve environmental responsibility and increase market competitiveness. The paper indicates that such changes are achievable with gradual digital transformation, strategic planning and continuous strengthening of employees' competencies. Although significant obstacles were identified, such as limited financial resources, lack of professional staff and resistance to change, it was shown that they can be overcome through the coordinated action of companies, state institutions and the education system. This confirmed that the synergy of Industry 4.0 and the principles of sustainable development represents a realistic path towards the modernization of the domestic economy and the improvement of its overall performance. The application of Industry 4.0 technologies, with adequate institutional and organizational support, can become a driver of sustainable development of domestic companies, through strengthening their competitive position and contribution to socially responsible business, thus providing an answer to the defined research question (RQ:1).

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Radiotracers in Industrial and Environmental Processes

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Abstract. Radiotracers represent irreplaceable tools in modern science and industry, enabling precise monitoring of physical, chemical, and biological processes without disrupting operational conditions. This review analyzes the types and applications of radiotracers, including the classification into intrinsic and extrinsic tracers based on their chemical identity relative to the target substance, as well as the criteria for their selection (half-life, radiation energy, system compatibility, and detection methods). Special emphasis is placed on tracers derived from radionuclide generators ($^{99}Mo/^{99m}Tc$, $^{113}Sn/^{113m}In$, $^{68}Ge/^{68}Ga$), which provide short-lived isotopes with suitable radiological and chemical characteristics for a wide range of engineering and environmental applications. Labeling methods for solid, liquid, and gaseous phases are described, including both surface and volume tagging techniques. Industrial applications are illustrated through specific case studies involving flotation circuit optimization, reservoir diagnostics, particle segregation monitoring, and efficiency assessment of wastewater treatment facilities. Radiotracers enable the determination of residence time, leakage detection, flow modeling, and CFD validation, while offering high sensitivity, non-invasiveness, and cost-effectiveness. This review highlights the key advantages of radiotracer techniques and confirms their irreplaceable role in diagnostics, optimization, and improvement of complex industrial processes.

Keywords: radiotracers, radionuclide generators, CFD validation, leakage detection, process optimization

INTRODUCTION

Radioactive tracers found their first industrial application in the middle of the last century, and since then their use has been steadily growing. Today, techniques based on radiotracers are widely used in industry around the world, primarily for diagnostics, troubleshooting and optimization of complex technological processes [1]. Within the framework of the International Atomic Energy Agency (IAEA), almost fifty developing countries have formed expert groups dealing with the application of radiotracers. The main goal of modern radiotracer application methodology is to provide practical, experience-based guidelines that include all phases of the research process. When designing research, one of the first and most important steps is the choice of a suitable tracer. Key criteria include its complete compatibility with the medium being monitored, as well as representative behavior in relation to the movement and transformations of that medium.

The methodology includes the application of the most commonly used radioisotopes for monitoring solid materials, aqueous solutions, organic liquids and gaseous phases, along with a detailed description of the system for injecting, detecting and measuring radiation. Special attention is paid to the influence of the experimental design, type and energy of radiation, as well as the characteristics of the detector, on the quality and reliability of the collected data. The raw data is processed and analyzed in order to determine the residence time distribution (RTD). The practical value of radiotracers is illustrated by numerous case studies, which confirm that radiotracer techniques represent an extremely powerful and irreplaceable tool for understanding, optimizing and improving complex industrial and environmental processes [1-5]. In addition to experimental techniques, modern software tools for data processing and interpretation play an important role, including simulation packages based on Monte Carlo methods, which enable dose estimation, optimization of experiments and detailed analysis of flows within complex industrial systems. In planning and conducting radiotracer experiments, the correct interpretation of the results depends on a comprehensive knowledge of the tested system, process and potential measurement limitations [5]. The flow of matter in systems can be described at different levels of complexity – from the molecular approach, as used by lattice gas simulations, to macroscopic models based on the Navier–Stokes equations. For many engineering applications, a global approach based on the concept of residence time distribution (RTD), developed by Dankverts, Levenspil and other authors [6, 7] is sufficient. RTD describes the age distribution of particles leaving the system. Under the assumption of linearity of the system, the RTD makes it possible to predict the response to any excitation [5].

Security

Radiotracers emit ionizing radiation, which can pose a health risk, so the application of appropriate radiation protection measures is mandatory in all phases of work. The international basic safety standards for protection against ionizing radiation and safety of radiation sources (BSS) [8], developed by FAO, IAEA, ILO, OECD/NEA, PAHO and WHO, are based on the findings of UNSCEAR and recommendations of ICRP, and their goal is to enable the safe use of radiation sources while maximizing benefits and avoiding disproportionate protection costs. Working with radiation sources is considered a practice that must meet the requirements defined in the publication Safety Fundamentals [9] and BSS [8], with additional guidelines from Safety Guides [10] and Safety Reports [6]. The key principles of protection include justification of application (acceptable benefit in relation to risk), limiting doses for public and professional exposure in accordance with BSS [8], and optimization of protection according to the ALARA principle, whereby doses, number of exposed and probability of exposure are maintained at the lowest reasonably achievable level.

CHARACTERISTICS OF THE RADIOTRACER

The choice of an appropriate radiotracer is a key step in planning a tracer experiment, as it must faithfully follow the flow of the material being tested. In the ideal case, the tracer should be chemically identical to the monitored substance, which enables complete representativeness of the measurement.

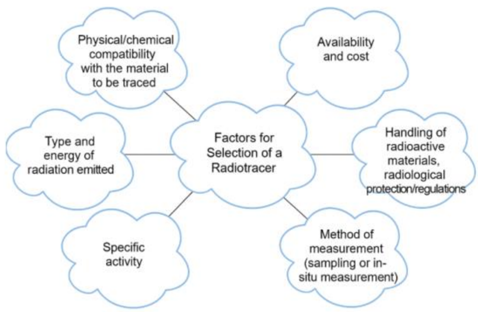

Figure 1. Important factors in the selection of radio tracers

Intrinsic (chemical/internal) tracers are used, for example, in the study of chemical reactions, kinetics, solubility, vapor pressure, and processes dominated by atomic or molecular diffusion. Examples include H_3HO (HTO) for water, $^{24}NaOH$ for sodium hydroxide, and $^{14}CO_2$ for carbon dioxide. Intrinsic (chemical) tracers contain the isotope (radioactive or stable) of a natural element from the molecules of the monitored medium, which enables precise detection by nuclear or conventional methods. They faithfully reproduce the dynamic behavior of materials because they are monitored at the molecular level [4, 11]. However, the application of intrinsic tracers is not always possible, especially when the corresponding gamma-emitting isotopes do not have a long enough half-life or beta isotopes are used, which limits the possibility of measuring through the walls of the system [5].

When chemical identity is not necessary or when an intrinsic tracer is not available, **extrinsic (physical/external) radiotracers** are used. They must meet the basic physical and physico-chemical conditions — to be miscible with the monitored substance, not to be adsorbed on the walls of the system and not to pass into another phase. They have similar dynamic characteristics and mass flow as the investigated medium, but are not incorporated into its molecular structure. In most practical applications, physical radiotracers are more often used than chemical radiotracers, and the choice of isotope depends on factors such as operational safety, waste disposal method, availability and cost.

Radioisotope generators

A radionuclide generator is a chemical, physical or mechanical system based on a nuclear "mother-daughter" bond, which enables the separation (elution) of a short-lived daughter from a longer-lived, stationary mother. In the most common constructions, the parent radionuclide, produced in a nuclear reactor or cyclotron, is adsorbed on a carrier (eg ion exchange resin) in a small format column. The short-lived daughter radionuclide is then eluted with a suitable solvent (eluent).

The extracted daughter radionuclide can sometimes be directly applicable as a radiotracer, as is the case with ^{99m}Tc in the form of pertechnetate ($^{99m}TcO_{4^-}$) for tracing water flow under certain conditions. In other cases, chemical labeling is necessary.

Radioisotope generators are key sources of short-lived radionuclides. They are especially important in countries without nuclear reactors. The most commonly used are Mo/^{99m}Tc, Sn/^{113m}In and Cs/^{137m}Ba, each having specific advantages in terms of half-life, gamma radiation energy, availability and cost as can be seen in Table 1. Their use enables the realization of a wide range of experiments in the liquid and solid phase without the need for large facilities for the production of isotopes [4].

Table 1. Characteristics and application of radioisotope generators

Type of radioisotope generator	Half-life of radiotracers	Energy of γ-radiation	Price/availability	Benefits	Restrictions	Typical applications
Mo/^{99m}Tc	Short	Low	Low cost, universally available	Economical, widely applied (~20% of tracer studies)	Not effective for thick-walled vessels	General liquid and solid phase tracer studies
Sn/^{113m}In	Longer than Mo/^{99m}Tc	Higher than Mo/^{99m}Tc	Limited number of suppliers, 2–3 times more expensive than Mo/^{99m}Tc	Suitable for testing through thick walls.	Expensive and limited availabilit	Measurements in vessels with relatively thick walls
Cs/^{137m}Ba	Very short (radiotracer) / long generator lifetime (years)	High	It is no longer commercially available, ^{137}Cs available for custom creation	Excellent for routine field measurements, easy detection, no problems with disposal of radioactive waste	Required production in a laboratory with professional staff	Liquid flow measurement, flow meter calibration

INDUSTRY EXAMPLES

In one industrial case study, the irregular distribution of the fluid in the packed bed column of the vacuum tower was analyzed. Such columns, although efficient, are sensitive to pressure changes, and poor liquid or gas distribution can significantly reduce performance. The standard gamma-scan method provides insight into mechanical integrity, but has limited sensitivity and may miss significant distribution problems. The radiotracer RTD technique enabled more precise detection and quantification of the distribution for both phases. The experiment was performed by injecting compatible liquid and gaseous tracers, whereby the detectors were placed in two horizontal rings of four, evenly distributed around the layer. Signal analysis showed a preferential flow of liquid towards the southern quadrant, which was not detectable by gamma-scanning. This example illustrates that the combination of gamma-scan and RTD radiotracer gives a more complete diagnostic picture, identifies both mechanical and hydrodynamic irregularities, and enables targeted measures to optimize column operation.

In the gold beneficiation plant, RTD analysis was applied to diagnose the key reservoirs of the leaching process. Experimental RTD curves showed the occurrence of by-pass and the existence of dead zones, where in tank 1 the dead zones amounted to about 13%, and in tanks 7 and 8 between 27–30% of the volume. The surface flow, more pronounced in tank 1, allowed part of the pulp to pass directly from the inlet to the outlet without adequate mixing, which negatively affects the efficiency of gold extraction. The obtained results indicated the need for modification of the tank construction in order to improve mixing in the entire working volume. It was recommended to extend the mixers towards the bottom, to increase the diameter and depth of the pipe for guiding the flow, as well as to install partitions between the inlet and outlet in order to reduce the by-pass flow.

As part of the copper flotation optimization study, a comparative RTD analysis of three industrial flotation cells (DO – 148 m^3, WE – 160 m^3 and TK – 160 m^3) was carried out to evaluate their hydrodynamic efficiency and identify stagnation zones. The tests included the liquid and solid phase, whereby Na-24 was used to monitor the flow of the solid phase, and Br-82 was used for the liquid phase, which made it possible to obtain experimental RTD curves in real time. The results showed significant differences between the effective and theoretical mean retention times (MRT), where stagnant volumes of 45% were observed in TK, 35% in DO and only 7% in WE cell.

Wastewater treatment plants are complex systems of multiphase flows, in which the removal of solid and dissolved pollutants is achieved through a series of successive processes - from mechanical pretreatment and primary sedimentation, through biological aeration and secondary sedimentation, to anaerobic digestion of sludge. The efficiency of these processes is highly dependent on the hydrodynamic behavior of the fluid, with disturbances such as short circuits and inadequate settling directly affecting the quality of the output water. The use of radiotracers enables detailed diagnostics and optimization of plant operation, because by choosing the appropriate isotopes, the movement of the solid, liquid and gas phases can be monitored simultaneously, while in anaerobic digesters and sediment transport they are often the only possible test method. The results obtained by this method allow engineers to make reliable decisions about changing the configuration or operation mode in order to achieve optimal plant performance [5].

CONCLUSION

Radiotracer techniques, developed and perfected over more than half a century, today represent a unique and irreplaceable tool in the diagnosis, optimization and improvement of complex industrial and environmental processes. Their ability to enable precise, non-invasive and economically viable monitoring of physical, chemical and biological flows – often without system interruption – ranks them among the most valuable methods of process analysis. The review presented in this paper confirms that with the correct selection of radiotracers, optimization of marking methods and adequate application of the retention time distribution (RTD) theory, it is possible to reliably identify hydrodynamic irregularities, quantify process efficiency and verify mathematical and cfd models. The role of radionuclide generators is particularly significant in providing short-lived isotopes suitable for a wide range of applications, which enables the realization of experiments in countries without their own infrastructure for the production of radionuclides. The combination of modern detection equipment, advanced data processing and interdisciplinary approach makes the radiotracer methodology still one of the most powerful techniques available to engineers and researchers, with great potential for further development and expansion of application in the future.

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Overview of Air Pollution Monitoring Software Tools

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Abstract. Air pollution is one of the most important global problems that can contribute to serious consequences for life and the environment. The main sources of gas emissions are industry, transport and the energy sector, whereby elevated concentrations of these gases can seriously threaten human health and the environment. In order to accurately monitor and reduce pollution, many software tools have been developed for air quality modeling, simulation and analysis. This research paper provides an overview for software solutions such as HeBIS, CMAQ and GEOS-Chem that enable the evaluation of gases, assessment of health effects, as well as cost optimization of measures. Special importance is placed on the integration of databases and GIS technology, which contributes to effective decision-making in the field of environmental protection. The analysis of these available tools represents an important step towards sustainable development and improvement of the daily quality of human life.

Keywords: air pollution, software tools, monitoring, health impact, decision support

INTRODUCTION

Pollution of the environment and its elements: air, water and soil is different throughout the ages of mankind. According to the degree of degradation in the development of human civilization, there are three eras: the agricultural one that lasts until 1850, the industrial one until 1950, and the technical-technological one that includes the second half of the 20th century and lasts until today. In the first epoch, the degradation was minimal - negligible, and with the increase in population and increasing human activity in nature, the degree of degradation of natural ecosystems and the environment as a whole increase. Later, the intensive development of industry and production for the sake of profit, the use of fossil fuels as energy sources leads to the endangering of the environment on a larger scale, so that the question of the survival of life on planet Earth [1] is raised. In international law and the internal rights of states, environmental law, as a relatively young branch of law, represents a significant factor in developing people's awareness of the importance of this problem and the responsibility of each individual in the process of overcoming it [2].

CAUSES OF AIR POLLUTION

In urban areas, for example in Europe, more than 70% of the population lives in cities, where traffic and industry contribute to increased concentrations of pollutants. The release of pollution can have a negative impact on the population itself (health risks, accelerated deterioration of buildings and houses, collapse of historical monuments and sites and damage to vegetation in and around cities) [3,4]. Air pollution is the presence of various substances and gases in the air, which pose a health risk. Air pollutants are nitrogen oxides, sulfur dioxide, carbon dioxide, particulate matter, volatile organic substances and toxic substances, such as mercury. The combination of nitrogen oxides and volatile organic compounds in the air, in the presence of ozone, is the main component of smog. Some air pollutants cause ecosystem changes, such as acid rain and climate change. According to the forecast of climatologists, if the concentration of carbon dioxide continues to increase, the planet will become warmer, which will affect human health and the natural environment. Climate change is accelerating, and our planet is constantly warming. Residents of the Northern Hemisphere saw off the warmest winter in the last 125 years, since the weather has been regularly recorded. One of the main causes of global warming is accelerated industrial development, which has brought with it significantly increased emissions of so-called greenhouse gases. According to data from 2000, the largest producers of carbon dioxide emissions are the USA 20.6%, China 14.80%, Russia 5.7%, India 5.5% and Japan 4%. In Europe, the emission of this gas is about 11% of the total world emission [5]. Air pollutants can be classified according to their origin, chemical composition, size and method of release into closed or open spaces. Pollutants that are emitted directly into the atmosphere are called primary pollutants, while those that are formed as a result of chemical reactions with other pollutants or gases in the atmosphere are called secondary pollutants. This difference is important from the point of view of reducing pollution. Although there is a direct relationship between the emission of primary pollutants and their concentrations in the environment, the reduction of precursors does not automatically lead to a proportional reduction in the level of secondary pollutants. In fact, the level of ozone in the ambient air may paradoxically increase if the emission of nitrogen oxides is reduced. Figure 1 shows an overview of primary and secondary pollutants [6].

Classification of air pollutants

A. Primary-secondary pollutants
(i) Primary: pollutants emitted directly into the atmosphere (eg, SO_2, some NO_x species, CO, PM)
(ii) Secondary: pollutants that form in the air as a result of chemical reactions with other pollutants and gases (eg, ozone, NO_x, and some particulates)
B. Indoor-outdoor pollutants
(i) Indoor pollutants
(a) Sources: cooking and combustion, particle resuspension, building materials, air conditioning, consumer products, smoking, heating, biologic agents
(b) Products: Combustion products (eg, tobacco and wood smoke), CO, CO_2, SVOC (eg, aldehydes, alcohols, alkanes, and ketones), microbial agents and organic dusts, radon, manmade vitreous fibers
(ii) Outdoor pollutants
(a) Sources: industrial, commercial, mobile, urban, regional, agricultural, natural
(b) Products: SO_2, ozone, NO_x, CO, PM, SVOC
C. Gaseous-particulate pollutants
(i) Gaseous: SO_2, NO_x, ozone, CO, SVOC (eg, PAH, dioxins, benzene, aldehydes, 1,3-butadiene)
(ii) Particulate: coarse PM (2.5-10 μm; regulatory standard = PM_{10}), fine PM (0.1-2.5 μm; regulatory standard = $PM_{2.5}$); ultrafine PM (<0.1 μm; not regulated)

NOx, Nitrogen oxides; SVOC, specific volatile organic compounds.

Figure 1. Overview of primary and secondary pollutants

THE INFLUENCE OF THE AUTOMOBILE INDUSTRY ON AIR POLLUTION

Air pollution originates from various sources, among which the burning of fossil fuel products is the main source. Energy sources that rely on fossil fuels are major polluters of the environment and cannot ensure a sustainable future. From the perspective of sustainability, renewable energy sources such as wind and water represent good alternatives to solve this problem. Electric vehicles have been one of the most discussed topics in recent years. In addition to the use of these vehicles enabling sustainable energy consumption, supplying these vehicles with energy from renewable sources represents a "Yin-Yang" figure. Otherwise, the dream of a clean environment, energy sustainability and low carbon emissions cannot be realized. According to a report by the European Environment Agency (EEA), road traffic accounts for approximately 72% of emissions in the transport sector, with passenger vehicles accounting for over 60% of carbon dioxide emissions from the said sector [4,6,7]. Emissions come not only from traffic, but also from production and logistics processes in the automotive industry (for example: transport of components from supplier to factory, storage, delivery to the production line, reverse logistics, etc.). Today, factories are often equipped with numerous devices (such as processing robots, welding, etc.) and machines that do much of the work themselves. However, the sophistication of that equipment leads to higher energy consumption, and therefore to increased electricity consumption and increased air pollution[4,8]. Diesel engines as sources of nitrogen monoxide, nitrogen dioxide and PM2.5 particles are increasingly the cause of respiratory and cardiovascular diseases. In 2014, the European Union (EU) adopted the "Euro 6" standard, which aims to limit emissions of nitrogen oxides from diesel vehicles. Research shows that emissions from vehicles often exceed prescribed limit values, especially in older vehicles with poorly maintained exhaust gas systems[4,9,10]. When it comes to the automotive industry, a software tool that can be used within an air pollution monitoring and control system is SCADA (Supervisory Control and Data Acquisition).

NEGATIVE ASPECTS OF AIR POLLUTION ON HUMAN HEALTH

Exposure to outdoor air pollution is associated with a large number of acute and chronic health conditions, from irritations to death. While the impact on respiratory and cardiovascular diseases is well documented, new science shows that air pollution is also emerging as a risk factor for children's health and even diabetes. Sensitive and vulnerable groups are especially affected, such as pregnant women, children, the elderly and people who are already suffering from respiratory and other serious diseases or people from low-income groups. When it comes to diseases of the respiratory system, they include increased respiratory symptoms, infections, increased airway reactivity, irritation, pneumonia, increased respiratory mortality and hospital visits, hospitalization, decreased lung function, worsening of asthma, worsening of chronic obstructive pulmonary disease, increased risk of lung cancer. Research has shown that lung function growth in children is reduced in areas with high concentrations of suspended particles; this function improves when children are moved to areas with less air pollution or worsens when children are moved to areas with more air pollution. When it comes to diseases of the nervous and cerebrovascular system, these include neurodevelopmental disorders, inflammation of nerve tissue, oxidative stress, changes in the blood-brain barrier, headache, anxiety, stroke, Alzheimer's disease, Parkinson's disease [11]. Long-term exposure to elevated levels of suspended ultra-fine particles (UFPs), PM (particle pollution) and lipopolysaccharides (LPS) can lead to the direct transfer of these pollutants to the central nervous system (CNS), where they can cause neuropathological changes through various pathways and mechanisms. Alternatively, air pollutants may not enter the CNS directly but may have an adverse effect on the CNS by triggering the release of soluble inflammatory mediators from primary entry organs or secondary sites of deposition. The release of inflammatory agents may then lead to or affect susceptibility to neuroinflammation and neurodegeneration in the CNS. Figure 2 shows the impact of air pollution on the brain through different mechanisms [12].

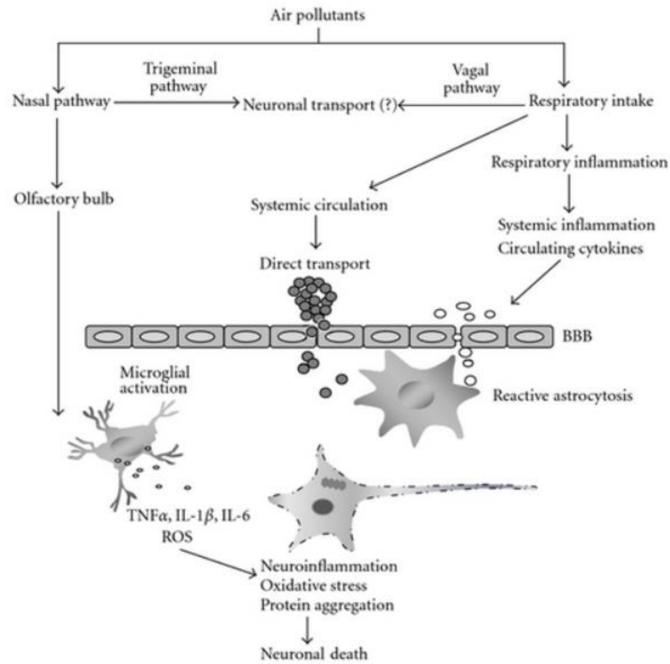

Figure 2. Impact of air pollution on the brain through different mechanisms

When it comes to the cardiovascular system, the most common diseases can occur altered cardiac autonomic function, myocardial infarction, angina pectoris, increased blood pressure, arteriosclerosis, increased cerebrovascular ischemia, etc. [11].

OVERVIEW OF SOFTWARE TOOLS IN THE FIGHT AGAINST AIR POLLUTION

Air pollution is one of the most serious global problems, especially in low- and middle-income countries. Due to large emissions from industry, transport and the energy sector, system solutions for monitoring, analyzing and controlling pollution are necessary. In this context, an increasingly important role is played by software tools for air quality management, which enable: Modeling and simulation of the spread of pollution (based on meteorological and emission data), Assessment of the impact of pollution on health and the economy, Planning of measures to reduce emissions based on scientific and technological analyses, Management of large data sets and implementation of cost-benefit analyses. The goal of such solutions is to enable precise quantification of the benefits of reducing emissions - both in terms of population health and economic benefits, including the optimization of emission control costs [13].

HeBIS

The HeBIS implementation method includes three steps: (1) establishing relevant databases; (2) selecting health and economic impact computing models; (3) analyzing and evaluating the results received. To perform step (1), the necessary main data groups must be prepared, including data on changes in PM2.5 concentrations, health data sets and data sets on exposed population size in the study area. The modules integrated into HeBIS perform different functions. First, the SACA (Surface Air Quality Control Benefit Analysis) module calculates the change in surface air PM2.5 quality due to changes in emission load contributions from local sources when implementing the Clean Air Program (CAP). The algorithm base in SACA calculates the quality benefit of PM2.5 concentration achieved due to the change in contributed emission load. The module calculates and allows visualization of the improvement in surface air quality under changes in emission loads controlled using GIS technology. Programming methods are applied to integrate mathematical models, databases and surface air quality control benefit maps. The module calculates and allows visualization of the improvement in surface air quality under changes in emission loads controlled using GIS technology. Programming methods are applied to integrate mathematical models, databases and surface air quality control benefit maps. The CEFA (Cost-Effective Analysis) module calculates control costs to minimize emissions. International Cost Estimate Tool (ICET) is computerized to calculate the corresponding PM2.5 precursor emission reductions for the year 2030. The HEBLA (Health and Economic Benefits/Loss Analysis) module allows calculating economic and public health benefits/losses using output from SACA. Algorithms to calculate economic and public health benefits/losses from the current state of regional air quality are programmed and integrated into this module. The BECO (Benefit/Cost Optimization) module, using the output from the HEBLA module, performs analysis and evaluates the effectiveness of benefits from improving air environment quality and optimizing real control costs. The effectiveness of the Benefit/Cost ratio (B/C) is analyzed based on the economic benefits and investment costs of PM2.5 pollution control solutions for scenarios in 2030 [13]. Figure 3 shows the process of building and integrating the module [13].

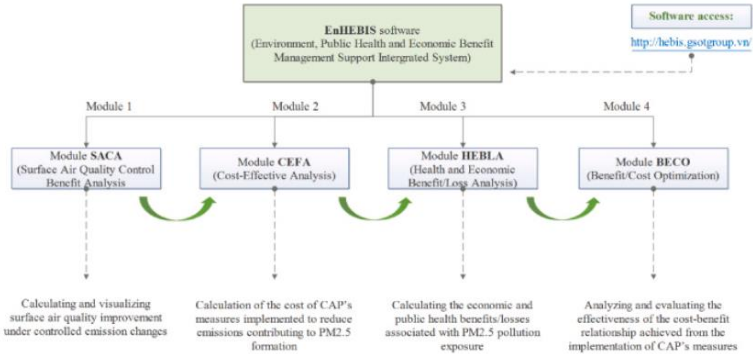

Figure 3. The process of building and integrating modules

CMAQ

The Community Multiscale Air Quality (CMAQ) model is a comprehensive multipollutant air quality modeling system developed and maintained by the US Environmental Protection Agency's (EPA) Office of Research and Development (ORD). Recently, version 5.1 of the CMAQ model (v5.1) was released to the public, incorporating a large number of scientific updates and extended capabilities over the previous release version of the model (v5.0.2). These updates include the following: improvements in the meteorological calculations in both CMAQ and the Weather Research and Forecast (WRF) model used to provide meteorological fields to CMAQ, updates to the gas and aerosol chemistry, revisions to the calculations of clouds and photolysis, and improvements to the dry and wet deposition in the model. Sensitivity simulations isolating several of the major updates to the modeling system show that changes to the meteorological calculations result in enhanced afternoon and early evening mixing in the model, periods when the model historically underestimates mixing. Updates to the clouds and photolysis calculations greatly improve consistency between the WRF and CMAQ models and result in generally higher O3 mixing ratios, primarily due to reduced cloudiness and attenuation of photolysis in the model. Updates to the aerosol chemistry result in higher secondary organic aerosol (SOA) concentrations in the summer, thereby reducing summertime PM2.5 bias (PM2. 5 is typically underestimated by CMAQ in the summer), while updates to the gas chemistry result in slightly higher O3 and PM2.5 on average in January and July. Sensitivity simulations for several hypothetical emission reduction scenarios show that v5.1 tends to be slightly more responsive to reductions in NOx (NO+NO2), VOC and SOx (SO2+SO4) emissions than v5.0.2, representing an improvement as previous studies have shown CMAQ to underestimate the observed reduction in O3 due to large, widespread reductions in observed emissions [14].

GEOS-CHEM

GEOS-Chem is a global 3-D model of atmospheric chemistry driven by meteorological input from the Goddard Earth Observing System (GEOS) of the NASA Global Modeling and Assimilation Office. It is applied by hundreds of research groups around the world to a wide range of topics involving atmospheric composition. Regional refinement capabilities and efficient parallelization enable rapid fine resolution simulations. Scientific direction of the model is provided by the international GEOS-Chem Steering Committee and by Working Groups. The model is managed by the GEOS-Chem Support Team, based at Harvard University and Washington University with support from the US NASA Earth Science Division, and the Nanjing University of Information Sciences and Technology. GEOS-Chem is a grass-roots open-access model owned by its users, and ownership implies some responsibilities as listed in our welcome page for new users. If you are interested in using GEOS-Chem, please review our extensive documentation and support guidelines[15]. Figure 4 mean photolysis frequencies for NO_2 (J_{no2}) and O_3 to $O(^1D)$ ($J_{o1}D$) in surface air in July 2016. The left panels (a, c) show the values computed by Fast-JX within GEOS-Chem. The right panels (b, d) show the differences (Δ) with the values computed by TUV within CAM-chem.

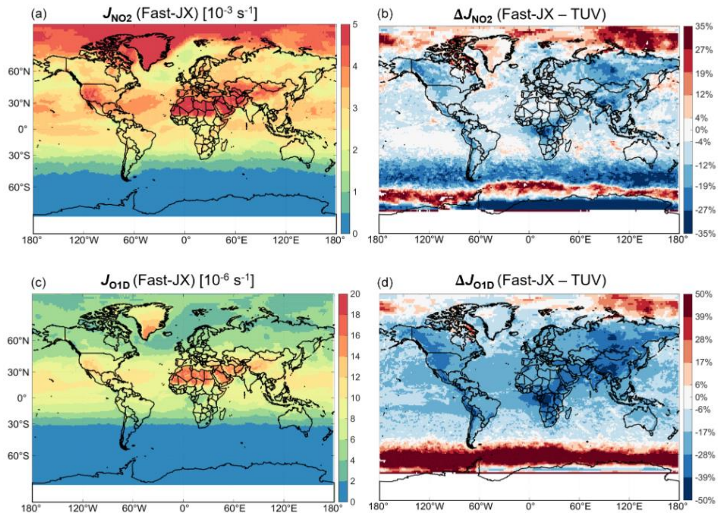

Figure 4. Photolysis frequencies for NO_2 (J_{no2}) and O_3 to $O(^1D)$ ($J_{o1}D$) in surface air in July 2016 [16]

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Adoption of Sustainable Logistics Practices and Their Impact on Environmental Performance in Manufacturing Supply Chains

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Abstract .This paper examines the influence of sustainable logistics practices on environmental performance in manufacturing supply chains. Data were collected from 32 managers in 24 Serbian manufacturing firms using a structured questionnaire covering digital logistics integration, reverse logistics, and green transportation measures. Using descriptive statistics, correlation analysis, and regression modeling, the study found that all three dimensions significantly and positively impact environmental performance. Reverse logistics emerged as the strongest predictor. The findings highlight the need for a comprehensive approach to sustainable logistics for achieving measurable environmental benefits in industrial contexts.

Keywords: sustainable logistics, environmental performance, reverse logsitics, manufacturing

INTRODUCTION

Sustainable logistics has become a central theme in contemporary supply chain management, particularly in the manufacturing sector, where environmental concerns and resource efficiency are increasingly prioritized. As global pressure mounts to reduce ecological footprints and comply with environmental regulations, manufacturing firms are rethinking their logistical strategies to align with sustainability objectives[1]. Sustainable logistics practices encompass a broad range of activities aimed at minimizing the negative environmental impacts of supply chain operations[2]. These include, but are not limited to, the use of fuel-efficient transportation, deployment of electric or hybrid delivery vehicles, implementation of renewable energy solutions in warehousing, adoption of recyclable or reusable packaging, and route optimization techniques that reduce fuel consumption and carbon emissions.

Despite the recognized advantages, the adoption of sustainable logistics practices is not uniform across the manufacturing industry. A variety of factors influence whether and how companies integrate these practices. On one hand, external pressures such as environmental legislation, consumer expectations, and global sustainability standards act as strong drivers. Companies aiming to strengthen their brand image or secure access to international markets often perceive sustainability as a strategic imperative. Internal motivations, including long-term cost reductions and enhanced supply chain visibility, further encourage implementation. However, significant barriers persist. High initial investment costs, limited availability of green technologies, and insufficient managerial or technical expertise often hinder adoption. In many cases, firms also face challenges in transforming existing logistical infrastructure, especially in regions with underdeveloped digital and transportation networks[3]. Resistance to organizational change and uncertainty about return on investment add further complexity to the decision-making process.

The impact of these practices on environmental performance is a critical area of inquiry. Environmental performance refers to the extent to which organizations achieve ecological goals through operational activities. In the context of logistics, this typically involves indicators such as reduced greenhouse gas emissions, improved energy efficiency, decreased water and material usage, and lower levels of industrial waste[4]. Companies that systematically apply sustainability principles in logistics often report measurable improvements in these areas. Such gains not only contribute to compliance with international environmental standards but also enhance competitiveness, as stakeholders increasingly value transparency and accountability in environmental management.

BACKGROUND RESEARCH

Sustainable logistics practices in the manufacturing sector have evolved in response to growing awareness of the environmental consequences of industrial operations. Within manufacturing supply chains, logistics plays a crucial role in determining resource consumption, emissions, and waste generation. Companies that embrace sustainable logistics seek to redesign their supply chain activities to minimize ecological harm while maintaining or improving operational efficiency[5]. These practices include transitioning from fossil fuel-powered vehicles to electric or hybrid fleets, implementing energy-efficient systems in warehouses, adopting real-time tracking technologies to reduce idle time and fuel consumption, and integrating reusable or biodegradable packaging materials. The introduction of reverse logistics systems that enable the return, recycling, or repurposing of products and materials further contributes to a circular flow of resources, reducing landfill use and lowering the demand for raw materials.

Energy optimization within warehousing operations represents another critical component of sustainable logistics. Through the deployment of automated inventory systems, motion-sensitive lighting, and advanced climate control technologies, firms can significantly reduce electricity consumption. Additionally, renewable energy sources, such as rooftop solar panels, are increasingly being used to power logistics facilities. Smart warehousing systems, often supported by artificial intelligence and IoT devices, contribute to better stock rotation, demand forecasting, and reduction of spoilage, particularly in temperature-sensitive industries like food and pharmaceuticals[6].

METHODOLOGY

A structured survey instrument was used to gather data from 32 logistics and supply chain managers employed in 24 manufacturing firms across various industrial sectors in Serbia, including automotive, food processing, chemicals, electronics, and textiles. These respondents held mid- or senior-level managerial positions, making them suitable for evaluating sustainability initiatives and their operational outcomes.

The survey instrument was designed using a 7-point Likert scale, ranging from 1 (strongly disagree) to 7 (strongly agree). The questionnaire consisted of 20 items grouped into four thematic dimensions:

1. Digital Logistics Integration (DLI) – use of digital tools and platforms in managing logistics and supply chain operations.
2. Reverse Logistics Practices (RLP) – implementation of systems for product returns, recycling, and reprocessing.
3. Green Transportation Measures (GTM) – use of fuel-efficient or electric vehicles, route optimization, and eco-driving policies.
4. Environmental Performance (ENV) – self-reported improvement in emission reduction, waste minimization, energy efficiency, and environmental compliance.

Each dimension included 5 items designed to capture the implementation level of specific sustainable practices and their perceived environmental outcomes. Cronbach's alpha values were calculated to ensure scale reliability.

To test the relationships between logistics practices and environmental performance, the following hypotheses were formulated:

- H1: Adoption of digital logistics integration (DLI) positively influences environmental performance (ENV).
- H2: Implementation of reverse logistics practices (RLP) positively influences environmental performance (ENV).
- H3: Adoption of green transportation measures (GTM) positively influences environmental performance (ENV).

Data analysis was conducted using SPSS software. Descriptive statistics (mean, standard deviation, Cronbach's alpha) were calculated for all dimensions. Pearson correlation coefficients were used to assess the strength and direction of relationships between independent variables (DLI, RLP, GTM) and the dependent variable (ENV).

RESULTS

Table 1 presents the descriptive statistics and internal consistency (reliability) for each of the four measured variables: Digital Logistics Integration (DLI), Reverse Logistics Practices (RLP), Green Transportation Measures (GTM), and Environmental Performance (ENV). The mean values, which range from 4.96 to 5.32 on a 7-point Likert scale, suggest a generally high level of agreement among respondents regarding the implementation of sustainable logistics practices and the observed environmental outcomes. Standard deviations between 1.21 and 1.36 indicate moderate variability in responses, reflecting diverse levels of adoption across the surveyed manufacturing firms.

The reliability of each construct, as assessed using Cronbach's Alpha, exceeds the commonly accepted threshold of 0.70, indicating strong internal consistency for all measurement scales. Environmental Performance ($\alpha = 0.915$) and Digital Logistics Integration ($\alpha = 0.902$) exhibit particularly high reliability, suggesting that the items within each dimension consistently measure the intended concept. These results confirm the appropriateness of the instrument used to capture the constructs relevant to the study.

Table 1. Descriptive statistics and reliability analysis

Variable	Mean	Std. Dev.	Cronbach's Alpha
Digital Logistics Integration (DLI)	5.18	1.32	0.902
Reverse Logistics Practices (RLP)	4.96	1.29	0.884
Green Transportation Measures (GTM)	5.10	1.36	0.893
Environmental Performance (ENV)	5.32	1.21	0.915

Table 2 displays the Pearson correlation coefficients between the three independent variables—Digital Logistics Integration (DLI), Reverse Logistics Practices (RLP), and Green Transportation Measures (GTM)—and the dependent variable, Environmental Performance (ENV). All correlations are positive and statistically significant at the 0.01 level, indicating that higher levels of sustainable logistics practices are associated with better environmental outcomes. Among the three, Reverse Logistics Practices ($r = 0.503$) shows the strongest correlation with Environmental Performance, followed closely by Green Transportation Measures ($r = 0.486$) and Digital Logistics Integration ($r = 0.421$).

Additionally, moderate positive correlations are observed among the independent variables themselves, suggesting that firms which adopt one type of sustainable logistics practice are also likely to engage in others. For instance, the correlation between DLI and RLP is 0.528, reflecting a tendency for digitally integrated firms to also implement reverse logistics. These results provide initial support for the proposed hypotheses and suggest that each independent variable has a meaningful relationship with the environmental outcomes targeted in this study.

Table 2. Correlation matrix

Variables	DLI	RLP	GTM	ENV
DLI	1			
RLP	0.528**	1		
GTM	0.462**	0.481**	1	
ENV	0.421**	0.503**	0.486**	1

Table 3 presents the results of the multiple linear regression analysis conducted to examine the influence of three independent variables—Digital Logistics Integration (DLI), Reverse Logistics Practices (RLP), and Green Transportation Measures (GTM)—on the dependent variable, Environmental Performance (ENV). All three predictors show statistically significant positive effects on ENV, with p-values below 0.01. Reverse Logistics Practices ($\beta = 0.334$) emerged as the strongest predictor, followed by Green Transportation Measures ($\beta = 0.297$) and Digital Logistics Integration ($\beta = 0.278$). These results support all three hypotheses and indicate that each type of sustainable logistics practice contributes meaningfully to improved environmental outcomes.

The model explains 56.3% of the variance in Environmental Performance ($R^2 = 0.563$), which suggests a moderate to strong explanatory power. The overall model is statistically significant ($F = 12.040$, $p < 0.001$), confirming that the combination of predictors reliably explains changes in the dependent variable. These findings underscore the importance of adopting a multi-dimensional approach to sustainability in logistics, as each practice contributes uniquely to ecological performance within manufacturing supply chains.

Table 3. Regression analysis

Y	X	β	p-value	R^2	F	F Sig.
		Intercept: 1.872				
	DLI	0.278	<0.0001			
ENV	RLP	0.334	<0.0001	0.563	12.040	<0.0001
	GTM	0.297	<0.0001			

CONCLUSION

The results of this study confirm that sustainable logistics practices—specifically digital logistics integration, reverse logistics, and green transportation—have a significant and positive impact on environmental performance in manufacturing supply chains. Among the examined factors, reverse logistics showed the strongest influence, underscoring its strategic relevance. The findings support the integration of sustainability as a core component of logistics planning and operations. Manufacturing firms aiming to enhance their ecological outcomes should consider adopting a balanced combination of digital tools, green mobility, and circular logistics processes.

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Radon-222 as a Tracer for Managed Aquifer Recharge in Karst Systems: Preliminary Results from Southern Istria, Croatia

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Abstract. Radon-222 commonly accumulates in groundwater systems. The highly fractured nature of karst terrain facilitates rock-water interaction, allowing radon emanation from uranium bearing limestone and dolomite formations into groundwater. In managed aquifer recharge (MAR) projects, radon measurements serve as valuable tracers to delineate groundwater flow patterns, estimate residence times, and track mixing between recharged surface water and native groundwater. This case study, part of the BLUE RECHARGE project (Interreg Italy-Croatia), employs the RAD8 Radon Monitor (Durridge Company). The paper presents the first results of the ongoing sampling campaign in the southern Istria pilot research area, evaluating long-term performance in complex karst aquifer environments.

Keywords: radon, karst, managed aquifer recharge

INTRODUCTION

Radon is a noble, alpha-emitting gas that generates from the uranium series. With a half-life of 3.8235 days, radon-222, generally simply known as radon, is the most prevalent isotope of radon. Other isotopes include radon-220, also known as thoron, which has a half-life of 55.6 seconds, and radon-219, also known as action, which has a half-life of 3.96 seconds. Only radon-222 is typically used in geological and environmental research; the other two isotopes are typically disregarded because of their extremely brief half-lives [1].

Radon-222 emerges from the radioactive decay of radium-226 within carbonate rock matrices that characterize karst terrains. While limestone formations typically contain modest uranium concentrations compared to other rock types, the unique hydrogeological properties of karst systems create favorable conditions for radon mobilization and transport [2]. The alpha decay process that generates radon atoms within carbonate mineral structures provides sufficient recoil energy to liberate these atoms from crystal lattices, particularly when decay occurs near grain boundaries or within zones of structural weakness [3].

The effectiveness of radon emanation in karst environments is enhanced by the characteristic weathering and dissolution processes that continuously modify the physical properties of carbonate rocks. Chemical weathering along fracture surfaces and grain boundaries increases the surface area available for radon escape, while simultaneously creating microscopic porosity networks that facilitate initial radon migration from source minerals into the broader hydrological system [4].

Radon can penetrate and build up in groundwater when it is created from radium [5]. The concentration of radon in water increases with the mean residence time of water and can, therefore, help to date groundwater [6]. When air and water come into contact, radon is emitted from the water until the air and water radon levels reach an equilibrium. At that point, the radon concentration in the air is around four times that of the water at 20°C [1].

KARST SPRING SYSTEMS AND RADON DISCHARGE

Karst springs represent critical discharge points where radon-enriched groundwater emerges at the surface, creating potential pathways for radon release to the atmosphere and human exposure [7]. The rapid flow velocities characteristic of karst spring systems minimize radon decay during transport, allowing high radon concentrations to be maintained from source areas to discharge points. Large karst springs, which can discharge hundreds to thousands of liters per second, represent major conduits for radon flux from deep carbonate aquifer systems to surface environments.

The temporal variability of karst spring discharge creates corresponding variations in radon concentrations and flux rates. During high-flow periods, enhanced groundwater circulation through the karst network may mobilize radon from previously stagnant zones, while low-flow conditions may concentrate radon in reduced discharge volumes. Understanding these temporal patterns is essential for assessing long-term radon exposure risks associated with karst groundwater utilization [8].

The unique characteristics of radon transport in karst aquifer systems have significant implications for groundwater management and public health protection strategies. The rapid and efficient transport pathways inherent in karst systems can result in varying radon concentrations in groundwater supplies that serve residential, commercial, and institutional facilities. The heterogeneous nature of karst aquifer systems creates spatial variability in radon concentrations that requires comprehensive monitoring approaches to adequately characterize exposure risks [6].

Furthermore, the dynamic nature of karst groundwater flow systems means that radon concentrations may vary significantly in response to hydrological changes, seasonal variations, and long-term evolution of the karst network structure. This temporal variability necessitates long-term monitoring programs and adaptive management approaches to ensure continued protection of public health in karst terrain regions [8].

ISTRIA CASE STUDY

Sample collection

Groundwater for radon analysis was sampled from 6 locations in southern Istria (Figure 1). These locations include 4 wells, one spring and one borehole. A single 250 mL sample was taken on each location on June 11, July 9 and August 12, 2025.

Water sampling is one of the most significant sources of measurement errors. It is important to make sure that the water is representative of the water being tested and has never come into contact with air before taking a radon sample. In order to meet the former, the water was drawn from the well for a while before to sampling, ensuring that it was fresh from the well's depths. A faucet aerator was taken out of the tap to satisfy the latter. After that, water was gradually added to a bucket to prevent turbulence, which would have aerated the sample. Then, if a narrow tubing could be attached to the faucet, the tubing was inserted into the sample bottle and the bottle was submerged into water where it was filled. If a narrow tubing could not be connected to the faucet, then the bottle was slowly submerged into the water in the bucket, avoiding bubbling. In both cases, the cap was screwed under water. At the end of the sampling, it was ensured that the water in the bottle does not include any air bubbles.

Figure 1. Locations of groundwater sample collection.

Sample analysis

A RAD8 radon monitor (Durridge Co., Billerica MA, USA) [9], along with the RAD H2O kit for water analysis, was used to obtain radon concentrations in water samples [10]. The solid state alpha detector in this continuous radon monitor measures the energy of alpha particles produced by the decay of radon and thoron progeny inside the measurement chamber. Since the device can only detect radon in air, radon in a water sample must be discharged into the air within the instrument's closed loop before the radon content of the air is measured. The device determines the radon concentration in the water sample by knowing the ratio of radon in air to water.

Each 250 mL bottle's water was first aerated for ten minutes. The radon concentration was measured in two 30-minute cycles following an extra 10-minute wait to achieve equilibrium. The concentrations were adjusted for the decay correction factor based on the amount of time that passed between sampling and analysis because the measurement was done either one or two days after sampling.

RESULTS

Concentrations of radon measured at 6 locations in Istria are listed in Table 1 and presented in Figure 2. At most locations radon concentrations remain relatively stable. Of course, longer monitoring period would be needed for any strong conclusions about water dynamics in the underground.

Radon concentrations reached the highest values in Loborika borehole, in each month of the monitoring. The lowest concentrations were measured at Škatari well. Unfortunately, due to some technical difficulties, the first measurement at Škatari is missing.

Table 1. Radon concentrations of water collected in 250 mL bottles and estimated measurement errors. All values are given in Bq/m^3.

location	11. 6. 2025	9. 7. 2025	12. 8. 2025
Karpi well	2 899 ± 220	2 356 ± 310	5 315 ± 300
Peroj well	4 029 ± 260	2 537 ± 200	2 859 ± 220
Tivoli well	1 570 ± 160	1 229 ± 140	1 797 ± 160
Karolina spring	6 882 ± 340	3 629 ± 250	4 107 ± 240
Škatari well	-	710 ± 110	144 ± 50
borehole Loborika	17 865 ± 800	11 927 ± 410	15 509 ± 470

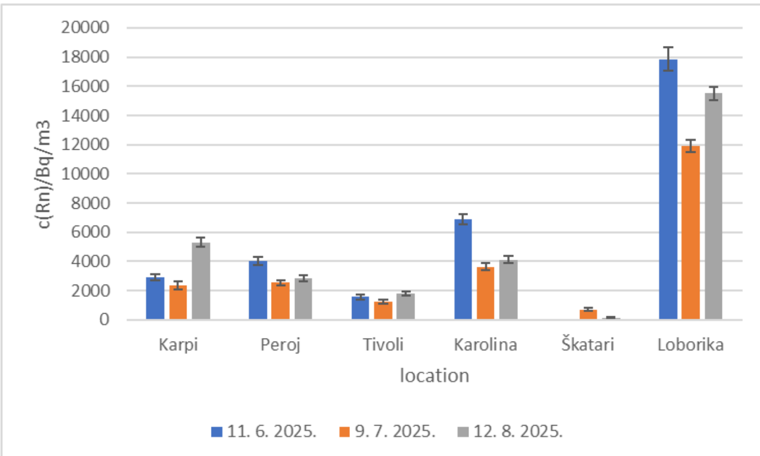

Figure 2. Radon concentrations of water collected in 250 mL bottles and estimated measurement errors.

CONCLUSION

In limestone, radium releases radon, a naturally occurring radioactive gas. Radon can then emerge from cracks and openings in stone, but also dissolve in groundwater. Radon monitoring in groundwater can, therefore, be used to assess the water dynamics in karst.

In order to trace groundwater patterns in a complex karst aquifer environment, a case study was carried out on a pilot research area in southern Istria, Croatia. Over the course of three months in 2025, samples of groundwater were taken at six distinct places. The preliminary results indicate that radon levels are comparatively constant. The Loborika borehole had the highest radon concentrations each month, while the lowest concentrations were measured at Škatari well.

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Analysis of the Energy Efficiency of the Syrup Evaporation Plant

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Abstract. The paper describes an analysis of the rationalization of energy consumption at the syrup evaporation plant, as well as the rational use of the waste heat of secondary vapour. Energy costs represent a key item in the product cost price. Any recovery of waste heat has an impact on reducing production costs. Energy saving can be achieved by installing a heat exchanger - recuperator. The paper presents a technological solution for the rational use of waste heat in the process industry at a real production plant - a syrup evaporation station. At the syrup evaporation station, 1655 kg/h of secondary vapour is available (as waste heat). This corresponds to a heat output of 1066 kW_{th}.

Keywords: evaporation, recovered heat, secondary vapour, energy efficiency, heat exchanger

INTRODUCTION

The energy crisis at the beginning of the seventies, followed by numerous economic and environmental reasons, forced many countries to take certain measures to save energy and use it rationally. In addition to numerous activities, the possibilities of economic utilization of waste heat were examined [1,2].

In the industry sector, there are large reserves for increasing total energy efficiency at the country level. All new energy security projects are very expensive and their implementation requires a lot of time. Based on that, the directions of preventive measures for increasing energy efficiency can be determined. One of those measures is the development and application of technological solutions, from the aspect of the possibility of using waste heat in industry. A special case is placed on plants in the economy, ie. process industry with high energy consumption (evaporation, heating, drying). The paper presents the results of the research for the rational use of energy at the syrup evaporation plant. This will have significant effects related to: reduction of specific energy consumption per unit of product in a given process [3,4].

In our country, within the industry sector, about 60% of the total available energy is consumed, so it is obvious that there are large reserves for increasing energy efficiency, by applying methods for optimal energy use.

Materials and methods

The largest amounts of waste heat in industry are in the area below 100 °C. These are: vapour condensate, cooling water, waste water from industrial processes, output air from thermal power plants, etc. High and medium temperatures of waste heat can be used for vapour production, air preheating, etc. From the aspect of using waste heat, the most favorable case is when waste heat can be used to increase the efficiency of thermal degree in the technological process itself. For example, overheating of combustion air in a boiler using flue gases. Using the heat of waste gases for the needs of direct drying or overheating of materials is also possible without a heat exchanger. The quality of waste heat is primarily in its use value, not in its quantity.

The possibility of using waste heat in the air conditioning, heating and cooling (ACHC) systems and other technological processes often exists in the following cases [5,6]:

- vapour condensate that is not returned to the boiler room can be used for heating domestic hot water, or by means of exchangers in ACHC systems,
- output gases and cooling water can be used to overheating liquids, etc.

Based on general estimates, energy savings of about 20% are possible in the industry by applying appropriate energy technologies. Use of energy in the technological process is determined by the application of thermodynamic laws based on energy balances, in which total invested energy, used energy and losses are taken into account [7,8].

The paper describes an analysis of the rationalization of energy consumption at the syrup evaporation plant, as well as the rational use of the waste heat of seconadry vapour. Energy costs represent a key item in the product cost price. Any recovery of waste heat has an impact on reducing production costs. Energy saving can be achieved by installing a heat exchanger - recuperator [9]. The installation of heat exchanger - recuperator, on existing plants and on new designed systems, aims to reduce heat losses and belongs to modern technical solutions.

This paper presents a technological solution for the rational use of waste heat in the process industry on a real production plant such as a syrup evaporation plant - a syrup evaporation station.

In order to improve, tests and measurements were carried out at plant in real production conditions.

At the syrup evaporation station, 1655 kg/h of secondary vapour is available (as waste heat). This corresponds to a heat output of 1066 kW_{th}.

Figure 1 shows the technological scheme of the syrup evaporation plant. Water vapor of pressure p = 4 bar and temperature t = 143 °C is used for heating the first stage of the evaporation station.

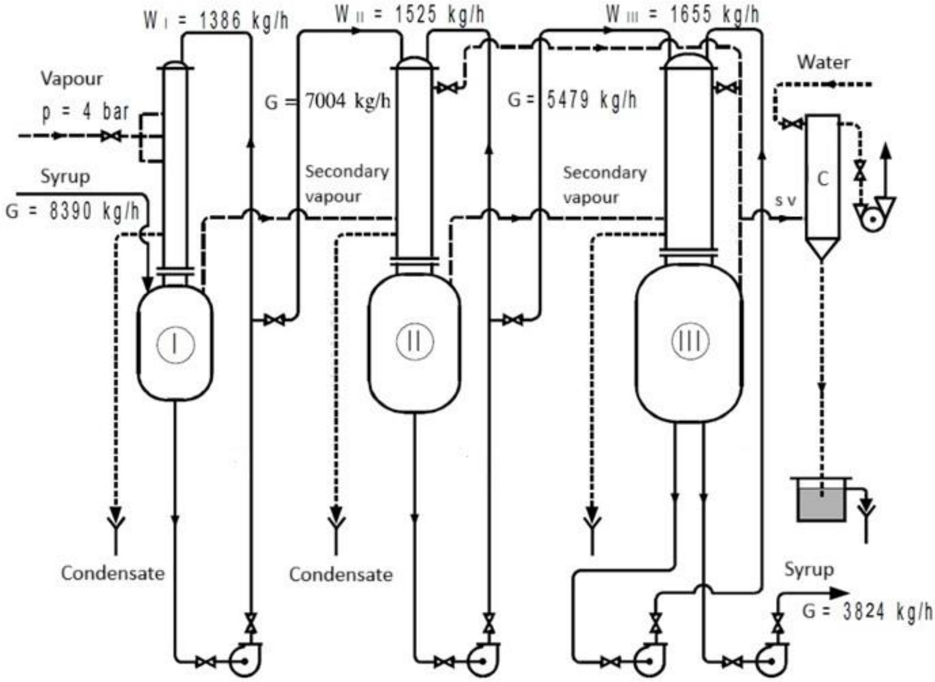

Figure 1. Technological scheme of the three-stage syrup evaporation

Results and discussion

The recovered heat will be used for heating buildings and production plants. This will result in a reduction of specific energy consumption per product unit and an increase in the efficiency of work and the efficiency of thermal degree of the plant [10].

With all heat consumers, energy machines, as well as boilers, stoves, dryers, etc. only a part of the supplied heat is used effectively. A large part of the heat is lost in the form of waste heat, through the chimney or cooling water.

The proposed method of optimal energy use will result in a saving of about (10 to 15)% of the thermal power installed at the plant and an increase in the efficiency of thermal degree. Such a method will be rational in terms of investment and profitable for the exploitation period of 1-2 years [6,11-13].

The recovered heat can be used for the needs of central heating of production plants as shown in Figure 2. The energy and material balance of the syrup evaporation process is given [1-3].

Energy savings can be achieved by using secondary vapour, by installing a heat exchanger - recuperator. Reducing heat losses also requires financial investments, which can be positively offset by a corresponding reduction in fuel consumption [4-6].

Table 1 shows the results of testing key energy parameters at the syrup evaporation plant [10,14,15].

Table 1. Energy parameters at the syrup evaporation plant

Title	Mark	Unit of measure	Amount
Amounts of evaporated water in stages I, II and III	W_I W_{II} W_{III}	[kg/h]	1386 1525 1665
The amount of evaporated water in all three stages	W	[kg/h]	4566
Heat balance in all three stages	Q_I Q_{II} Q_{III}	[kJ/h]	3 011 778 3 038 000 3 200 000
The required amount of water vapor for heating in the stage I	D_I	[kg/h]	1410
Specific water vapor consumption	d	[kg of vapour / kg of evaporated water]	0,308
Required heating surfaces in stages I, II and III	A_I A_{II} A_{III}	[m^2]	33 43 58
Amount of secondary vapour	$G_{bp} = W_{III}$	[kg/h]	1655
Recovered heat	Q_{bp}	[kW$_{th}$]	1066
The surface of the heat exchanger - recuperator	A	[m^2]	25

It is necessary to install a heat exchanger - a recuperator - on the line of the pipeline that connects the 3rd evaporation stage with the condenser. Figure 2 shows the technological scheme of using the waste heat of the secondary vapour.

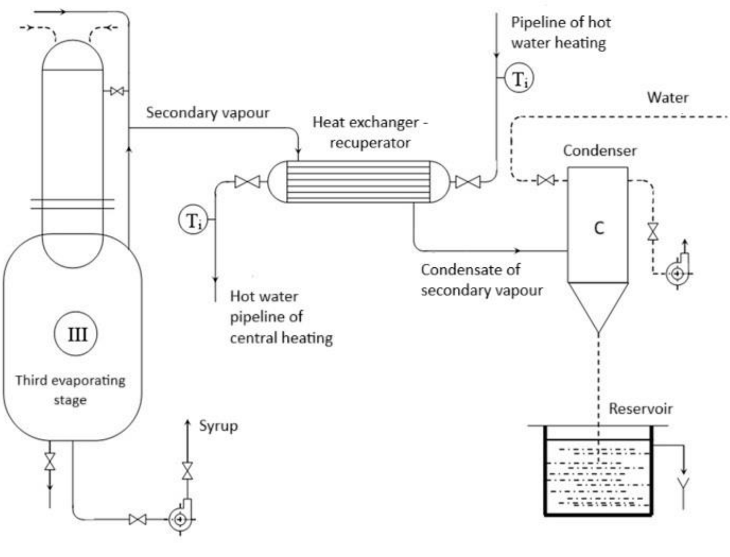

Figure 2. Technological diagram of the pipeline connection with the heat exchanger-recuperator

CONCLUSION

The analysis of energy savings on a three-stage syrup evaporation station justifies the application and installation of a heat exchanger - recuperator. The proposed method of using waste heat for heating the industrial plant is also rational from an investment point of view, considering the amortization of the investment already in the first year of exploitation.

Given that the results are based on data from a real industrial plant of a syrup evaporation station, the given technological solution of heat recovery can be used in such and similar plants in the economy. Based on that, the research results have a useful value, and can also be used for educational purposes. The application of research results should enable the reduction of energy consumption and the increase of energy efficiency.

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Modeling Toxic and Flammable Gas Dispersion of Hydrogen Sulfide and Propane at the Oil Refinery

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Abstract. This paper presents the modeling of two representative gas leak scenarios at the Pančevo Oil Refinery using the ALOHA software. The first scenario involves the short-term release of hydrogen sulfide (H_2S), a highly toxic gas, while the second considers a large-scale release of propane, a flammable hydrocarbon. Based on defined process, technical, and meteorological parameters, hazard zones were calculated and compared to AEGL threshold values. The results show that the H_2S scenario, although spatially limited, poses a high toxic risk even at short distances, while the propane scenario extends over larger areas with significant fire and explosion hazards. These findings highlight the importance of continuous monitoring, protective equipment, and compliance with safety regulations.

Keywords: hydrogen sulfide, propane, gas dispersion, ALOHA, oil refinery

INTRODUCTION

Industrial facilities handling hazardous substances face risks of accidental gas releases that can endanger both human health and the environment. Hydrogen sulfide (H_2S) and propane (C_3H_8) are particularly relevant due to their toxic and flammable properties, as well as their frequent presence in refinery operations. To evaluate potential accident consequences, dispersion modeling provides a reliable tool for defining hazard zones and planning emergency response measures. This study focuses on two representative scenarios at the Pančevo Oil Refinery, aiming to assess the extent of hazard zones based on meteorological and technical parameters, with special attention to AEGL threshold values.

THEORETICAL CONSIDERATION

Hydrogen sulfide is a flammable, colorless gas with a strong odor, heavier than air, and highly toxic. It inhibits cellular respiration, causing organ damage, rapid unconsciousness, pulmonary edema, and death, particularly in occupational settings. Its toxicity is linked to the inhibition of cytochrome oxidase in mitochondria, with concentrations above 30 ppm affecting mammalian tissues (Sastre, 2013; Dorman, 2002). H_2S is dangerous even at very low concentrations, with odor detectable at 0.05–5 ppm, eye irritation occurring at 10–30 ppm after several hours, respiratory problems appearing at 50–100 ppm within 30–60 minutes, loss of smell at 150–200 ppm within minutes, unconsciousness and convulsions at

350–450 ppm in 2–15 minutes, severe respiratory and cardiac effects at 500–600 ppm, and instant lethality at 700–1500 ppm within 0–2 minutes (Ebrahimzadih, 2016).

Meteorological conditions strongly influence dispersion during leaks or fires. According to the Gaussian model, gases similar in weight to air disperse more with higher wind speeds, reducing hazard zones. However, for denser-than-air gases, such as H_2S and propane, higher wind speeds can expand hazard zones near the ground or water surfaces (Chambers, 2009).

Propane is a highly flammable, colorless gas, heavier than air, commonly used as fuel in heating, cooking, industry, and vehicles. In case of leaks, it accumulates in low-lying spaces, creating explosion hazards. Odorants like ethyl mercaptan are added for leak detection, but this method is not fully reliable due to uneven distribution, adsorption, low concentration in full tanks, and reduced olfactory sensitivity in some individuals (Smoot, 1996).

ALOHA (Areal Locations of Hazardous Atmospheres) is a model used for simulating the dispersion of hazardous gases, such as H2S. The model estimates gas concentration and displays threat zones at three levels (red, orange, and yellow) according to the degree of toxicity. It uses a time-specific exposure level (e.g., 60 minutes) to determine the boundaries of the threat zones. ALOHA allows for the assessment of gas spread under different conditions, including the effects of temperature, humidity, and wind speed, and distinguishes the behavior of gases heavier than air from neutrally buoyant gases. The model is useful for safety planning, risk assessment, and predicting the consequences of incidents such as pipeline leaks. ALOHA models the dispersion of hazardous gases such as H_2S, showing threat zones based on toxicity levels and environmental conditions. It is applied to assess the spread of heavier-than-air gases and to support evacuation and safety planning (Ahmed, 2021).

Prevention relies on sensors positioned according to physicochemical gas properties and the use of personal protective equipment (Zhang, 2018). Compliance with regulations (Seveso III, REACH) and national standards requires risk assessment, installation of detection systems, and the preparation of accident protection plans (Gabryelewicz, 2022).

MATERIALS AND METHODS

Site description

Pančevo, a city in Serbia with about 122,000 inhabitants (2011 census), consists of the urban area and nearby settlements such as Starčevo, Kačarevo, and Jabuka. The highest population density is in Pančevo and Kačarevo (over 151 inhabitants/km²), while Starčevo and Jabuka have 101–150 inhabitants/km². The economy is strongly tied to major industrial complexes, including the Pančevo Oil Refinery (RNP), HIP Petrohemija, and HIP Azotara.

The Pančevo Oil Refinery is located in the industrial zone between Pančevo, Starčevo, and Vojlovica, about 4 km from the city center. It includes modernized facilities such as the hydrogen plant S-5000, with developed road, rail, river, and pipeline infrastructure. The refinery is about 150 m from the nearest residential houses in Starčevo, although earlier planned facilities were farther away. Parts of the industrial zone do not fully meet WHO recommendations for a protective belt from urban areas (Pojmetal, 2012).

Input data

The modeling was based on meteorological data from Pančevo (August 8, 2025, 11:00), with wind speed 2.7 m/s (SE), 31 °C, 31% humidity, stability class B, and clear weather. Input parameters included an unsheltered single-story building with an air exchange rate of 0.47 h^{-1}.

The remaining physicochemical properties, such as molecular weight, boiling point, vapor pressure, explosive limits (LEL/UEL), AEGL (Acute Exposure Guideline Levels) thresholds, and IDLH (Immediately Dangerous to Life or Health) values for H_2S and propane, are already available within the ALOHA database and therefore are not elaborated in detail here.

Leak scenarios

This study analyzes two scenarios of flammable gas leaks at the Pančevo Oil Refinery, without combustion. The aim is to assess gas dispersion, hazard zones, and potential impacts through defined technical, process, and meteorological parameters, focusing on exceedance of AEGL-1/2/3 thresholds.

Scenario 1 – H_2S leak:

A small-diameter closed pipe (1 cm, 25 m) with an opening of 0.79 cm^2, overpressure 1,000,000 Pa, and fluid temperature 35 °C releases hydrogen sulfide for 1 minute at a rate of 0.392 g/s, totaling 23.5 g. Due to the small mass, hazard extent is highly dependent on meteorological conditions.

Scenario 2 – Propane release:

A large-diameter pipe (10 cm, 25 m) connected to an infinite source, with an opening of 78.5 cm^2, overpressure 700,000 Pa, and fluid temperature 31 °C, releases propane for 1 hour at 457 kg/min, totaling 27,416 kg. The high release rate results in extensive hazard zones with potential AEGL exceedances over large areas.

RESULTS

Scenario 1 – H_2S

The presented figure 1 illustrates the hazard zone for the hydrogen sulfide (H_2S) release scenario modeled using the Gaussian dispersion approach. Based on the calculated values, the zone exceeding the AEGL-1 threshold concentration (0.51 ppm for 60 minutes of exposure) extends up to 52 meters downwind from the source, while the AEGL-2 (27 ppm) and AEGL-3 (50 ppm) zones are not shown, as they fall within a radius of less than 10 meters, where the model's reliability decreases due to near-field concentration patchiness effects. The yellow area on the diagram represents the region where the H_2S concentration exceeds the AEGL-1 threshold, while the wind direction confidence lines indicate the variability of possible contamination spread depending on meteorological conditions at the time of the incident.

The modeled hydrogen sulfide (H_2S) release shows that AEGL-3 and AEGL-2 zones remain confined to the immediate vicinity of the source. In contrast, the AEGL-1 threshold (0.51 ppm) extends up to 52 m downwind, requiring preventive safety measures despite not being lethal. Due to H_2S toxicity and the risk of olfactory fatigue, even small releases can be hazardous, emphasizing the need for technical monitoring. The dispersion graphic indicates wind direction with the central axis, dashed lines showing possible deviations, and grid lines for distance measurement.

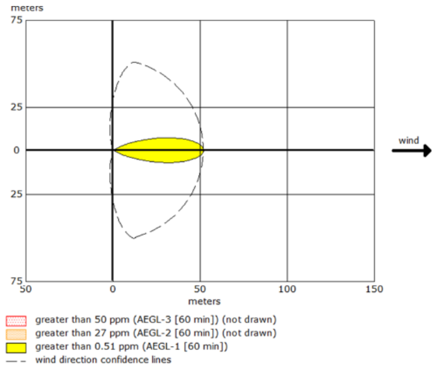

Figure 1. Hazard zone for the H_2S

Scenario 2 – Propane

The presented figure 2 shows the hazard zone for the propane release scenario modeled using the Heavy Gas method. Based on the calculation results, the AEGL-3 zone (33,000 ppm, 60-minute exposure), representing concentrations with potentially lethal outcomes, extends up to 33 meters downwind from the source but is not graphically displayed due to the model's limited reliability at short distances caused by near-field concentration patchiness. The AEGL-2 zone (17,000 ppm), which poses a serious health risk, extends up to 53 meters downwind and is shown in orange. The widest is the AEGL-1 zone (5,500 ppm), indicating concentrations that may cause mild or reversible effects, extending up to 107 meters downwind and marked in yellow. The black dashed lines represent wind direction confidence lines, while the wind arrow indicates the direction of the gas cloud's spread.

The propane release scenario shows that AEGL-3 concentrations occur within 33 m of the source, AEGL-2 extends to 53 m, and AEGL-1 up to 107 m downwind. While propane is mainly hazardous due to flammability, high concentrations near the source can be life-threatening even without ignition. The teardrop-shaped dispersion pattern highlights wind influence, requiring protective measures downwind and across a wider area than the wind axis.

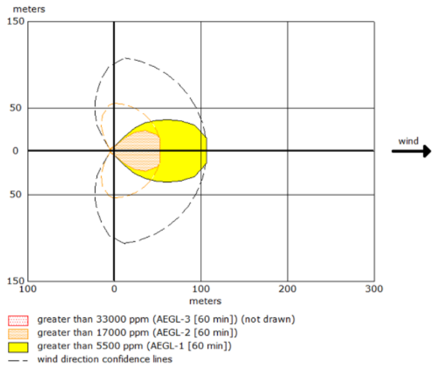

Figure 2. Hazard zone for the propane

DISCUSSION

Both scenarios indicate that the hazard zones are relatively limited in spatial extent, but the potential severity of consequences requires a serious approach to safety measures.

For the hydrogen sulfide (H_2S) leak scenario, the AEGL-2 and AEGL-3 zones are practically confined to the immediate vicinity of the source, which may create the impression of low spatial risk. However, due to the extreme toxicity of H_2S, even minimal distances pose a high health risk, especially considering that this gas can cause a loss of the sense of smell, reducing the ability for self-detection. This characteristic highlights the importance of continuous technical monitoring and the immediate evacuation of personnel from the direct vicinity of the leak source.

The propane leak scenario shows wider hazard zones, dominated by the AEGL-1 threshold downwind, while AEGL-3 and AEGL-2 remain at significantly shorter distances. The main risk with propane arises from its flammability and the potential for asphyxiation at high concentrations. Given the substantial mass of gas released, under unfavorable meteorological conditions (low wind, low-lying terrain) the gas cloud may persist longer and spread beyond the model's predicted zones.

In comparison, the propane scenario covers a broader area, but with a primary focus on fire and explosion hazards, while the H_2S scenario, although spatially more limited, carries a high health risk even at very low concentrations. The comparative analysis further illustrates that the AEGL-1 zone for H_2S extends to about 52 m, whereas for propane it is roughly twice that distance; AEGL-2 and AEGL-3 zones for H_2S remain within 10 m of the source, while for propane they extend to 53 m and 33 m, respectively. These results emphasize the need for specific response procedures, with flammable gas scenarios focusing on ignition prevention and source control, and toxic gas scenarios prioritizing rapid detection, evacuation, and the use of personal protective equipment.

CONCLUSION

The analysis of modeled scenarios shows that hazard zones for both H_2S and propane are relatively limited in distance but differ in nature and severity. The H_2S scenario demonstrates extreme toxicity even with a small release, requiring rapid detection and evacuation procedures. The propane scenario indicates wider zones primarily associated with flammability and asphyxiation risks. These results emphasize the need for scenario-specific safety strategies, continuous monitoring, and strict regulatory compliance to minimize the consequences of accidental releases in refinery conditions.

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Strategies for Increasing Efficiency in the Clothing Production Line - A Theoretical Approach

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Abstract. This paper analyzes strategies for increasing efficiency in the clothing production line, based exclusively on theoretical research and literature from the fields of production management and the textile industry. The aim of the paper is to identify key factors that influence productivity and quality in clothing manufacturing, as well as to present strategies for process optimization, standardization, inventory management, and the implementation of technology. By analyzing theoretical sources, practical guidelines for improving production line efficiency are defined, with an emphasis on continuous improvement and the implementation of lean manufacturing principles. The paper contributes to a better understanding of how theory can support practical changes in the textile industry.

Keywords: production line, efficiency, optimization, standardization, textile industry

INTRODUCTION

The efficiency of the clothing production line represents one of the most important factors for success in the textile industry, which today is under the strong influence of globalization, digitalization, and increasing consumer demands. Companies are faced with shorter delivery deadlines, higher expectations regarding quality, as well as constant pressure to reduce production costs. In such an environment, organizations must seek ways to improve their production processes in order to remain competitive in both domestic and international markets.

The clothing production line consists of a series of interconnected activities – from the procurement and preparation of materials, through cutting and sewing, to finishing operations, quality control, and packaging. The efficiency of each of these stages directly affects the final outcome: production time, labor costs, resource utilization, and customer satisfaction. Even minor inefficiencies in one part of the chain can cause significant losses in the entire process.

In the theory of management and production organization, efficiency is understood as the ability to use resources – human, material, and technological – in an optimal way, minimizing losses and maximizing productivity. Numerous studies in the field of production systems emphasize the importance of process optimization, standardization of operations, automation, and continuous improvement (kaizen) as key instruments for achieving long-term sustainability and competitive advantage.

The aim of this paper is, based on theoretical sources and literature, to present the most important strategies for increasing efficiency in the clothing production line. Special emphasis is placed on the integration of modern management approaches and technological solutions with the needs of the textile industry. The paper contributes to understanding how theoretical principles can serve as a basis for practical improvements and as a guideline for further research in this field.

Analysis of the Current State

The clothing production line consists of several key stages: cutting, sewing, assembly, quality control, and packaging. An analysis of operations reveals the following problems:

- Inefficient workplace layouts – unnecessary movement of workers and materials;
- Production delays – waiting for materials, machines, or work instructions;
- Insufficient process standardization – workers often use different methods for the same operations, which increases errors;
- Outdated technology – manual processes slow down production and increase the possibility of mistakes;
- Inadequate inventory management – lack of materials slows down or completely halts production.

Practical Strategies for Increasing Efficiency

1. ***Optimization of Workplace Layout***
   Optimization of workplace layout involves carefully planning the physical arrangement of the production line in order to minimize unnecessary movement of materials and employees. Efficient organization of workplaces enables a continuous production flow, reduces transportation time of components, and contributes to better coordination between different stages of the production process.

2. ***Standardization of Processes and Employee Training***
   Standardization of production processes includes defining clear procedures for each stage of production, which ensures uniformity in work, reduces errors, and facilitates quality control. Continuous employee training ensures proper application of standards, effective use of equipment, and the ability to quickly resolve problems in the production process.

3. ***Monitoring and Control of Production***
   Monitoring the production process involves systematically recording the time and resources required for each operation. Control enables the identification of problems such as bottlenecks, timely adjustment of resources and work procedures, and measurement of production line performance. This system also allows informed decision-making to improve productivity and quality.

4. ***Automation and Introduction of Technology***
   The introduction of automated processes and modern technologies can significantly reduce manual work, shorten product manufacturing time, and increase the precision of operations. Automation includes the use of machines that perform repetitive tasks, software tools for planning and monitoring production, as well as advanced devices for quality control. Technologically enhanced processes increase production stability and enable higher volumes of work without reducing quality.

5. ***Inventory and Material Management***
   Efficient inventory management involves planning and controlling the materials needed for production to ensure a continuous flow of the production process. Timely procurement, storage, and distribution of materials reduce work stoppages, prevent excess stock that increases costs, and provide flexibility in adjusting production to changes in demand.

6. ***Continuous Improvement***
   Continuous improvement implies constant analysis and evaluation of production operations, identification of weak points, and implementation of corrective measures. This approach enables long-term efficiency growth, adaptation to changes in technology and the market, and fosters a culture of innovation and accountability among employees.

Methodology

This paper is based on theoretical research of literature in the field of clothing production and production process management. A descriptive-analytical approach was applied, in which theoretical strategies and principles were synthesized and adapted for practical application in the context of clothing production. Professional articles, manuals, and other relevant sources were analyzed, with a focus on production line optimization, process standardization, automation, and inventory management.

CONCLUSION

Increasing efficiency in the clothing production line represents a key factor of success in the textile industry, especially under conditions of high competition and constant changes in market demands. The analysis of theoretical sources shows that efficiency depends on several interrelated factors: optimization of workplace layout, process standardization, employee training, application of technology, efficient inventory management, and continuous improvement. Implementing these strategies enables the reduction of operational losses, increased productivity, improved product quality, and better adaptation to demand fluctuations.

Furthermore, theoretical research highlights the importance of organizational culture and employee engagement, since their motivation and competencies directly affect the success of implementing efficiency strategies. Therefore, efficiency is not achieved only through technical or process-related measures, but also through the development of human capital and the continuous adaptation of the organization to new technologies and production principles.

Future research can contribute to a deeper understanding of practical challenges and enable the application of theoretical principles to concrete situations, thereby further enhancing competitiveness and efficiency in clothing production. The following are some suggested directions for future research:

1. Empirical research on the impact of different strategies on the efficiency of specific clothing production lines, including measurements of productivity, cycle time, and product quality.
2. Analysis of the efficiency of introducing automation and modern technologies in the textile industry, including implementation costs and return on investment.
3. Examination of the role of employee motivation and organizational culture in the implementation of lean principles and standardized processes.
4. A comparative study between traditional and modern production lines to identify best practices and factors that contribute most to efficiency.
5. Research on the impact of production process flexibility on adaptation to changing market demands and seasonal fluctuations in demand.

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Conceptual Challenges in Teaching Environmental Physics

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Abstract. The development of scientific literacy in environmental protection requires understanding key physical phenomena affecting the climate. A central topic in environmental physics is the greenhouse effect and the role of radiation in heating the atmosphere. This paper analyzes students’ conceptual understanding of these issues in the Environmental Protection program. A questionnaire with ten multiple-choice and one open-ended question was used, focusing on infrared (IR) radiation and the role of CO_2. Results show that while most students identify CO_2 as a greenhouse gas, many lack a deeper understanding of energy exchange and atmospheric processes. The paper recommends the use of visual models, simulations, and interdisciplinary methods to improve teaching. Findings suggest the need for clearer presentation of fundamental physics concepts in vocational curricula.

Keywords: environmental physics, greenhouse effect, conceptual understanding, infrared radiation

INTRODUCTION

A fundamental framework for understanding key environmental processes – such as energy transfer, atmospheric radiation, and the role of greenhouse gases – is provided by physics. Although these topics have been formally included in educational curricula, numerous studies have reported that fragmented and superficial knowledge of these concepts is often exhibited by students [1,2]. Study programs in Environmental Protection are typically structured around an interdisciplinary approach. However, fundamental physical concepts are frequently underrepresented or conveyed without sufficient conceptual clarity. In the present study, the initial understanding of the greenhouse effect among students was examined, with particular emphasis placed on IR radiation and the role of greenhouse gases. Insights obtained from this diagnostic assessment were used to inform the design and implementation of interactive simulations and instructional strategies.A questionnaire consisting of ten multiple-choice items and one open-ended question was administered. The analysis revealed both prior knowledge and prevalent misconceptions among the participants. The findings indicate that a conceptually integrated instructional approach is needed, one that connects physics content more effectively with real-world environmental challenges.

METHODOLOGY

A total of 15 undergraduate students enrolled in professional study programs in Environmental Protection and Mechanical Engineering participated in the study. In these programs, *Physics of the Environment* is taught as a mandatory one-semester course in the former and as an elective in the latter. Although the Greenhouse Effect Concept Inventory (GECI) [3] was not directly used, it served as a conceptual reference for the development of a questionnaire adapted to the specific educational context. Students had previously attended various types of vocational secondary schools. The instrument comprised ten multiple-choice and one open-ended question[*]. It was administered at the beginning of the semester, prior to formal instruction, to assess students' prior knowledge and identify conceptual barriers. The results were intended to inform the development of teaching methods aimed at improving understanding of greenhouse-related physical principles. Special focus in the questionnaire design was placed on: the difference between solar and terrestrial radiation, including spectral characteristics, the role of IR radiation in atmospheric heating, the mechanism of photon absorption and the physical behavior of greenhouse gas molecules.

ANALYSIS OF STUDENTS' UNDERSTANDING OF THE GREENHOUSE EFFECT AND INFRARED RADIATION

The analysis of student responses was used to reveal a varied level of understanding regarding concepts related to the greenhouse effect and the role of electromagnetic radiation in Earth's climate system. The highest accuracy was recorded in Question 8, in which 80% of participants responded correctly. It was suggested by this result that an intuitive understanding of the consequences arising from the absence of carbon dioxide in the atmosphere is held by most students. A strong performance was also noted in Question 6 (66% correct responses), in which the basic mechanism by which CO_2 molecules behave following the absorption of IR radiation was assessed. In addition, 60% of questions related to the spectrum of radiation emitted by Earth and the influence of CO_2 on atmospheric temperature were answered correctly.

A moderate level of understanding was observed in questions addressing the selective absorption of infrared radiation and the general process of interaction between radiation and gases, with accuracy rates ranging from 47% to 53%. It was indicated by these findings that the role of CO_2 as a greenhouse gas is partially recognized by students; however, key concepts such as spectral selectivity and the distinction between the spectral distributions

[*] The content of the questionnaire is available at the following link:
https://drive.google.com/file/d/169FGy9SweoBKE66lcgnCuIas3QTXzk2N/view?usp=sharing

of solar and terrestrial radiation remain insufficiently understood. Of particular concern was the result for Question 7, for which no correct answers were provided. A significant conceptual gap was thereby indicated in students' understanding of IR radiation emitted by Earth, its partial atmospheric retention, and its subsequent re-emission in all directions.

These patterns of understanding were found to be largely consistent with findings from previous studies. For example, it was demonstrated by Shepardson et al. [1] that while students often possess some intuitive knowledge of global warming, a distinction between solar and terrestrial radiation was not made, and a clear connection between atmospheric temperature and CO_2 concentration was not established by most students. Likewise, it was identified by Niebert and Gropengiesser [2] that a common belief was that CO_2 forms a layer at the top of the atmosphere which prevents the escape of heat, functioning as a barrier.

The moderate performance on questions related to selective absorption was found to be in alignment with earlier findings suggesting that alternative conceptions about radiation–matter interactions are frequently held by students, particularly concerning the absorption, emission, and transfer of energy in the atmosphere. The complete absence of correct responses to one of the questions was interpreted as an indication that some essential concepts are not recognized, even intuitively, thereby reinforcing the need for more explicit and conceptually grounded instructional approaches.

In general, the results were found to reflect the prevalence of fragmented knowledge among the majority of students, along with the absence of a well-structured conceptual framework. This was taken to underscore the necessity for pedagogical strategies in which physical concepts are presented not in isolation, but in close correlation with relevant and authentic contexts such as climate change and environmental science.

VISUALIZING SPECTRAL DIFFERENCES BETWEEN SOLAR AND EARTH RADIATION USING AN INTERACTIVE SIMULATION

The comparison of the spectral distribution of radiation emitted by objects at different temperatures is enabled by the Blackbody Spectrum simulation [4], and the distinction between incoming solar radiation and terrestrial radiation emitted by Earth is clearly illustrated. When the temperature is set to approximately 5800 K, corresponding to the Sun, the emission spectrum is observed to peak in the visible and near IR regions. In contrast, for a temperature of around 288 K, representative of Earth, the peak is shifted into the far-infrared region, around 10 μm. This difference, consistent with Wien's displacement law, is used to provide both visual and conceptual insight into the mechanisms of the greenhouse effect, particularly when the simulation is applied in conjunction with carefully designed questions and instructional activities. One effective strategy is based on having students prompted to reflect on which gases are present in the atmosphere and, among them, which are classified as greenhouse gases. Although most gases are successfully listed by students, difficulty is commonly encountered when non-greenhouse gases are to be identified. This outcome highlights the need for instruction in which rote memorization is replaced by conceptually grounded activities that foster a clear distinction between greenhouse and non-greenhouse gases. More importantly, such an approach allows a fundamental question to be raised: What specific features of molecular structure enable certain gases to absorb IR radiation and thereby contribute to the greenhouse effect?

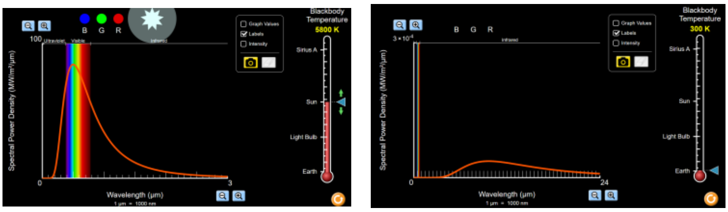

Figure 1. Spectral distribution of radiation emitted by bodies at different temperatures, as shown in the Blackbody Spectrum simulation [4]

MODELING VIBRATIONAL MODES OF ATMOSPHERIC GASES THROUGH INTERACTIVE LEARNING TOOLS

A visual exploration of the interaction between photons of different wavelengths and gas molecules is offered by the Molecules and Light simulation [5], and the selective absorption of IR radiation, a process central to understanding the greenhouse effect, is clearly illustrated.

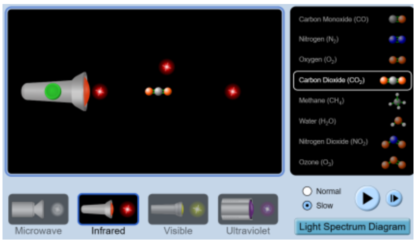

Figure 2. Visualization from the *Molecules and Light* simulation showing the interaction between IR radiation and a CO_2 molecule [5]

The type of radiation (UV, visible, or IR) can be selected by users, and its effects can be tested on various atmospheric molecules such as CO_2, H_2O, CH_4, O_2, and N_2. It is demonstrated through the simulation that molecules like CO_2, H_2O, and CH_4 absorb IR photons and are brought into vibrational modes (bending and stretching), while O_2 and N_2 remain unaffected, with photons passing through without any observable interaction.

The crucial point that is emphasized is that the mere presence of a molecule in the atmosphere is not sufficient; instead, its structural properties and specifically its ability to absorb radiation of a given wavelength determine its role in the greenhouse effect. While this difference can be identified through the simulation, the reason why some molecules interact with IR radiation and others do not is not explained directly within the tool. This distinction is derived from the presence, or absence, of a variable dipole moment, which serves as a physical prerequisite for interaction with IR radiation. Only molecules whose vibrational modes produce changes in their dipole moment are capable of efficiently absorbing IR photons.

Although CO_2 is a linear molecule with a symmetric equilibrium structure and no permanent dipole moment, a transient dipole is generated during specific vibrational modes (e.g. bending), making it responsive to IR radiation. In contrast, O_2 and N_2, being homonuclear diatomic molecules, lack both permanent and variable dipole moments and thus do not absorb IR photons [6].

This connection highlights the importance of physics in climate-related instruction: although the concept of dipole moment is frequently introduced in both secondary and higher education, usually in the context of electrostatics, its relevance to electromagnetic radiation absorption is often omitted. Therefore, a strong foundation for inquiry-based learning is provided by the simulation. By analyzing the molecular structure of CO_2, the guiding question can be posed: when and why does this molecule act as an efficient absorber of IR radiation?

CONCLUSION

The importance of integrating conceptual physics into environmental education, particularly for understanding the greenhouse effect and IR radiation, is highlighted in this paper. Key misconceptions, especially regarding radiation absorption and the structural differences between greenhouse and non-greenhouse gases, were revealed through an analysis of students' initial knowledge, confirming prior research on fragmented mental models. To address these gaps, interactive simulations such as Blackbody Spectrum and Molecules and Light were found to be effective. Abstract concepts such as spectral distribution, molecular vibrations, and dipole moments were visualized, and active engagement was encouraged through the use of these tools, thereby supporting deeper understanding. When implemented within inquiry-based and context-rich instructional settings, improvements in student performance in the Physics of the Environment course were observed.

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Measuring the Speed of Sound with Smartphones: Bridging Physics and Environmental Science

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Abstract. In this paper, we present a low-cost, high-engagement lesson in which students use their own smartphones to measure the speed of sound in various environments. The paper presents the classroom activities, where students learn the basic method, and provides suggestions for repeating the experiment outdoors. The students can measure the speed of sound in streets, parks, and near water, while recording temperature, pressure, and humidity. By plotting their results, the students can investigate how environmental factors influence sound speed and reflect on the physical properties of their surroundings. The presented lesson plan is suited for both high-school and undergraduate students.

Keywords: speed of sound, experiment, smartphones, environmental physics

INTRODUCTION

In most physics classes, students learn how to estimate the distance to a lightning strike by timing the delay between the flash and thunder – assuming the speed of sound is already known. But what if they had to measure that speed themselves?

Over many years of teaching mechanics in both high school and university courses, we've found that students tend to follow a surprisingly similar line of reasoning, often arriving at clever variations of the same basic experiment. Some of their ideas are flawed in execution but valuable in concept; others are both creative and effective.

In this paper, we present the most interesting student-generated variations as well as the "official" solution to the problem and discuss how these methods can be further developed and implemented in environmental physics education.

MEASURMENT METHODS

Allegedly, Galileo attempted to measure the speed of light by placing observers with lanterns on two distant hills. One observer would uncover a lantern, and as soon as the second observer saw the light, they would uncover theirs. By measuring any perceived delay, Galileo hoped to detect the time it took for light to travel between the hills. Of course, the experiment failed – not because the method was flawed in principle, but because the speed of light is too great to be measured without precise instruments.

Students are often aware of this story, and they sometimes propose similar approaches. They suggest that a student could clap their hands while another, standing some distance away, starts a stopwatch at the same time. When the second student hears the clap, they stop the stopwatch. The idea is that, knowing the distance the sound traveled, and measuring the time it took, one could calculate the speed of sound.

However, as with Galileo's original idea, this method fails due to human reaction time and measurement error. While the idea is simple and intuitive, it's not feasible for accurate results. The students quickly recognize the problem themselves. Generating this kind of "naïve" ideas is not only harmless – it is, in fact, very useful. In our experience, encouraging students to voice "half-baked" ideas fosters creativity far more than insisting on immediate correctness. Open discussion and unfiltered idea-sharing often lead to better solutions through rapid iteration. In contrast, especially among university students who are more concerned with being correct, this creative process is often stifled, making it harder to reach meaningful results.

Improving time measurements with phyphox

To improve measurement accuracy, we need to eliminate the variability introduced by human reaction time. Ideally, a stopwatch would start automatically the moment a sound is detected and stop upon detecting another. Fortunately, such a tool exists: the *Acoustic Stopwatch* in the *phyphox* app [1].

The Acoustic Stopwatch starts timing when it detects a loud sound and stops with the next loud sound. To use it effectively, two settings must be fine-tuned through trial and error:

1. *Threshold* – sets the sound level required to trigger the stopwatch. It must be high enough to ignore background noise but low enough to detect a hand clap.
2. *Delay time* – sound reflections from walls, ceilings, or furniture may falsely trigger the stopwatch. By introducing a short delay (e.g., 1 second), we ensure that reflections settle before the second clap occurs.

Experimental setup: different ideas and solutions

The first student-proposed setup involves placing two smartphones approximately $l = 5 - 6$ meters apart, typically the length of a classroom. One student stands next to Phone A and claps. If the threshold and delay parameters are set up properly, both phones detect the clap and start their stopwatches, but due to the speed of sound, Phone B starts slightly later, by a time Δt. A second clap stops both stopwatches.

However, this method doesn't work as expected, which can be easily verified experimentally. Although Phone B starts Δt later, it also stops Δt later, meaning both stopwatches display the same time (Figure 1). This failed result becomes a valuable teaching moment as the students quickly understand why no time difference is recorded.

Figure 1. Unsuccessful student solution – both stopwatches record the same time interval

To overcome this, students devised two elegant solutions, that are original, simple and effective.

Moving the second phone

After starting the stopwatch on Phone B with the first clap, the phone is quietly moved next to Phone A (Figure 2). When the second clap occurs, both phones receive it simultaneously, stopping their timers. Phone B now shows the delay Δt relative to Phone A, which corresponds to the time it took for the first clap to reach to the Phone across the original distance.

Figure 2. Moving the second phone from position B1 (for the first clap) to position B2 (for the second clap)

Clapping in the middle

Alternatively, the second clap can be performed at the midpoint between the two phones (Figure 3). This ensures the sound reaches both phones at the same time, so only the starting times differ. The difference in recorded times again yields Δt.

Figure 3. Performing the second clap in the middle of the phones

The official method and global clock model

While we prefer the students' solutions due to their creativity and elegance, going through a method presented in [2] could be useful to students. While initially confusing, we had success explaining it using the idea of a global clock (Figure 4).

Assume the first clap occurs at time t_1. Phone A, being nearby, registers the sound at t_1, while Phone B hears it at $t_1 + \Delta t$. The second clap, performed near Phone B at timet_2, is registered immediately by Phone B, and at $t_2 + \Delta t$ by Phone A. Thus, the time difference between the two phones is $2\Delta t$. Knowing the distance between phones, students can calculate the speed of sound by dividing the phone distance with Δt.

The global clock approach can be used alongside the intuitive method illustrated in Figures 1, 2, and 3 to help reinforce students' understanding.

Figure 4. Performing the second clap in the middle of the phones

Results and limitations

Using any of these methods, students can successfully measure the time it takes sound to travel across a known distance and calculate the speed of sound. Our results were consistent, and they closely matched the expected value of approximately 340 m/s.

A word of caution: as described, the experiment requires two smartphones, and compatibility matters. In our experience, Android devices worked reliably, while iPhones consistently produced erroneous results, by a factor of 2. We recommend using two devices of the same type, preferably Android, for best performance.

IDEAS FOR ENVIRONMENTAL PHYSICS

For ideal gas, the speed of sound can be expressed as [3]:

$$c = \sqrt{\gamma \frac{p}{\rho}} = \sqrt{\gamma \frac{RT}{M}} \tag{1}$$

where γ is the adiabatic index, and p, ρ, T, and M represent pressure, density, absolute temperature and molar mass of gas, respectively. R is the universal gas constant. For dry air at 20°C, typical values are $\gamma \approx 1.4$ and $M \approx 29$ g/mol.

In varying atmospheric conditions (pressure, temperature, humidity) the speed of sound will also vary. Using the methods presented in this paper, students can measure the speed of sound in different environments such as streets, parks, and near bodies of water. While doing so, they can simultaneously record environmental variables like air temperature, barometric pressure, and humidity.

By plotting their measurements and comparing them with theoretical predictions from equation (1), students can investigate how environmental factors influence the speed of sound, as well as whether the ideal gas approximation is applicable to real atmospheric air.

CONCLUSION

In this paper, we have shown how smartphones can be used to measure the speed of sound. The presented and suggested activities offer a highly accessible and engaging way to introduce students to both fundamental physics and environmental science.

The variety of student-generated solutions demonstrates the power of open-ended exploration in the classroom. By using tools such as the *phyphox* app and conducting measurements in real-world environments, students can meaningfully connect theoretical models with empirical observations. With minimal resources and a high level of engagement, this experiment can be effectively implemented across both high school and undergraduate curricula.

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Movement of Quantity and Morphological Composition of Municipal Waste in the Subotica Agglomeration

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Abstract. Municipal waste management poses a global challenge in the context of the impact of the consumer society of the linear economy. In order to reduce the amount of waste and its negative impact on the environment, it is essential to monitor and control the structure and quantity of municipal waste. The municipal waste is treated in the central complex of the Subotica waste region, which consists of seven local municipalities, where secondary sorting and waste disposal are carried out in accordance with EU standards. In addition to the treatment and disposal of solid municipal waste, the technology also performs industrial composting.

Keywords: waste management, municipal waste, primary and secondary sorting, disposal

INTRODUCTION

The Subotica regional waste management system was designed and built to accept municipal waste from 250,000 inhabitants on an annual basis, representing 80,000 tons. The basic guideline, or the organization of functioning, is foreseen at the beginning of the process on the primary selection (wet and dry fraction) of waste, and on the secondary selection of the recyclable fraction, with the fact that in the following period, during the gradual development, the selection of glass and green waste should be specifically introduced [1,2].

AMOUNT OF MUNICIPAL WASTE RECEIVED FOR TREATMENT AND DISPOSAL

In the period between 2020 and 2024, the regional system first recorded a linear growth and for the last two years an exponential growth in the amount of received waste. The amount of municipal solid waste in the period 2020-2024 is shown in Table 1.

Table 1. The amount of municipal solid waste in the period (2020-2024)

Period (years)	Municipal waste received in the regional system (tons)
2020.	17.427,08 t
2021.	26.770,78 t
2023.	28.792,27 t
2024	59.223,33 t
2025.	69.567,51 t

In 2023, the city of Subotica started harmoniously organized collection according to the projected project quantities, and transported waste recorded an exponential jump, even growth in 2024. In 2023 and 2024, 74,967.46 tons of municipal waste were received from Subotica. In addition to the city and in some municipalities, the amount of transported municipal waste increased, but this growth does not show exponential growth, but gradualness. According to the project quantities, Subotica produces 54.7% of waste in the total amount.

STRUCTURE AND MORPHOLOGICAL COMPOSITION OF MUNICIPAL WASTE

In total, or in the amount of communal solid waste, the largest percentage is waste of an organic nature, which consists of kitchen waste, food waste and green waste. Due to the significant amount of organic waste, a technological unit of industrial composting was built, which has a useful value. The rest of the waste structure is separated secondarily after the primary selection of the wet and dry fraction (in the green-blue bin system), namely: paper, glass, PET packaging, plastic waste, metal and aluminum on the separation line (MRF) [3,4]. Figure 1 shows the percentage structure of municipal waste in the Subotica agglomeration.

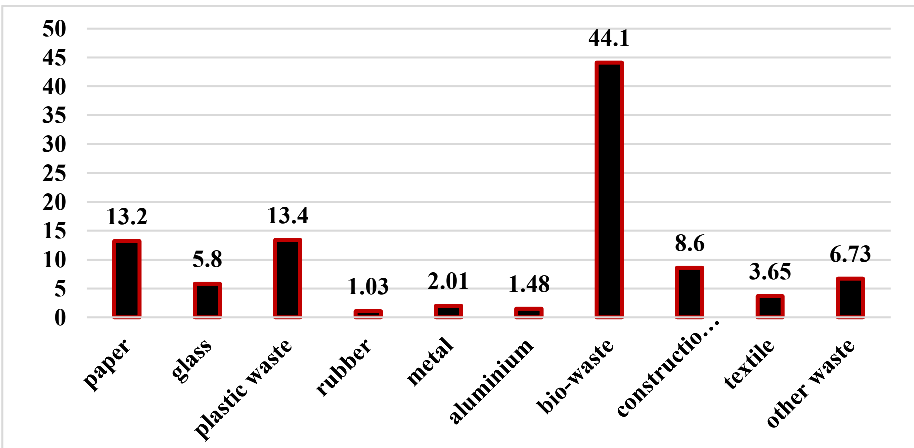

Figure 1. Percentage (%) ratio of municipal waste structure in the Subotica agglomeration

The quantitative ratio of the wet (green bin) and dry fraction (blue bin) is shown in Figure 2.

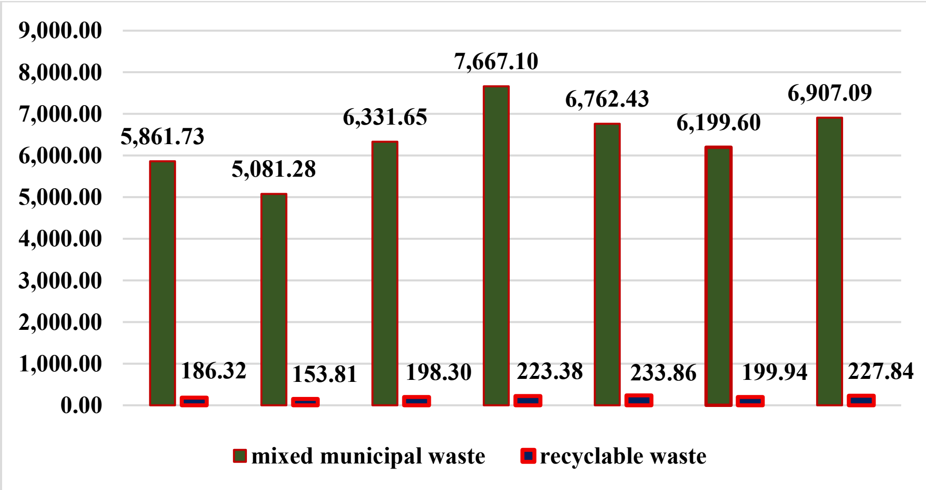

Figure 2. Quantitative ratio of wet (green bin) and dry fraction (blue bin)

These recyclable fractions after baling are handed over to waste operators for recycling. In addition to the separation of the recyclable component as a secondary raw material, a mixed structure is also prepared from a lower-quality or unusable structure such as (Refuse Derived Fuel, or RDF) - solid fuel [5], which is submitted for burning as an energy source to cement factories in order to reduce the use, or use of the free space of the sanitary landfill. The rest of the waste, or the unusable structure that makes up the majority of it, is disposed of at a sanitary landfill built according to European standards, directives [5]. Picture 3 shows the technological line of secondary selection - MRF (Material Recovery Facility)

Figure 3. Technological line of secondary selection - MRF (Material Recovery Facility)

In addition to municipal waste, the regional waste management system, due to the obtained IPPC permit for integrated prevention and control of environmental pollution, can also receive industrial non-hazardous waste for disposal, as well as organic, biodegradable waste as a resource from business entities in order to obtain compost material according to European directives, standards [7,8]. Compost from biodegradable waste is shown in Figure 4.

Figure 4. Compost from biodegradable waste

CONCLUSION

The success of a regional waste management system requires continuous development. In addition to increasing the rate of municipal waste recycling in line with the guidelines of international professional institutions, it is important to develop and complete the introduction of primary selective waste collection in the Subotica region. It is important to raise awareness and consciousness in households about primary selective waste collection in order to achieve the highest quality secondary selective waste collection. It is important to promote alternative options for the energy efficiency of the technological units of the regional system and to transform waste into products in accordance with the principles of the circular economy.

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Neoliberal Globalization and the National Environmental Protection System

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Abstract. In the process of neoliberal globalization, the power of nation-states is weakened in favor of increasingly powerful transnational corporations and international financial institutions. The activities of transnational actors potentially override national environmental protection laws when these laws threaten the freedoms of multinational companies. Sovereign states no longer maintain robust policies regarding the growing global ecological challenges. More specifically, in developing countries, environmental security and corresponding legal regulations are weak or virtually nonexistent. In contrast, through the expanding alter-globalization movement, citizens demand financial and democratic tools that enable them to control their own destinies, apply their expertise, and develop diverse economic sectors that are genuinely sustainable.

Keywords: neoliberal globalization, multinational corporations, comprador elite, environmental protection, alter-globalization movement

INTRODUCTION

"Leaving the fate of the land or people to the market would be equivalent to their destruction."

Karl Polanyi [1]

Changing the world and our perception of the world we live in, globalization according to Anthony Giddens is: **"…connecting distant places in such a way that local events are shaped by occurrences thousands of kilometers away and vice versa."** [2] For a vast number of people, ecological, social, and economic problems and issues arise, which are to a greater or lesser extent linked to the trend of globalization. In other words, globalization affects everyday life as much as it does events at the global level. Thus, globalization denotes the expansion and deepening of social relations and institutions across space and time, particularly when everyday activities are increasingly influenced by events occurring on the other side of the globe, and when the actions and decisions of local groups or communities have significant global repercussions.

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Globalization is often equated with economic globalization, which implies the dominance of the free market, international economic integration, reduction of trade barriers, and free flow of capital. According to Thomas Friedman: **"...globalization means the spread of free-market capitalism to almost every country in the world."** [3] Thus, globalization is characterized as the rule of the world market, or in other words, the dominance of neoliberal ideology. At the core of the free-market ideology lies a model frequently attributed to Adam Smith, according to which market forces—motivated by profit—act as an invisible hand guiding the economy toward efficient outcomes. Since, according to this model, there is no need for government intervention—that is, free and unrestricted markets function perfectly—these policies are classified as neoliberal and are based on market fundamentalism [4].

Alongside the positive possibilities offered by globalization, numerous risks also arise. Today, we face the dominance of "manufactured risks" that are a direct consequence of human knowledge and technology's impact on the natural world. Global climate change and the dangers it poses represent catastrophic consequences of neoliberal globalization: the greenhouse effect, genetically modified food, pandemics such as COVID-19, scarcity of drinking water. According to Anthony Giddens, some of these manufactured risks have truly catastrophic proportions, such as global ecological risks, the spread of nuclear technology, or the collapse of the global economy. Risk, which today has reached alarming proportions, transforms the modern world into risk societies beyond our control: **"…some kind of runaway world…"** [5]. The unimaginable scale of risks is an inherent consequence of the prevailing type of techno-economic development, with risks increasing alongside its advancement.

LOSS OF SOVEREIGNTY OF NATION-STATES

"After the triumph of the speculative, casino economy organized by the enlightened neoliberal technocrat, a kind of virtual parliament of big business emerged, possessing veto power over governments and entire states."
Andrej Grubačić [6]

In the process of globalization, the power of nation-states weakens in favor of increasingly powerful transnational corporations, whose strength breaks down all previously established boundaries. Neoliberals, who have high expectations for the abolition of nationally organized democracies, aim to accelerate globalization processes and place global economic relations beyond the reach and control of citizens. Neoliberals justify the rejection of any political state intervention in the supposedly self-regulating market as "destabilizing democratic illusions." In this context, Jürgen Habermas writes: **"In the process of the disappearance of societies organized as nation-states, postmodernism recognizes the 'collapse of politics,' in which neoliberalism also places its hopes, wishing to delegate as many governing functions as possible to the market."** [7]

These insights are shared by Joseph E. Stiglitz, who argues there is reason to be concerned about globalization's impact on democracy. Globalization often replaces the old dictatorships of national elites with new dictatorships of transnational corporations and international financial institutions, which control democratically elected governments through the imposition of "structural adjustment" programs. As Stiglitz writes, **"Countries have been effectively told that if they do not comply with certain conditions, the IMF or capital markets will cease to grant them loans. These countries are essentially forced to partially relinquish their sovereignty and allow corporate capital markets to discipline them, telling them what they should and should not do."** [8]

This brings us to postmodern neocolonialism, in which the nation-state is only formally independent despite possessing attributes of international sovereignty, as its policies and economy are controlled externally. As Slobodan Antonić emphasizes, neocolonialism is the flip side of informal imperialism—namely, an unofficial empire: **"...it governs the resources, markets, and random power of a formally independent but significantly weaker state... and the main governing instrument is the collaboration of a segment of the domestic economic and political elite, which is in an interest symbiosis with the structures of the empire."** [9] The domestic comprador elite, as part of transnational capitalist structures, according to sociologist Vera Vratuša, **"...mediates the implementation of predatory privatization and the colonial, enslaving sale of strategic systems."** [10]

ENVIRONMENTAL PROTECTION AND TRANSNATIONAL ACTORS

Through the process of neoliberal globalization, nation-states are undermined by the activities of transnational actors, who potentially override national laws in the field of environmental protection (as well as labor and social rights) if these laws threaten the freedoms of multinational corporations to control the economic affairs and social life of the nation-states. Consequently, the response of the comprador national elite to global climate change and environmental pollution amounts to formal policies: **"…seemingly grand plans devoid of substance."** [11] This justifies Giddens's conclusion that sovereign states lack any serious policies regarding the growing global ecological problems. More precisely, in developing countries, environmental security and related legal regulations are weak or nearly nonexistent. Some multinational corporations sell products (GMO seeds and pesticides harmful to biodiversity and human health) that are controlled or banned in developed countries. According to Nobel laureate Joseph E. Stiglitz, during his tenure as Chief Economist of the World Bank from 1997 to 2000, what he witnessed radically changed his views on globalization and economic development: **"I saw firsthand the devastating effects globalization can have on developing countries, especially on the poor in those countries."** [12]

Highly developed countries, which ought to lead the fight against the climate crisis by transitioning to low-carbon economies and implementing radical social and economic reforms, face what they describe as the problem of competition from economies reliant on dirty technologies. Their economies may suffer difficulties because they are exposed to competition from goods produced more cheaply in other countries where environmental taxes and regulatory restrictions are absent. This is also why many multinational corporations cite the principles of free-market competition, the abolition of state interventionism, and rejection of regulations as justification for: **"…slow responses to initiatives aimed at implementing climate change mitigation measures."** [13]

The loss of state control capacity, or loss of autonomy, indicates that an individual state, by its own power, cannot protect its citizens from the external effects of other actors, nor from the chain reactions of processes originating beyond its borders. Habermas notes that this is a case of: **"…spontaneous transgression of boundaries…"** [14], as in the cases of global warming, environmental pollution, pandemics, migration crises, arms trade, and in another case, calculated consequences created without the participation of those affected: the risk of a nuclear reactor accident built outside the national state whose safety standards do not meet those of the local state.

DISASTER CAPITALISM

"These terrible times offer the best opportunities for those who understand the need for fundamental economic changes."

John Williamson

Multinational corporations with large international investments in foreign countries sought a stable and profitable environment: lenient investment and environmental protection laws, compliant workers, and no surprises in the form of nationalization of multinational corporate assets. However, in today's disaster capitalism, wars, terrorist attacks, natural disasters (hurricanes, tsunamis, wildfires, pandemics), and economic collapses of states themselves are sources of enormous profits. As a fundamental form of capitalism, "disaster capitalism" is essentially a model of exploiting crises and catastrophes that are necessary for its advancement and the generation of enormous profits.

By managing to turn disasters to their long-term advantage, floods of catastrophes transform into spectacular profits. Even economic systems that oppose all attempts at legal regulation and environmental protection generate a steady flow of disasters—whether military, ecological, or financial in nature. Our collective dependence on dirty energy sources creates a stable supply of various crises: natural disasters such as oil spills in oceans and seas, and wars fought over control of scarce resources, which in turn lead to terrorist attacks, which again lead to highly profitable military interventions.

The active creation of crises worldwide by disaster capitalists was anticipated by John Williamson, the architect of the "Washington Consensus," already in 1993 at a gathering of the "neoliberal tribe": **"…one must ask whether there is any logic in the idea of deliberately provoking a crisis to remove a political obstacle to reforms... Could a smaller-scale crisis serve? Is it possible to plan a crisis that would serve the same political function…"** [15]

CONCLUSION

Although protests against neoliberal policies and the actions of international institutions have been present for decades in developing countries, whenever harsh structural adjustment programs proved too severe in those countries, their protests were generally unheard in the complacent West. However, the situation has changed.

Today, symbols of the global economic movement are everywhere targets of attack. Meetings of the international elite of power have become occasions for large demonstrations by the alter-globalization movement. Almost overnight, globalization has become the pressing issue of our time. Every meeting of the *IMF*, *the World Bank*, or *the World Trade Organization* sparks demonstrations.

Although critics of the alter-globalization movement point to its lack of a "central theme" or "coherent ideology" as a flaw, this is in fact its greatest strength, distinguishing it from previous movements and making it appealing to ordinary people. The alter-globalization movement attempts to create horizontal networks of organizations as opposed to vertically organized structures such as political parties or corporations, and these networks rest on the postulate of decentralized, non-hierarchical direct democracy. The emphasis is thus on pluralism and diversity, which manifests the spirit of the alter-globalization movement by basing the future on global dialogue rather than decisions imposed by domestic or foreign elites. Alter-globalization movements arise because people observe how national governments act according to the dictates of multinational corporations and international financial institutions. Therefore, citizens demand financial and democratic tools with which they can control their own destinies, utilize their expertise, and build diverse economic sectors that are truly sustainable.

Social forums, demonstrations, and all movements and efforts must coalesce into a unified pattern of social change; when that happens, the question will no longer be whether social and ecological justice will be established, but when.

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Neoliberal Capitalism and Global Climate Change

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Abstract. The global ecosystem, on which the survival of human civilization as well as all plant and animal species on Earth depends, is deteriorating exponentially due to climate change caused by economic development based on the exploitation of fossil fuels and dirty technologies. The reality of the climate chaos we have entered is both tangible and visible, as are its causes: corporate interests and a decades-long shift toward the ideology of the free market, which opposes the legal regulation of corporate behavior. Therefore, thinking about the causes of the climate crisis leads us to the neoliberal model of capitalism, that is, to an economic model of unlimited consumption. Only radical transformations in the economy and the state, or changes in our techno-economic paradigm, can lead us out of the global crisis. What is needed is collective social action of unprecedented historical proportions, such as the New Deal or the Marshall Plan, aimed at building a global society that no longer threatens the survival of the human species or harms the global ecosystem.

Keywords: climate change, capitalist society, Green New Deal, state interventionism

INTRODUCTION

"The planet is not our captive, patient, machine, nor our monster. It is our world, and the solution to global warming lies not in changing that world but in changing ourselves."

Naomi Klein [1]

At the beginning of the 20th century, Herbert J. Wells, in his lecture at the Royal Institute in London (King's College London), prophetically foresaw catastrophes on a global scale: **"It is impossible to prove that certain things will not completely destroy the human race and end its story, that night will not soon fall and render all our dreams and efforts futile… something from space, some contagion or a great disease of the atmosphere… or destructive madness in the human mind."** [2]

The "great disease of the atmosphere," namely climate change, has loomed over humanity as the primary global challenge of the 21st century. Planetary-scale climate disruptions are not a threat coming from the future but a present reality: **"…and not just a**

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few unlucky hotspots but on all continents," notes Naomi Klein [3]. And Bill McKibben argues that global warming is war but: **"…it is a world war against all of us."** [4]

GLOBAL CLIMATE CHANGE AS A THREAT TO THE SURVIVAL OF HUMAN SOCIETY

Global climate change is unfolding much faster than projected by climatological models. Less than a decade ago, in January 2017, the *Bulletin of the Atomic Scientists* moved the hands of the Doomsday Clock to two and a half minutes to midnight, warning of a level of danger not seen in the previous thirty years. As stated by Rachel Bronson, executive director of the Bulletin, two main threats to the survival of the human species prompted scientists to make this adjustment: the threat of nuclear weapons and uncontrolled climate change. Additionally, the journal condemns world leaders who **"...are failing to act with the speed and on the scale required to protect citizens from potential catastrophe..."** [5], thereby endangering all human beings on the planet, as they are not fulfilling their duty — ensuring the vitality and preservation of human society.

However, events that have occurred since that warning have only strengthened the scientists' resolve to move the clock even closer to midnight, as we are faced daily with an abundance of new evidence demonstrating just how serious the global climate crisis has become [6].

According to reports by the United Nations' World Meteorological Organization, if we continue on this path, global temperatures are projected to rise by 3 to 5 degrees Celsius, calling into question the very foundations of the world as we know it. In other words, if humanity continues polluting the environment at this pace, it will face consequences that are fundamentally incompatible with the survival of the global community. As Stephen Hawking emphasized, our resources are being consumed at an alarming rate, and we have given our planet a dreadful gift — climate change: **"...temperatures are rising, the polar ice caps are shrinking, forests are being cut down, and animal species are being decimated."** [7]

Humanity is eroding the health of ecosystems, the foundations of the economy, life itself, health, and quality of life across the planet. Devastating hurricanes, droughts, floods, and the overall warming of the planet clearly indicate, as Slavoj Žižek puts it, that **"...we are witnessing something for which the only appropriate term is 'the end of nature.'"** [8] It is for this reason that Greta Thunberg calls for urgent action: **"I want you to act as if the house is on fire, because it is."**

Reports by the Intergovernmental Panel on Climate Change (IPCC) continuously stress the urgent need to replace fossil fuels with alternative energy sources in order to avoid the worst outcomes and to achieve a sustainable economy within a few decades — that is, to implement the Principles of Sustainable Development globally by the end of this decade. **"If we do not,"** writes Noam Chomsky, **"we will cross a point of no return, and the consequences will first and most severely affect the most vulnerable — those least responsible for the crisis... Many communities may find their environments uninhabitable."** [9]

Supporting Chomsky's statement, it should be noted that the World Health Organization calculated back in 2015 that, over the previous decades, nearly 150,000 people per year had died as a result of climate change, and that 22 million people had been displaced from their homes due to extreme weather events and rising sea levels [10]. The most vulnerable populations in Africa and Bangladesh are not even in a position to adapt to the consequences of climate change.

CAPITALISM AND CLIMATE CHANGE

According to Marv Waterstone, environmental injustice disproportionately affects the poor - those who have contributed the least to climate chaos, yet suffer its most severe consequences: **"In a sense, the planet is engaged - or we are engaged - because of our socio-economic system; we are engaged in a kind of genocide across the planet."** [11]

It is important to note that the global health crisis caused by the SARS-CoV-2 virus is also a consequence of climate change. As a major stressor in the lives of bats - carriers of coronaviruses - climate change contributes to other zoonotic spillovers as well. **"COVID-19 is a global disease that corresponds to global warming... when this illness passes, the Earth will send many more plagues our way,"** warns Andreas Malm [12], adding that the level of interaction between the capitalist economy and virtually all potential reservoirs of infectious species is rapidly increasing. Waterstone agrees, noting that climate change also contributes to: **"...vector-borne infectious diseases as species migrate to new zones."** [13]

In this context, we should recall the words of Rosa Luxemburg, who linked the deaths of workers to the inhumane conditions of capitalist society: **"If they look through their microscope, doctors may trace the fatal infection in the victim's poisoned gut; but the true bacillus that caused the death of those in shelters is called capitalist society."**

The global ecosystem - upon which the survival of human civilization, as well as all plant and animal species, depends - is deteriorating exponentially due to climate change driven by an economy based on fossil fuel exploitation. Humanity is destroying natural resources, altering the climate, and devastating biodiversity, pushing many species toward extinction. As such, our global village is also threatened by the loss of biological diversity. Throughout geological history, five mass extinctions of flora and fauna have occurred. Humanity is now causing the sixth: **"We are destroying the book of life before we have even read it... Preserving the richness of our biosphere has intrinsic value - one greater and more important than its usefulness to us humans."** [14]

For the first time in Earth's history, a single species holds the planet's fate in its hands - and can jeopardize both its own survival and the survival of an immeasurable wealth of life.

When capitalism encounters nature, it does not step back in awe of its beauty - quite the opposite: it despises the vacuum of wilderness. **"Capital can only relate to wilderness by attaching itself to it, forcing it to yield products that hold exchange value,"** [15] Malm writes. The most influential philosopher of the plantation, John Locke, expressed capitalism's contempt for the "wild pasture of nature," or the original state of the world, in these words: **"Land that is entirely left to nature, not improved for pasture, tillage, or planting, is called a 'wilderness,' and rightly so; and we shall see that its value is almost nothing."**

Thus, Andreas Malm concludes, in the eyes of early capitalists: **"Wilderness is worthless waste - an abomination to capitalists, because it represents a field of resources not yet subjected to the law of value."** [16]

“I beg you, please do not fail us on this.”
Greta Thunberg, address to the European Parliament, 2019

Despite Greta Thunberg’s pleas, world leaders continue to uphold the status quo when it comes to addressing global climate change. At the end of 2015, global leaders met in Paris to tackle the problem of unchecked climate disruption. After the agreement was adopted, French Foreign Minister Laurent Fabius triumphantly declared: **"This is a small step that can achieve great things,"** and that it is a: **"legally binding document."** [17] However, many obstacles remain in its implementation - not least the requirement that the agreement only becomes legally binding after ratification by all participating countries’ governments.

The reality of climate chaos is indisputably present, as are its causes: corporate interests and a decades-long shift toward the ideology of the free market - an ideology that resists legal regulation of corporate behavior. It is clear that the roots of the climate crisis lie in the neoliberal model of capitalism, that is, an economic system based on unlimited consumption and the exploitation of environmental resources, combined with a demand for the anti-regulatory role of the state, as Naomi Klein points out: **"We have been looking at the climate crisis from the wrong angle, because the problem isn’t carbon - it’s capitalism, its extreme anti-regulatory version that has seized the global economy and is steering us toward destruction."** [18]

By denying climate change, the neoliberal capitalist system reveals that it does not think in terms of collective existence - it is always about a handful of capital owners, solely motivated by personal profit [19]. Or, as Noam Chomsky puts it: **"Why organize for a just future for all, when we can destroy the planet to help wealthy corporations become even wealthier?"** [20]

CONCLUSION

"The things they told us were impossible must start happening today, immediately, and now." [21] - Naomi Klein states emphatically. Precisely because of the dominance of global powers - who also happen to be the planet’s largest polluters - only radical transformations in the economy and the state, that is, a shift in our techno-economic paradigm, can lead us out of the global crisis. What is needed is collective social action of unprecedented historical scale, akin to the New Deal or the Marshall Plan, aimed at building a global society that no longer threatens the survival of the human species or harms the global ecosystem [22].

A new Green New Deal, rooted in state interventionism, can create the revolutionary economic and social environment necessary for the development of a green economy - a transformation of both national and global economies.

Faced with a choice between a just future or continued systemic injustice, we need a new Green New Deal to unite stakeholders from the public, private, and civil sectors and orient them toward long-term outcomes, with the public interest as the central guiding principle.

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Climate Change, Green Technologies, and State Interventionism

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Abstract. The carbon lobby, along with the associated industrial lobby, has continuously sought to obstruct measures aimed at reducing global pollution caused by greenhouse gas emissions. Through climate change denial or redirecting focus toward models of "green capitalism," neoliberal capitalism resists any undertaking of radical action in response to climate change. However, if driven by profit maximization, green technological innovations are unlikely to lead to a resolution of the climate crisis, nor do they represent a call for a fundamental transformation of the dominant socio-economic order or a change in the way we live. In his fundamental diagnosis of the era we live in, Žižek argues that today's global crisis is not, at its core, economic. It is an ideological crisis.

Keywords: global climate change, power, neoliberal capitalism, green innovations, state interventionism, ideology

INTRODUCTION

"Accumulate, accumulate! That is Moses and the prophets... Accumulation for the sake of accumulation. Production for the sake of production!" [1]

Recalling Karl Marx's idea of primitive accumulation of capital, Andreas Malm emphasizes the well-known fact that capital, by growing, merely expands its circulation. The larger the number of biophysical resources that can be transformed into commodities and sold, the greater the profit; with greater profit comes the ability to acquire more resources - and so the cycle continues. Hence, in her book *The Origins of Totalitarianism* [2], Hannah Arendt corrects Marx's insights by claiming that primitive capital accumulation is a cyclical phenomenon: whenever capital encounters a new living space, it transforms it into a resource. In *Dialectic of Enlightenment*, Max Horkheimer and Theodor Adorno point out that Enlightenment - understood in the broadest sense as progressive thinking - has always aimed to free humans from fear and make them masters. But the fully enlightened world **"...radiates under the sign of triumphant calamity... Humans pay for the increase of their power with alienation from what is in their**

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power. Enlightenment relates to things as a dictator does to people. It knows them only by manipulating them...”[3] Thus, Horkheimer further notes that humans treat nature as mere instrumentality. Nature becomes the object of unlimited, total exploitation because boundless imperialism is never satisfied. Human domination of planet Earth has no parallel in previous epochs of natural history, in which other animals represented the highest forms of life. Their appetites were limited by their survival needs. However, Horkheimer does not believe that greed is innate to the human species, but rather that it arises from the values of capitalist society. He writes: **“Man’s greed to extend his power into the two infinities - microcosm and universe - does not stem directly from his own nature, but from the structure of society... the totalitarian assault of the human race on everything outside itself originates more from interpersonal relations than from innate human qualities.”** Paradoxically, through the exponential expansion of our freedom and power **“...that is, our growing capacity to transform nature around us, even to the point of destabilizing the basic geological foundations of life.”** [4] - we are limiting our freedom. This becomes increasingly visible through the consequences of global warming. Is Noam Chomsky, then, once again right in claiming: **“There used to be the idea that together we could overcome the crisis. That sense has been lost. Now it feels like we are trapped with no way out.”** [5]

DENIAL OF CLIMATE CHANGE

In the symbolic order that structures capitalist society, man is driven by the desire for power and always wants more of it. Precisely for the sake of preserving the power of the wealthy ruling minority, the dominant discourse today defends the view that climate change does not exist - or that it is a leftist fabrication. The carbon lobby, along with related industrial interests, continuously seeks to prevent measures aimed at reducing global pollution caused by greenhouse gas emissions. By denying climatology or diverting attention toward models of "green capitalism," neoliberal capitalism resists any radical action in response to climate change.

Thus, skeptics regarding the catastrophic consequences of anthropogenic climate change emphasize: **"And while it is true that a rise in global average temperature of 4 degrees Celsius would likely represent dangerous climate change by most measures, it need not be catastrophic in the sense of threatening extinction. The evidence suggests that the challenges our descendants will face will be difficult but survivable."** And: **"In terms of global climate, potential catastrophes and alleged tipping points remain, in a sense, mythical aspects: they are part of a useful way of thinking about potential rapid surprises in a system we do not fully understand, but it is difficult to see how to incorporate that uncertainty into our strategies."**[6].

The reasons for such a position are entirely clear, claims Andreas Malm, because corporate and politically affiliated interests of the ruling minority are always at play: **“Carbon dioxide is the exhaust gas that forms the material basis for the production of surplus value - fossil fuel - and thus also a coefficient of power. Many interests are entangled in the ongoing release of carbon dioxide into the atmosphere.”**[7]. Numerous authors also point out that denying climate chaos is in fact a defense of market fundamentalism and the neoliberal ideological project whose influence on the course of historical events has meant that **“the spontaneous evolutionary process has been replaced by designed evolution.”**[8]

In the late 1980s, this extreme anti-regulatory version of capitalism began to dominate the global economy, steering us toward global climate destruction. As Naomi Klein illustratively states: **“During that period, we expanded two-lane roads into carbon-spewing highways, and then into six-lane superhighways.”** [9] Climate change essentially represents a powder keg placed beneath the ideological structure of contemporary capitalism. The economic system that has dominated for the past forty years is especially destructive, resulting in enormous damage to the natural environment. As Noam Chomsky notes: **“It has harmed most of the population, resulted in a huge increase in inequality, and damaged both democracy and the natural environment.”** [10]

Namely, when capital latches onto nature, it cannot help but exhaust it, and with the aggressive cutting of production costs and the race for ever-greater profits, we arrive at **“...a point where certain segments of the labor force and nature will be destroyed.”** [11] Chomsky illustratively points out the devastating consequences of neoliberal dogmas by drawing a distinction between physicists and economists: **“Physicists don’t say ‘let’s investigate something that could destroy the world because it would be interesting to see what happens.’ Economists do.”** [12] He concludes that enrichment is the sole imperative of neoclassical economic theory.

For that reason, it is worth recalling 18th-century economic thinkers such as Adam Smith, the founder of neoclassical economic theory, who in his magnum opus *An Inquiry into the Nature and Causes of the Wealth of Nations* [13], claims that economic actors in a free market naturally coordinate among themselves, and that rational individuals should be left to decide for themselves, without state interference, because that is the best way to manage a market economy. However, as Herbert Simon observed: **“The world is too complex for our limited intelligence to comprehend.”** [14] In other words, we always articulate our opinions according to the dominant symbolic order of reality.

STATE INTERVENTIONISM

“We need the state. That’s what distinguishes us from the anarchists.”
Lenin

Of course, when it comes to policies related to climate change, the role of the state does not imply a return to centralized planning, as Slavoj Žižek emphasizes: **“I’m saying the biggest problem is whether we can somehow regain control over financial capital without falling into the trap of totalitarianism again.”** [15] Noam Chomsky also stresses that the alternative to the late phase of capitalism is **“...not a planned economy governed by an authoritarian state.”** [16] Giddens also highlights the importance of the role of the state in relation to climate change, but rejects calls for a return to centrally planned governance, arguing that we must preserve the advantages that a regulated market provides: **“We will have to ensure that we do not revert to the traditional state model or discard the benefits that complex market mechanisms can offer us.”** [17]

In order to prevent global temperature rise beyond 1.5 degrees Celsius, thorough, precise planning is essential. Further warming of the planet will not stop due to spontaneous drops in demand for goods and services, nor will "rational" individuals suddenly and voluntarily abandon their consumer habits. Simple solutions to the problem of climate change - such as the implementation of carbon taxes or the establishment of greenhouse gas emissions trading markets - have proven insufficient to deal with the issue. Emissions trading systems cannot, on their own, lead us down a green path.

What is needed is a socio-economic plan at both the national and global level, coordinated action by major powers, the long-term vision of the Apollo 11 mission, and moral responsibility toward unborn future generations.

ARE GREEN TECHNOLOGIES AN ALTERNATIVE?

Criticizing free-market capitalism, Ha-Joon Chang believes we need to break up with reckless capitalism: **"…which has brought so little good to humanity and instead introduce some kind of better regulated version."** [18]

According to activist Angelica Navarro Llanos, we need a plan that must: **"…trigger the transfer of finance and technology on an unprecedented scale. Technology must meet the demands of reality in all countries to ensure a reduction in harmful gas emissions while simultaneously raising the quality of life."** Nobel laureate Joseph E. Stiglitz stresses the necessity of managing technological innovations for sustainable development: **"Innovations at all levels are essential when considering the transition to more sustainable forms of production, reducing energy consumption, and quality management. Management implies institutionalization as well as measures to ensure that scientific and technological progress serves sustainable development."** [19] Chair of the Intergovernmental Panel on Climate Change Hoesung Lee also agrees in the Sixth Assessment Report: **"…we have the tools, we have the technology, and we have the knowledge to solve our climate change."** [20] To some extent, Erik Reinert agrees, claiming: **"…innovations and new knowledge are the fundamental driving forces in the history of economic development."** [21]

Reinert also emphasizes that the change of the techno-economic paradigm alters value systems in all spheres of the economy, state, and society. Economist Joseph Schumpeter called this evolutionary process "creative destruction," where old values, knowledge, and capital are destroyed, and only knowledge connected to innovations will survive and increase in value. [22] In this sense, Reinert writes: **"Entrepreneurship, new technology, and a strong state. These are the key concepts for new sustainable growth."** [23]

CONCLUSION

However, in today's technological age, our main concern is to extract the greatest possible benefit from everything. So, Slavoj Žižek asks: **"...isn't the whole point of frugal resource use, recycling, and so on, to maximize utilization? The ultimate products of capitalism are piles of waste - useless computers, cars, televisions, video recorders, or hundreds of airplanes that have found their eternal resting place in the**

Mojave Desert. The idea of total recycling (in which even the last leftover is reused) represents the ultimate capitalist dream, even - or especially - when it is presented as a means of preserving the Earth's natural balance. Another testimony to capitalism's ability to absorb ideologies that seemingly oppose it." [24]

Like Žižek, Marv Waterstone is also skeptical, pointing out that we can easily overlook the fundamental problems at the core of capitalism because we believe the technological fix for global climate change is just around the corner: **"It doesn't demand major changes to the status quo - if it demands anything at all."** [25] If driven by profit maximization, it is unlikely that technological innovations will lead to a solution to the climate crisis, nor is that a call for a fundamental change in the dominant socio-economic order and the way we live. In truth, we continue the same patterns - just with a more benign appearance.

In his fundamental diagnosis of the times we live in, Žižek argues that today's global crisis is not essentially economic. It is an ideological crisis, and a powerful one: **"Ideology is at work in our everyday perception when we can't even imagine change. And I think our first task is not to propose models for what should be done, but simply to open space for alternative thinking. You know, that's not as easy as it seems. Often, when we believe we have alternatives, we still remain within the framework of hegemonic ideology. Thinking of a true alternative is very difficult. But at the same time, it is possible."** [26]

But above all, it is necessary to make a choice.

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New Materials in Packaging Industry

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Abstract. Packaging plays a crucial role in protection of the product, that transportation and storage. In order for the packaging to fulfill its role, the correct choice and characteristics of the packaging material is important. In recent years, bio-based materials and biodegradable materials, as well as materials that are light and, in addition, perfectly withstand all challenges and are resistant to possible damage, have taken precedence. We will deal with exactly such types of packaging materials in this work. Also, we will present our experiences in choosing adequate packaging in cooperation with a company for the production of household chemicals.

Keywords: bio-based materials, biodegradable materials, sustainability, packaging materials, lifetime cycle

INTRODUCTION

Bio-based materials (cellulose, starch, polyhydroxyalkanoates), offer sustainable solutions. Namely, these materials have a dual impact on environmental protection. Firstly, these materials are derived from renewable raw materials, primarily of plant origin; secondly, they are biodegradable. Moreover, these materials contribute to sustainable development due to their origin and degradability. All of these materials are positioned as eco-friendly alternatives to traditional plastics [1]. Packaging prevents different types of biological, microbiological and chemical changes in the product and ensures the quality and safety of the product in the process from production to consumption [2]. Sustainability continues to be an increasingly important issue for the packaging value chain. The major trends poised to transform the packaging industry in the future, in terms of the type and characteristics of used packaging materials, are: [3,4]:

- Bio-based materials are derived from sustainable and renewable biomass, instead of finite petrochemicals. For example, microbial cells and enzymes can be used to produce bio-based plastics. This type of plastic can be biodegradable, but it doesn't have to be, and it has a large and unlimited application in packaging, agriculture, and other industries. Bio-based materials are usually divided based on their size, and this type of material includes: biobased polymers, nanomaterials, natural fibers and their composites.
- Eco-Friendly Packaging - biodegradability, recyclability of packaging materials, lightweight packaging, packaging waste minimization, edible materials for packaging, etc.

- Interactive and active packaging,
- Smart packaging,
- Circular packaging - circular packaging solutions incorporate the principles of the circular economy and integrate seamlessly into sustainability efforts.

In the following text of this paper, we will analyze some of the new packaging materials, as well as the life cycle of some of the above.

BIO-BASED MATERIALS AND ECO-FRIENDLY MATERIALS

As already mentioned, bio-based materials are widely used in the packaging and packaging industry. Table 1 provides a detailed breakdown of bio-based materials.

Table 1. Division of bio-based materials

BIO-BASED MATERIALS		
Name	Characteristics (Molecular Size)	Types
Biobased polymers	In the chemical sense, they are very similar to classical polymers. The sizes of polymers are within the molecular level, which can vary with the category and the origin of the polymers. As for the length of the molecular chain, in most biobased polymers, it ranges from 10 to 1000 nanometers.	Cellulose, hemicellulose, chitosan/chitin, lignin, starch, pectin, alginate and proteins.
Biobased nanomaterials	They consist mainly of nanocrystals and nanofibers, which contain many polymer chains. The sizes of nanocrystals usually have diameter with sizes of several nanometers and lengths ranging from 1000 of nanometers to several micrometers, so they are somewhat larger than bio-based polymers	Cellulose nanofibers (CNF), cellulose nanocrystals and bacterial cellulose.
Row header natural fibers and their composites	They are larger fibers with one or more chemical components. The general structure of composite materials consists of one component being the matrix and one or more components being the fillers. The nature of the matrix classifies composite materials (polymer, metal, ceramic).	Paper, lignocellulosic, silk, wool, flax, hemp, cotton lint, sisal fibers, coconut fibers, wheat straw fibers, fibers from brewing spent grains and olive pomace fibers from almond shell, rice husk, and seagrass as lignocellulosic wastes (betel nut), rice straw or husks, sugarcane bagasse, barley straw or husks, or maize (corn cob, corn husk), bagasse or bamboo fibers, cacao pod husks and asbestos.

Assessment of environmental sustainability achieved by the production of bio-based materials is important to understand their decarbonization potential, and all associated impacts with their life cycle and can be measured with life cycle assessment (LCA) tool [5]. Bio-based plastics have the potential to save up to 315 million tons of CO_2 equivalents annually [6,7]. Reducing packaging material to the least possible weight to preserve the packaged product is one of the most effective ways to reduce waste reduce a package's carbon footprint. The attractiveness of the Life Cycle Thinking concept relies in the fact that every life cycle stage represents an opportunity and has the potential of reducing environmental impacts. Biopolymers can be derived from renewable resources by producing either the structural monomers via fermentation or through direct polymerisation of the biopolymer by microbial cells during fermentation [8]. During 2019, the European Commission conducted a detailed study of the impact of some types of bio-based packaging and its impact on the environment using, among other things, the life cycle method. On that occasion, 17 different indicators were analyzed, some of which are: climate change (kg CO_2 eq), ozone depletion (kg CFC^{-11}eq), particulate matter (kg PM2.5 eq), Acidification, Water use (m^3) etc. All analyzed bio-based materials show significant advantages in terms of climate change, however, in other parameters there are numerous deviations, even deteriorations depending on the type and characteristics of the tested material [8]. From the above, it can be unequivocally concluded that it is necessary to carry out analyzes on each type of packaging bio base material, as well as the final packaging (bottle, bag, box, etc.).

An ideal bio-based packaging material cycle is schematically illustrated in Figure 1. Figure 1 shows that biomaterials must be modified in order to improve their barrier properties, then adequately processed to obtain adequate packaging and at the end of their life cycle they can be biodegraded and/or recycled. recycling, of course, also requires additional efforts in terms of separation, and for this reason, these materials must be adequately marked, so that they can be selected.

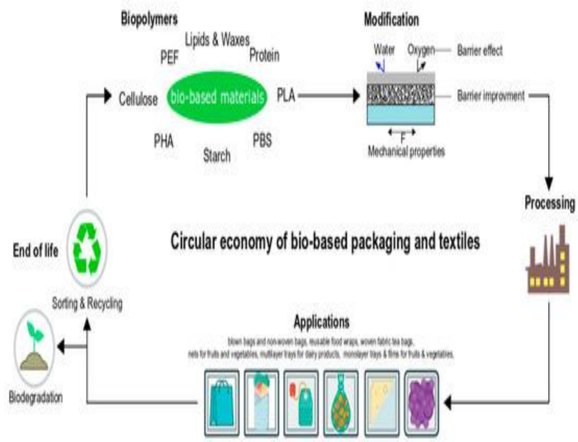

Figure 1. Schematic illustration of an ideal cycle of bio-based material to be used for packaging application (PLA: polylactic acid, PEF: polyethylene furanoate, PBS: polybutylene succinate, PHA: polyhydrodyalkanoate) [9]

Packaging circularity is one of the core pillars sustainability strategy. It encompasses innovating to develop more sustainable packaging solutions, collaborating to develop recycling infrastructure and engaging stakeholders to participate in a circular economy for packaging. Eco-friendly materials is introduced to support the sustainable development of the consumer firm [9], and it aims to reduce or completely eliminate the impact on the environment. In addition, these materials can be biodegradable or compostable. It is important to emphasize that these materials are expected to influence the reduction of energy consumption and, as already pointed out, the reduction of the amount of packaging waste. A sustainable approach that helps reduce plastic packaging pollution is to replace conventional plastics with biodegradable materials.

In addition to biodegradable packaging materials, eco-friendly packaging materials also include:

- Recyclable & Reusable Packaging;
- Minimalist Packaging;
- Lightweight Packaging;
- Edible Packaging (especially in the food industry). These materials are an integral part of the products and are consumed with the products, so they are also inherently biodegradable in composting and other biological recycling and could include ingredients like rice, seaweed, or starch.

OUR COLLABORATION WITH BEOHEMIJA TO INTRODUCE NEW PACKAGING MATERIALS

We cooperated with the company Beohemija as part of the Project "Valorization of powdered by-products from the production of perlite". During the research, special emphasis was placed on the development of packaging and the application of new, innovative packaging materials. Beohemija apply new, energy-efficient technical and technological knowledge, use biodegradable raw materials, recyclable packaging materials and follow all trends in the field of ecology [10]. In cooperation with the company, we led to the accelerated implementation of the new Directive for a Packaging and Packaging Waste Regulation [11]. As part of the project, work on harmonizing primary and secondary packaging with the goals of the updated the rules, first laid out in the Packaging and Packaging Waste Directive 94/62/EC (PPWD) [12] and now the Packaging and Packaging Waste Regulation 2025/40 (PPWR) [11], regulate what kind of packaging can be placed on the EU market, as well as packaging waste management and prevention measures.

We are currently working on the design of new, innovative packaging, significantly less grammage (lightweight packaging), with an increased percentage of recycled materials and with refills. Particularly interesting are the new solutions of refill packaging, which falls into the eco-friendly category. The next steps and further cooperation include the development of packaging materials based on waste and by-products from plant production and the food industry.

CONCLUSION

With a steadfast commitment to innovation and a willingness to embrace change, the future of packaging holds boundless potential for those willing to seize it. These trends reflect a growing emphasis on innovation, consumer engagement, and environmental responsibility within the packaging industry. summarizing the future of the packaging industry is in improving and increasing its sustainability. he trend of development of packaging materials will be focused on how to obtain more understandings on the biodegradation and sustainability of these materials for minimizing their environmental impact after using. More efforts are demanded to develop greener processes that should involve less or no toxic organic solvents. Eco-friendly, sustainable and biodegradable biobased materials are required for the protection of the environment.

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GIS Analysis of Agriculture–Ecotourism Land Use Conflict in Kladovo Municipality, Serbia

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Abstract. Multifunctional landscapes offer diverse development possibilities, however, they are often transformed into single-function landscapes. Kladovo municipality is located in Eastern Serbia, in an area suitable for both agriculture and ecotourism. The suitability analysis for both activities have been conducted in GIS using AHP method, followed by the land use conflict analysis. The results indicate that the low intensity conflicts account for 9.37% of its territory. A medium intensity occurs over 35.14% of the municipality, while high and severe conflicts occupy 47.74% and 7.75%, respectively. It can be concluded that Kladovo municipality is prone to land use conflicts, which demands systematic and sustainable spatial planning.

Keywords: GIS, multi-criteria decision analysis, land use conflicts, Serbia

INTRODUCTION

The landscapes with the capacity to provide various products or services to human beings are called multi-functional landscapes [1]. Although multi-functional landscapes appear to offer a broader range of development opportunities, they are, more often than not, converted to more simple, single-function landscapes. In order to preserve the "natural capital" that multi-functional landscapes provide, they must be managed sustainably and by taking human demands and needs into consideration [1-3]. When individuals or groups have different views on the landscape management, the land use conflicts can arise [1,4].

There are many different scientific approaches to land use conflict (LUC) analysis in a landscape, the most common one being the defining the types of landscape functions, structures and conflicts between them [1-3,5,6]. As [6] point out, LUCs represent complex geospatial and social phenomena influenced by multiple factors through time. Since all LUCs are different, every single LUC analysis requires a unique approach, but still based on the appropriate scientific methods.

The aim of this study is to identify LUCs between agriculture and ecotourism in the Kladovo Municipality, Eastern Serbia, analyze their spatial distribution and explain their driving factors. The municipality covers an area of approximately 630 km^2 and belongs to the Bor District. Two protected areas cover around 165 km^2, which is a little more than a quarter of the municipality (26%). Geomorphologically, the municipality is divided into two heterogeneous parts: Donji ključ and Gornji ključ. Donji ključ is located in the eastern part of the municipality and consists of low and flat river terrace, while Gornji ključ is located in the western part and includes hilly and mountainous land. Altitude difference in the municipality is around 640 m [7]. In the SWOT analysis conducted for the Spatial plan of Kladovo Municipality [8], the first listed threat is “conflict between landscape users (industry-agriculture, tourism, etc.)”, which highlights the importance of this study.

MATERIALS AND METHODS

In land use planning, numerous spatial factors must all be taken into account in order to determine the most suitable locations for the development of each specific activity. Geospatial techniques, such as GIS and remote sensing, have found wide application in such analyses due to their ability to collect, store, analyze, model, and visualize spatial data. Among these, multi-criteria analysis has emerged as one of the most important methods used within GIS [9].

A commonly applied approach is the Analytic Hierarchy Process (AHP), which is frequently used for multi-criteria decision-making in land suitability assessments [9]. This method assigns weights of importance from 1 (equal importance) to 9 (most important) to different land uses through pairwise comparisons of parameters, evaluating them according to their relative significance [10].

Analyzing land suitability for agriculture is crucial for the growth and future planning of agriculture. Based on the previous research [5,9,11], the criteria chosen for this paper are slope (S) [12], land use/land cover (LULC) [13], geology (G) [14], distance from rivers (Dri) [15], landslide susceptibility (LS) [16], aspect (A) [12] and distance from roads (Dro) [15] (Table 1). Elevation was not included in the analysis, since the altitude difference in the municipality is only around 640 m. Additionally, climate elements were not taken into consideration, due to the lack of meteorological stations in Kladovo Municipality.

Table 1. Criteria and weights for agriculture suitability analysis

Criteria	Sub-criteria					Weights
	5	4	3	2	1	
S (º)	0-2	2-5	5-12	12-32	32-90	0.35
LULC	Arable land, agricultural areas	Pastures, vineyards	Natural grassland, transitional woodland/shrub	Wetlands and forests	Artificial surfaces and water bodies	0.24
G	River terrace sediments, eolian sediments (loess)	Colluvium-proluvium, river-lake terrace	Ultramafic rocks, tertiary clastic sediments	Flysch, alluvial sediments, mesozoic clastic sediments	Scree, Mesozoic carbonates, magmatic and metamorphic rocks	0.16
Dri (km)	0-1	1-2	2-4	4-6	>6	0.10
LS	0-2	2-4	4-6	6-8	8-10	0.07
A	S, flat	SE, SW	W, E	NW, NE	N	0.04
Dro (km)	0-2	2-4	4-6	6-8	>8	0.03

Emerged in the 1990s as a sustainable form of nature-based tourism, ecotourism requires creating development and conservation strategies, as well as identifying the most suitable locations for its development [17]. Previous research [7,17,18] indicate that the most important criteria for ecotourism development are LULC [13], slope (S) [12], distance from rivers (Dri) [15], settlements (Ds) [13], roads (Dro) [15], and nature protection (P) [19] (Table 2).

Based on the weighted coefficients, separate suitability maps were generated for agriculture and ecotourism in ArcGIS Pro 3.2. Each criterion layer was multiplied by its respective weight, and the resulting layers were summed to produce a suitability map with values ranging from 1 to 5. These values were reclassified into five suitability classes: 0–1 (class 1), 1–2 (class 2), 2–3 (class 3), 3–4 (class 4), and 4–5 (class 5). The agricultural suitability map was then multiplied by 10 and combined with the ecotourism map, producing two-digit pixel values where the first digit indicated agricultural suitability and the second ecotourism suitability. This composite map was subsequently reclassified following [5], with minor modifications due to pixel value differences (Table 3).

Table 2. Criteria and weights for ecotourism suitability analysis

Criteria	Sub-criteria					Weights
	5	4	3	2	1	
LULC	Sport and leisure facilities, forests	Open spaces with little or no vegetation	Vineyards, natural grasslands, transitional woodland/shrub, inland marshes	Agricultural areas	Artificial surfaces and water bodies	0.38
S (°)	2-5	5-15	15-25	25-35	0-2; 35-90	0.25
Dri (km)	0-0.5	0.5-1	1-2	2-3	>3	0.16
P	Protected areas				Unprotected areas	0.10
Dro (km)	0-1	1-3	3-5	5-10	>10	0.06
Ds (km)	0-1	1-3	3-5	5-10	>10	0.04

Table 3. Classification of conflict intensity

	1	2	3	4	5
1	11	12	13	14	15
2	21	22	23	24	25
3	31	32	33	34	35
4	41	42	43	44	45
5	51	52	53	54	55

	1 (no conflicts)
	2 (low intensity of conflicts)
	3 (moderate intensity of conflicts)
	4 (high intensity of conflicts)
	5 (severe intensity of conflicts)

RESULTS AND CONCLUSIONS

The results of the calculations show that 9.37% of the municipality has the low intensity of conflicts, and these areas are mostly located in the eastern, flatter part of the municipality. Moderate intensity of conflicts covers around 35.14% of the municipality, mainly in the protected areas and surrounding low intensity areas. High and severe intensities (47.74% and 7.75%, respectively) are located in the central parts of the municipality, with severe conflicts located on the hilly borders between Gornji Ključ and Donji Ključ. The visualization of the conflict intensity is given in Figure 1.

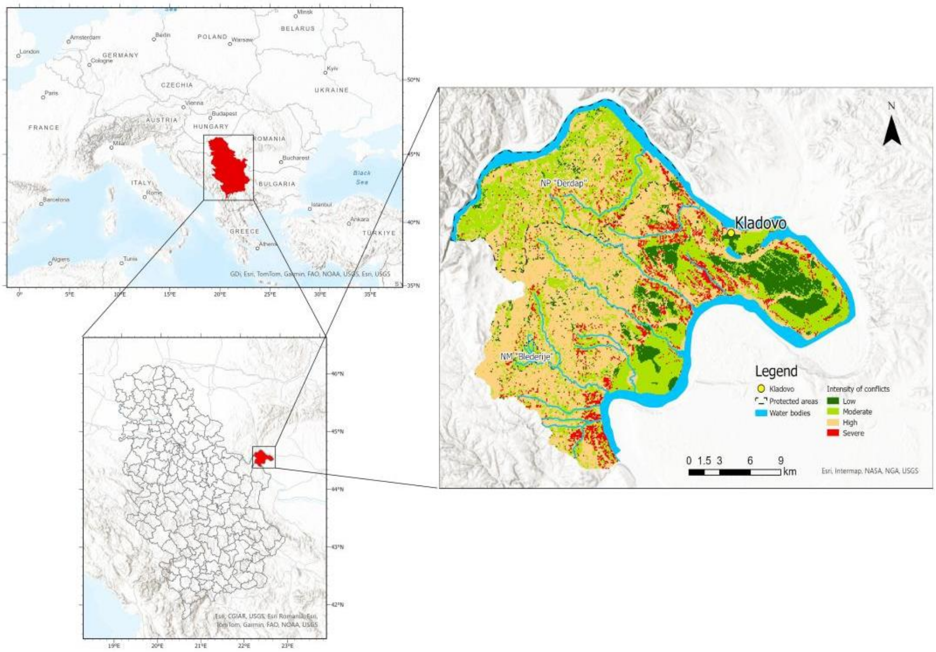

Figure 1. Conflict map of Kladovo Municipality

With its numerous diversities and protected areas, Kladovo Municipality is situated in a suitable geographic location for the development of both agriculture and ecotourism, resulting in high and severe conflict zones across the municipality. Despite the possibility of developing both activities, it is very likely that one will prevail over the other. Which one will prevail depends on numerous factors, primarily the current priorities of the individuals, the local community, or society as a whole. To make the best decision regarding land use, it is essential to understand both the natural and social processes and relationships present in the area. Each criterion must be thoroughly researched, followed by an analysis of the local community's perspectives, as well as an investigation into the demographic and economic structure of the population. This approach ensures a decision that is optimal from both a natural and social standpoint.

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PET Recycling in Textiles: Multiple Cycles, Quality and Circular Design

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Abstract: Plastic, although ubiquitous in modern life, has become one of the main sources of pollution globally. A viable solution to reduce the ecological impact is the recycling of PETs, which can be transformed into reusable textile fibers and reintegrated into the circular economy. The paper analyzes both mechanical recycling, which is more accessible but has limitations regarding the quality of the fibers after repeated cycles, and chemical recycling, which offers materials similar to those of PET non-recycled, but with high energy consumption. Current challenges such as the release of microplastics and the gradual degradation of quality in the recycling-product-recycling process are discussed. Concrete examples from industry (Adidas, Patagonia, Stella McCartney) illustrate the practical applicability and potential of circular fashion. The conclusions highlight the need for optimized technologies and design innovation to fully exploit the potential of recycling PET textiles.

Keywords: recycled PET, sustainable textiles, chemical recycling, mechanical recycling, circular design

THE STORY OF PLASTIC: WASTE OR RESOURCE?

Imagine a typical day: you wake up, drink water from a PET bottle, grab a sandwich wrapped in plastic, put on a synthetic T-shirt, and hit the road. Every object you use unconsciously is part of a huge plastic chain that crosses the entire planet. PET waste — bottles, packaging, and synthetic textiles — accumulates quickly, and billions of tons end up in nature, affecting soil, water, and wildlife.

But these materials, although often seen as pollution, can become a valuable resource through recycling. Their proper collection and recycling transforms garbage into textile fibers, which can be reused in clothes, furniture, technical materials and other everyday products. Thus, PET becomes part of a circular economy, where waste takes on a new life and is reintegrated into industry.

To better understand how this transformation occurs, it is necessary to analyze the technological processes through which recycled PET becomes raw material again.

The technological process of PET recycling

The technological process of PET recycling involves collection and sorting, followed by two main directions: mechanical recycling and chemical recycling, each with advantages and limitations. Regardless of the method, the material obtained is subsequently spun and transformed into textile fibers, demonstrating how a seemingly useless waste can become a valuable raw material again . Although the methods pursue the same goal – transforming PET into a new resource – the method of production and the quality of the fibers obtained differ significantly, as follows:

1. mechanical recycling, involves collecting, sorting and shredding PET to obtain flakes or granules, which are then melted and extruded to form new products, such as textile fibers or packaging. The process is efficient and economical, but can lead to degradation of the material, reducing the quality of the products obtained.

2. Chemical recycling, involves the depolymerization of PET into monomers through processes such as glycolysis, methanolysis, hydrolysis or aminolysis. These monomers can then be repolymerized to obtain higher quality PET, suitable for applications such as technical clothing or food packaging. Although more expensive and energy-intensive, these processes allow for the complete recycling of PET, including contaminated or multi-layered PET.

3. spinning recycled PET , after recycling, either by mechanical or chemical method, PET is transformed into continuous fibers through the spinning process, which allows them to be subsequently woven or knitted. The details of the process differ depending on the recycling method and the final destination of the fiber. The spinning of mechanically recycled PET and chemical spinning are presented below:

- *spinning from mechanically recycled PET* - PET granules obtained through mechanical recycling are melted and extruded through fine nozzles to form thin yarns, which can then be knitted or woven to obtain textiles for clothing, upholstery or technical materials.

  Limitations: fibers obtained by the mechanical method are often shorter and more fragile compared to non-recycled polyester, requiring blends with other fibers to increase durability and wear resistance [*].

- *spinning from chemically recycled PET* - Depolymerized and repolymerized PET produces a polymer with properties almost identical to those of non-recycled PET, allowing the spinning of high-quality fibers. The resulting fibers can be used in premium textiles, technical clothing or sports equipment.

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[*] https://www.mdpi.com/2673-7248/5/3/24 accessed 21.08.2025

Advantage: controlling the length and uniformity of the fiber allows for obtaining a material of constant quality †.

Mechanical vs. chemical recycling and spinning

Stage / Feature	Mechanical recycling	Chemical recycling
Process	Collection → Washing → Shredding → Melting → Spinning	Depolymerization → Cleaning → Repolymerization → Spinning
Material quality	Medium, shorter and more fragile fibers	Almost identical to virgin, uniform and durable fiber
Costs	LOWER	ridicule
Energy consumption	Microphone	Mare
Fibers obtained	Shorter, more fragile	Uniform length, durable
Typical applications	Fillings, low-cost clothes	Premium textiles, technical clothing
Advantage	Simple, effective	High quality, full recycling
limitation	Degraded material	Costs and energy losses

Analyzing the comparative table, it becomes clear that the chosen recycling method directly influences the quality and characteristics of the fibers obtained. Although *mechanical recycling* is more accessible and less energy-consuming, the resulting fibers are shorter and more fragile, requiring mixtures with other materials to be usable in textiles.

In contrast, *chemical recycling* allows for the production of uniform, resistant fibers of a quality close to virgin PET, suitable for premium applications. Regardless of the recycling method, the essential step that transforms it into usable yarn is *spinning,* a process that defines the length, uniformity and strength of the fibers, being decisive for the final applicability in clothes, technical materials or other textile products.

Multi-cycle recycling of PET in textiles

A fascinating aspect of PET recycling is the possibility of creating a continuous product cycle: PET bottles → textile fibers → clothing or furniture textiles → collection and recycling → new fibers → new textile products. This approach not only reduces the amount of plastic waste, but also decreases the dependence on new raw materials, contributing to the development of a sustainable and circular textile industry.

However, each recycling cycle brings technical challenges. In the case of mechanical recycling, the fibers become shorter and more fragile after each cycle, which can lead to a decrease in the quality of the final product ‡. In practice, the fibers obtained through

† https://www.sciencedirect.com/science/article/pii/S0921344924002532 accessed 21.08.2025

‡ https://www.mdpi.com/2673-7248/5/3/24 accessed on 22.08.2025

recycling are often mixed with new fibers or other materials to maintain the mechanical and aesthetic properties of the textiles, thus ensuring durability and a consistent appearance of the final products.

On the other hand, chemical recycling allows PET polymers to be restored to almost their original quality, which helps maintain the length and strength of the fibers even after multiple recycling cycles . [§]Although this recycling provides higher quality fibers, it is more expensive and energy-intensive, and the volume of recycled material depends on the amount of PET collected and its purity.

Another important aspect is the quantity of products obtained: repeated mechanical recycling can lead to material losses through contamination, thermal degradation or losses in the washing and spinning process. Thus, the actual volume of recycled textiles can be lower than that of PET introduced into the process. In chemical recycling, these losses are reduced, allowing the exchange of more consistent fibers and a larger quantity of final products compared to repeated mechanical recycling.

In conclusion, the continuous cycle PET → textiles → recycling → textiles is feasible and brings significant benefits for sustainability and circular economy, but the quality and quantity of the products depend on the recycling method used. This highlights the need for a balance between cost, quality and environmental impact, as well as the development of technologies that allow repeated recycling without major losses of material properties.

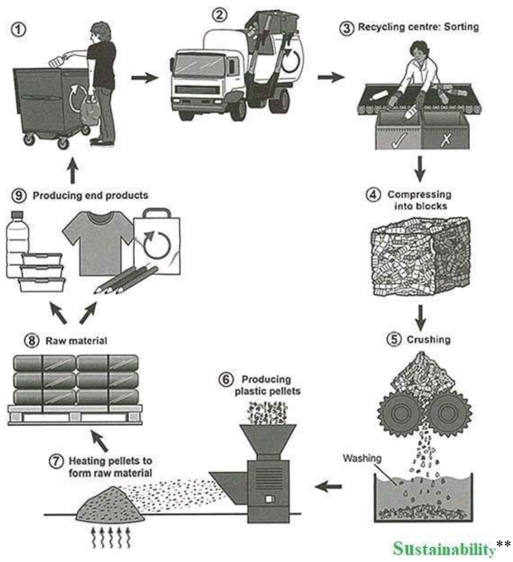

Figure 1. Repetitive PET textile recycling process steps

[§] https://www.sciencedirect.com/science/article/pii/S0921344924002532 accessed on 22.08.2025
[**] https://ro.pinterest.com/pin/354799276916777259/ photo

The image provides a clear representation of the PET textile recycling process, highlighting the importance of circular economies in reducing waste and promoting sustainability. However, it is essential to be aware of the challenges associated with this process and seek solutions to overcome them.

Recycling old collections: circular design and sustainability in fashion

An innovative aspect of recycling PET textiles is the reuse of old clothing collections to obtain new materials. This not only reduces the amount of textile waste, but also allows designers to transform previous creations into sources of raw materials for new collections. In this way, clothes become part of a circular cycle, in which the final product is reused to create materials for future items.

The recycling process of old collections

The process begins with the collection and selection of old clothes, which are then cleaned, sorted and, if necessary, broken down into individual fibers. In the case of mechanical recycling, the fibers can be short and brittle, which requires mixing with previously unprocessed fibers or other materials to obtain durable textiles. Chemical recycling, through depolymerization and repolymerization, allows the production of fibers with properties almost identical to the primary ones, allowing the creation of premium items, without compromising on quality [††].

Impact on product quality and quantity

A repetitive recycling cycle can affect the quality of the fibers: each mechanical process shortens the polymer chains, reducing the strength and elasticity of the material. In contrast, chemical recycling maintains the length and uniformity of the fibers, which allows the production of high-quality clothes and textiles even after multiple cycles. However, the actual amount of material can decrease with each cycle, due to losses in the washing, filtering and spinning processes. This is essential for brands that want to maintain a high standard of products without compromising sustainability.

Concrete examples from the fashion industry

Several renowned brands have implemented recycling programs for old collections:

- **Stella McCartney** has developed systems whereby clothes from previous collections are collected and transformed into recycled fibers for new collections.

[††] https://www.mdpi.com/2673-7248/5/3/24 accessed on 23.08.2025

- **Adidas x Parley** uses recycled materials from ocean plastic and repurposes some old products into new sportswear.
- **Patagonia,** through its "Worn Wear" program, allows you to return old clothes, which are then recycled or reconditioned into new textile products [‡‡].

Stella McCartney - a pioneer in bio-recycling and promoting circularity, is recognized as a leader in sustainable fashion. Since 2012, her brand has used recycled polyester in all of its collections, and since 2016, all of its wool jackets are made from Re.Verso™ recycled cashmere [§§]. In 2023, McCartney presented a parka jacket made from bio-recycling, collaborating with the company Protein Evolution to transform plastic waste into polyester fibers without using fossil fuels.[***]

Additionally, the brand launched Airslide shoes in 2021, made from recycled waste sourced directly from manufacturing plants, underscoring its commitment to the circular economy.

Figure 2. Stella McCartney – parka jacket made from biological recycling

Adidas x Parley - By transforming marine waste into high-performance products, Adidas and Parley for the Oceans have collaborated to create innovative products made from reclaimed ocean plastic. For example, the UltraBoost Uncaged Parley uses yarns made from plastic waste intercepted on remote islands and beaches. The Outdoor Parley collection also includes items such as jackets and pants made from Prime Blue, a material that contains at least 50% Parley Ocean Plastic.[†††]

[‡‡] https://www.patagonia.com/home/ accessed on 23.08.2025

[§§] https://youtu.be/6oVK2pgR-G0 accessed 24.08.2025

[***] https://fashionunited.com/news/fashion/stella-mccartney-unveils-first-garment-madeusing-biological-recycling/2023120457180?utm_source=chatgpt.com accessed 24.08.2025

[†††] https://fashionunited.com/news/fashion/adidas-launches-collection-made-from-ocean-plastic/2021041939496?utm_source=chatgpt.com accessed 24.08.2025

Figure 3. The Adidas x Parley Outdoor collection is made from Primeblue

Patagonia supports sustainability through its Worn Wear program, which allows customers to sell, buy, or repair old clothing items, thus directly promoting the circular economy.

This program helps reduce textile waste and extend the life of products, encouraging responsible consumption. In addition, customers can return Patagonia items to be repaired, recycled or reused, depending on their condition.[‡‡‡]


[§§§]

Figure 4. Technical staff during training at the cutting table. Photo: Ken Etzel

Sustainability and design benefits

This type of recycling offers designers the opportunity to experiment with new textures and combinations, integrating recycled fibers and natural materials. At the same time, it contributes to the circular economy, reducing dependence on raw materials and diminishing the impact on the environment. Thus, old collections become a valuable resource, and

[‡‡‡] https://www.patagonia.com/trade-in/?utm_source=chatgpt.com accessed 24.08.2025
[§§§] https://www.patagonia.com/stories/extended-play/story-32985.html photo

circular fashion is not only an ecological objective, but also a creative and innovative strategy.

Reflections on PET recycling in textiles and circular design

Recycling PET, either through mechanical or chemical processes, opens up new opportunities for sustainability in the textile industry. Transforming PET bottles, plastic packaging and old collections into new fibers shows that materials should not be considered waste, but valuable resources for future products.

Integrating recycling into multiple cycles and reusing old collections has allowed not only to reduce the environmental impact, but also to create a circular economy model in fashion. Brands like Stella McCartney, Adidas x Parley or Patagonia demonstrate that this possibility combines technological innovation, ecological responsibility and creativity in design, without compromising the functionality or attractiveness of the products.

At the same time, challenges remain: mechanically recycled fibers can be shorter and more fragile, and chemical recycling, while maintaining quality, is expensive and energy-intensive. However, the implementation of programs such as Worn Wear or the internal collection and recycling of old collections shows that solutions exist and can be scalable, with benefits for the environment, the economy and industry.

Thus, this theme emphasizes the importance of circular thinking in textile design, as well as the need to develop technologies and policies that allow for the repeated reuse of PET without major losses in quality or quantity.

CONCLUSIONS

Recycling PET into textiles is feasible and essential for a sustainable textile industry. The use of mechanical and chemical processes, combined with circular design and recycling of old collections, allows the creation of new products from reused materials, reducing the impact on the environment. The quality and quantity of fibers depend on the recycling method, but collection programs and advanced technologies can support a circular, innovative and sustainable fashion model. Brands that implement such strategies demonstrate that innovation, design and sustainability can coexist.

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Summer Measurements of Indoor Air Quality at TCAS

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Abstract. Quality of indoor air can significantly impact human health. During summer 2025 at Technical College of Applied Sciences in Zrenjanin indoor air quality parameters were monitored. uHoo air quality detector was used for temperature, humidity, pressure, total volatile compound, carbon-monoxide, carbon-dioxide, nitrogen-dioxide, ozone and particulate matter concentration measurements. The obtained results and level of air pollution are presented in this article.

Keywords: Indoor Air Quality, uHoo Detector

INTRODUCTION

Values of indoor air quality parameters in the Republic of Serbia are defined by regulations in the field of Occupational Safety and Health, as well as through the Rulebook on the procedure for inspecting and checking work equipment and testing working environment conditions [1]. Monitored parameters of air quality in work areas are determined and conditioned by the technological process and characteristics of the facility or rooms. In the Serbia, there is not a sufficient number of studies on indoor air quality where industrial processes do not take place.

Indoor air quality parameters

In this paper are presented measurements of the following parameters: total volatile organic compound (TVOC), particulate matter with diameter up to 2.5 microns (PM2.5), carbon-monoxide (CO), carbon-dioxide (CO_2), nitrogen-dioxide (NO_2) and ozone (O_3). Air pressure, temperature and humidity were also monitored. All these parameters can have negative effects on health if their concentrations are high, and above the recommended limits.

Total volatile organic compounds are gaseous compounds that are emitted indoors from various sources like colours, vaxes, glues, materials from which furniture is made, carpets, building materials, plastic, toys and cleaning productsc. Short-term exposure to high concentrations of VOCs can cause allergies, headaches, nausea, and respiratory infections [2]. The European indoor air quality guidelines released by the WHO recommend a target level under 0.05 ppm (0.25 mg/m^3).

Particulate matter is a set of all suspended particles in solid and liquid aggregate state in the air. As PM in ambient air most often originates from industrial processes and traffic, the concentration of PM in indoor spaces varies significantly due to human activities, season, weather conditions, and ventilation. The ventilation of the premises can lead to the migration of PM particles from the outside to the inside of the premises [3,4]. WHO recommendation is an annual PM2.5 level of 5 $\mu g/m^3$, while the recommended short-term (24-hour) PM2.5 level is 15 $\mu g/m^3$, defined as the 99th percentile (equivalent to 3-4 days of excess per year) of the annual distribution of 24-hour average concentrations. The US Environmental Protection Agency sets the level of the primary (health-based) annual PM2.5 standard at 9.0 $\mu g/m^3$, while the daily concentration recommendation is 35 $\mu g/m^3$. The American Institute of Indoor Air Hygiene requires a PM2.5 level of 12 $\mu g/m^3$ or less, with infrequent or no spikes of 35 $\mu g/m^3$ or higher.

Carbon-monoxide is a colourless, non-irritant, odourless and tasteless toxic gas. CO is produced indoors by combustion sources (cooking and heating, tobaco smoke, decorative fireplaces) and is also introduced through the infiltration of carbon-monoxide from outdoor air into the indoor environment (exhaust from motor vehicles). Incomplete oxidation during combustion may cause high concentrations of carbon-monoxide in indoor air. WHO gives a series of guidelines relevant to typical indoor exposures and recommended as follows: 100 mg/m^3 for 15 minutes and 35 mg/m^3 for 1 hour, 10 mg/m^3 for 8 hours and 7 mg/m^3 for 24 hours [5].

Indoor levels of nitrogen-dioxide are a function of both indoor and outdoor sources. Thus, high outdoor levels originating from local traffic or other combustion sources influence indoor levels. Levels in school classrooms have been found to be significantly correlated with traffic density and distance of the school from the roadway. A 1-hour indoor nitrogen-dioxide guideline from WHO is 200 $\mu g/m^3$ and an annual average indoor nitrogen dioxide guideline is 40 $\mu g/m^3$ [5].

Outdoor ozone penetrating into the indoor environment is the main source of indoor ozone. Indoor sources of ozone are the devices like air purifiers, disinfectors, laser printers, photocopiers, and others. In addition, the age of a building and various housing aspects (carpeting, air conditioning, window fans, and window openings) have been significantly associated with indoor ozone levels [6]. The WHO sets an exposure eight-hour limit at 100 $\mu g/m^3$ (0.1 mg/m^3) for ozone.

DETECTOR

uHoo air quality monitor [7] was used for indoor air quality measurements at TCAS. It is presented on figure 1 [7] together with a view of its application display at mobile phone. Detector has cylindrical shape with height 161 mm, 85 mm diameter and 270 g weight. The body of the detector is made from ABS thermoplastic polymer, and has different sensors incorporated inside it. It operates at temperatures between -10 C and 50 C, and at humidity from 0% to 100% non condensing.. uHoo has also a WiFi conncentions and application for mobile phones via which it is adjusted and monitored. Premium versions also offer dashboard for computers where additional facilities can be used. Detector was Laboratory tested.

Figure 1. uHoo air quality detector [7].

uHoo detector monitors nine air quality parameters: temperature, humidity, pressure, carbon-dioxide, total volatile organic compound, particulate matter with diameter up to 2.5 microns, carbon-monoxide, nitrogen-dioxide and ozone. It also estimates virus index. Each variable can be in green (good), yellow (poor) or red (bad) zone, depending on its value. These zones were defined by manufacturer. For temperature green zone is in range 21 C - 26 C, yellow zone is in range 0 C – 21 C and 26 C – 40 C. For humidity green zone range is 30%-50%, while yellow zone is 10%-30% and 50%-90%. Green zone pressure levels are 970 – 1030 mbar, while yellow zone is 600-970 mbar and 1030-1100 mbar. Carbon-dioxide green zone is 400-800 ppm, yellow zone is 800-1500 ppm and red zone is 1500-2500 ppm. TVOC green zone values are 0-400 ppb, yellow zone is 400-2200 ppb and red zone is 2200-3000 ppb. Green zone for PM2.5 is 0-50 $\mu g/m^3$, yellow zone is 50-100 $\mu g/m^3$, and red zone is 100-200 $\mu g/m^3$. Carbon monoxide green zone is 0-9 ppm, yellow zone is 9-35 ppm and red zone is 35-100 ppm. Nitrogen dioxide green zone is 0-100 ppb, yellow zone is 100-250 ppb and red zone is 250-500 ppb. Ozone green zone is 0-30 ppb; yellow zone is 30-70 ppb, red zone 70-100 ppb.

MEASUREMENTS AND RESULTS

During June 2025. air quality was monitored in office 208 at the first floor at TCAS. Room was in normal use during the measurement period, but first two weeks of June it was empty. During the second part of June, when it was occupied, air condition was also ocassionally used and windows were also sometimes kept open.

Temperature, humidity, preassure, carbon-monoxide, carbon-dioxied, ozone and PM2.5 all had the optimal values during the measurement period and they all were in green zone. It was noted that level of nitrogen-dioxide was increased (from green to yellow zone) upon opening the windows, as the pollution from the traffic enters the room. After closing the windows, level of NO_2 gradually falls to low (good) values (figure 4 and figure 5). Also TVOC was at low values when the office was empty which is good as it signifies that no dangerous chemicals are present in the room. TVOC values increased to yellow zone and sometimes also red zone only when there were the occupants as a consequence of human brething (figure 2 and figure 3).

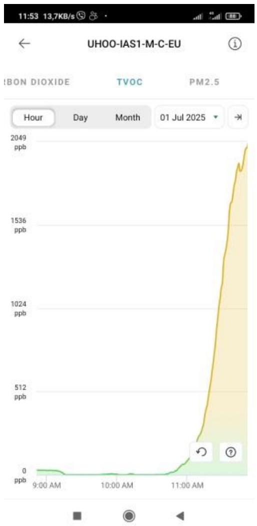

Figure 1. Example of TVOC gradual increase during one morning in June, upon the arrival of employee in the office, as a consequence of her breathing.

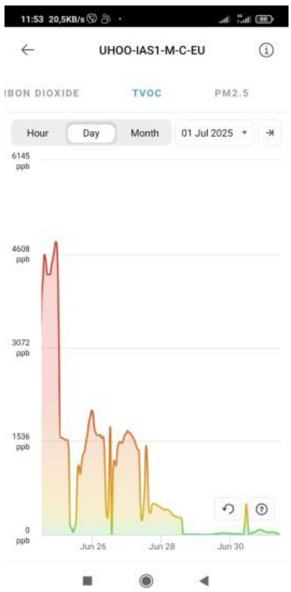

Figure 2. TVOC oscillations during few days in June. TVOC increases as the occupants enter the office and then gradually decrease after their leave.

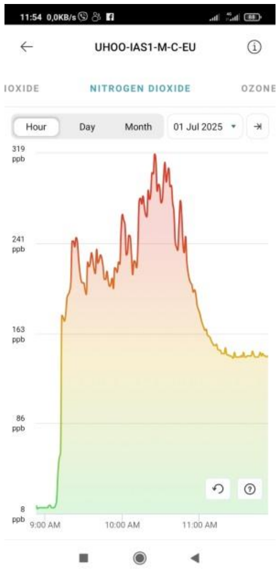

Figure 3. Example of Nitrogen-dioxide gradual increase during one day in June, after opening the office windows.

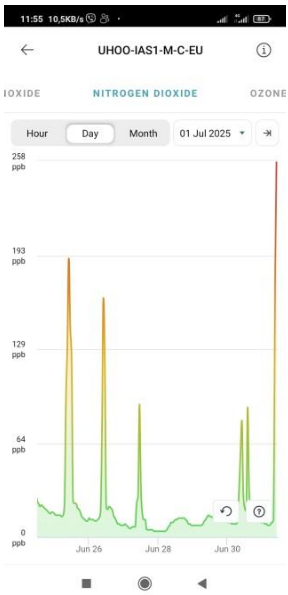

Figure 4. Nitrogen-dioxide oscillations during few days in June. It has peaks after opening the windows, and then slowly decreases to its good values after windows closure.

CONCLUSION

There are no Ntional regulatory permissible limits for these parameters in indoors of non industrial facilities, so mentioned limit levels of parameters concentrations serve as a guideline. Offices, classrooms and other rooms that are used as a workspace shold have appropriate ventilation. The main problem in indoor air quality of non industrial objects is the environment: distance from industry, traffic, distance of highways. The major influence on pollutant concentrations in indoor objects is the ambient air quality.

Obtained values of air quality parameters at TCAS are rather satisfying. We also plan to repat this air quality measurements during winter, when heating is in use.

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Modernising Physics and Mathematics Teacher Education: Integrating Digital Competencies and Sustainability for Primary Schools

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Abstract. As part of the national project *Pilot Renovation of Study Programmes*, the Faculty of Natural Sciences and Mathematics at the University of Maribor has updated its physics and mathematics teacher education programmes. The revised curricula now integrate digital competencies, sustainability topics, and innovative pedagogical strategies, in alignment with key European frameworks such as DigComp 2.2, DigCompEdu, and GreenComp. A particular emphasis is placed on the interdisciplinary integration of physics and mathematics, fostering inquiry-based learning, inclusive practices, and real-world application of knowledge. The use of digital tools and artificial intelligence supports the development of both subject-specific and cross-curricular competencies. Preliminary feedback from students suggests high levels of engagement and a generally positive reception of the updated programmes.

Keywords: physics education, curriculum reform, digital competencies, sustainability, teacher training

INTRODUCTION

The rapid transformations in society, technology, and the environment have placed new demands on educational systems and, consequently, on the preparation of future teachers. In particular, physics education is facing increasing pressure to become more relevant, interdisciplinary, and responsive to the real-world challenges that students will encounter in their personal and professional lives. Climate change, digital transformation, and social inequality are no longer abstract issues, but urgent realities that science educators must be prepared to address both in content and pedagogy [1,2].

In this context, the Faculty of Natural Sciences and Mathematics at the University of Maribor launched a comprehensive reform of its teacher education programmes. The initiative was part of the national project "NOO – Pilot Renovation of Study Programmes." This initiative was launched in response to the Slovenian Recovery and Resilience Plan, which called for the integration of green and digital competences into higher education [1,2]. The project's specific focus was on aligning study programmes with European frameworks such as DigComp 2.2 (digital competence), DigCompEdu (digital pedagogy), and GreenComp (sustainability competences) [1–3]. It also promoted inclusive, student-centred teaching practices.

The reform addressed both structural and pedagogical dimensions. New and revised courses were developed to incorporate sustainability-oriented content, digital tools, and active learning strategies. Existing syllabi were aligned with national guidelines to ensure systemic coherence. A unified competence profile for subject teachers was established, and special attention was devoted to innovative assessment methods and the potential of artificial intelligence to enhance inclusive learning environments [4].

This paper presents the key activities and outcomes of the reform, focusing on curriculum design, competence-based teaching, integration of EU frameworks, assessment practices, and programme-wide analysis. The examples presented stem from physics education but are situated within the broader reform of science and technology teacher training.

REFORM PROCESS AND METHODOLOGY

Key Stages in the Renewal of Teacher Education Programmes

We reformed teacher education programmes in science subjects with a strong emphasis on the integration of digital tools, sustainability-related content [1,2], and contemporary teaching approaches. New curriculum units were developed, existing courses revised, and a unified competence profile for teachers was established. We also introduced innovative assessment methods and explored the pedagogical potential of artificial intelligence [4].

Methodology: Case Study Approach

In this paper, we adopted a qualitative case study approach to examine a specific example of curriculum reform in higher education. The method was chosen not to produce statistical generalisations, but to gain insight into participants' perspectives, attitudes and responses to new teaching approaches. This allowed us to analyse the reform process on a small sample and understand its effects on those directly involved, namely students.

At the start of the reform, we spoke with course coordinators who had already considered updating their teaching. The NOO – Pilot Renovation of Study Programmes project provided clearer direction, especially regarding digital competences and sustainability. Coordinators felt the timing was appropriate, as higher education increasingly requires both digital adaptation and a broader understanding of sustainability [1,2].

To explore how these changes were received, we involved a small group of five students who had previously taken courses under the old syllabi. They reviewed parts of the revised syllabi, including new learning goals, digital tasks and sustainability content, and compared them with their past experiences.

We collected data through informal conversations and observation. Participants shared their impressions, noted areas that could be improved and identified elements they considered meaningful or clearer than before.

While the sample was small, the aim was not to generalise findings, but to reflect on student feedback. Their responses were positive. They viewed the changes as improvements and believed future students would benefit from a more engaging and updated learning experience. These results support the reform's intention to align academic content with current educational and societal needs [5,6].

Although no quantitative analysis was carried out in this phase, future research will aim to include structured data collection in order to further evaluate the effectiveness and impact of the reformed curricula.

CURRICULUM DESIGN AND IMPLEMENTATION

Development of New Curriculum Units across Disciplines

Within the pilot reform project, the Faculty of Natural Sciences and Mathematics at the University of Maribor developed and introduced several new or significantly redesigned curriculum units across different subject teacher education programmes. The purpose of these changes was to modernise pedagogical training by integrating sustainability-related content, digital competences, and active teaching strategies into concrete courses that form the foundation of future teachers' education [1,2].

A total of eight new or thoroughly revised courses were developed:

- Digitally Supported Teaching of Physics through Fieldwork, which promotes the use of mobile sensors and digital visualisation in outdoor environments.
- Practical Training for Teaching Biology 1, focused on school-based practice with digital and inclusive planning approaches.
- Didactics of Technology Education 2, which integrates the Sustainable Development Goals (SDGs) and digital fabrication tools.
- Didactics of Physics 2 with Practicum, emphasising experimental teaching and digital simulations, including acoustic waveform analysis such as vibrating guitar strings to demonstrate multirhythmicity and the distinction between chaotic and periodic signals [7].
- Chemistry Didactics 2, supporting inquiry-based learning and green chemistry topics.
- Didactical Practicum in Computer Science, centred on ICT-supported teaching, AI, and open-source tools.
- Didactics of Secondary School Mathematics, introducing non-traditional teaching methods and sustainability-oriented modelling.
- Didactics of Chemistry 2, which further strengthens digital integration and student engagement.

These courses have already been implemented and evaluated, and they serve as a foundation for further pedagogical innovation [5,9].

Interdisciplinary relevance for physics and mathematics teacher education

The integration of digital and sustainability dimensions in the curriculum units is particularly significant for future teachers of physics and mathematics. These disciplines share a strong foundation in analytical reasoning, modelling, and problem-solving-competences that are essential for addressing real-world challenges such as climate change, energy efficiency, and data literacy [1,2]. The reformed courses *Didactics of Secondary School Mathematics* and *Didactics of Physics 2 with Practicum* exemplify how context-based teaching, interdisciplinary learning, and digital tools can be used to enhance students' conceptual understanding and engagement [5–9]. By providing coherent and aligned training in both fields, the reform promotes cross-disciplinary collaboration and supports the development of reflective, digitally competent educators who can foster critical thinking [1] in secondary school students.

Systematic Revision of Existing Curricula with Green and Digital Integration

In addition to new course development, the reform also included a thorough revision of existing syllabi. This process was guided by national and European frameworks such as DigComp 2.2, DigCompEdu and GreenComp [1–3]. The process focused on the following five areas:

- Learning objectives: Outcomes were rewritten to include digital and sustainability aspects [1,2], using Bloom's taxonomy and competence-based formulations.
- Content integration: Green topics (e.g., climate change, circular economy) and digital themes (e.g., AI, data literacy, ethical technology use [1,2,4]) were embedded to enhance thematic relevance.
- Teaching methods: Modern strategies such as problem-based learning, flipped classroom, collaborative work and reflection were incorporated to promote active engagement.
- Inclusive education: Syllabi were adapted using Universal Design for Learning principles, ensuring accessibility and support for diverse learners.
- Assessment: Formative and digitally supported assessment methods [1,3] were introduced, including quizzes, e-portfolios, and reflective assignments.

A unified syllabus template ensured consistency across programmes and transparency in how green and digital elements were integrated. The revised syllabi reflect a forward-looking vision of education that combines technological innovation, environmental responsibility [1,2] and inclusive teaching practices.

Establishing a Unified Competence Profile for Subject Teachers

To ensure coherence across teacher education programmes, a unified competence profile was developed to guide curriculum design, teaching methods and assessment strategies. The profile defines the key knowledge, skills and attitudes expected of future teachers in four thematic areas:

- Teaching and Learning: Pedagogical knowledge, modern teaching strategies, and the use of digital tools to promote inquiry, scientific literacy and higher-order thinking [3].

- Collaboration with Society: Engagement with local and broader communities and application of scientific knowledge to socially relevant challenges [2].
- Professional Development: Lifelong learning, reflection on practice and critical use of research in teaching.
- Leadership and Organisation: Contribution to school development, teamwork, compliance with regulations and understanding of education policy.

The profile was based on national standards and aligned with European frameworks such as DigCompEdu [3] and GreenComp [2]. It served as a foundation for syllabus revision and competence progression. Its purpose was to help future teachers develop into critical, responsible and reflective professionals.

PEDAGOGICAL INNOVATIONS AND COMPETENCE DEVELOPMENT

Integrating Digital Competences through European Frameworks

The DigComp 2.2 framework defines five key competence areas for all citizens: information and data literacy, communication and collaboration, digital content creation, safety and problem solving [1]. These areas were embedded into course outcomes and activities, enabling students to work with digital information, use collaborative platforms, and apply technology ethically and securely.

The DigCompEdu framework served as a guide for educators. It includes six teaching-specific areas: professional engagement, digital resources, digital pedagogy, assessment, learner empowerment, and the promotion of learners' digital skills [3]. These principles were implemented at multiple levels of course design. They influenced everything from content delivery to feedback strategies.

To support integration, training workshops were organised for university staff and mentors. Participants explored a variety of digital tools, such as Moodle, Office 365, Canva, Nearpod and platforms for simulation and data analysis. The focus was on pedagogical value rather than technical proficiency. These tools were presented as ways to enhance interaction, inclusion and learner motivation [4].

In addition, strong emphasis was placed on critical digital literacy. Students were encouraged to reflect on issues such as algorithmic bias, data protection, digital footprints and the social implications of emerging technologies [1]. This approach aimed to foster a mindset beyond functional skills. It promotes ethical awareness and long-term sustainability in the use of technology in education.

Exploring AI Tools for Inclusive and Innovative Pedagogy

As part of the reform, we explored how artificial intelligence (AI) can support more inclusive, personalised and engaging learning environments [4]. The initiative focused on pedagogical uses of AI in line with the principles of Universal Design for Learning (UDL). These principles promote flexibility, accessibility and responsiveness to diverse learner needs.

Participants were introduced to various AI-based tools that support content creation (e.g. text and quiz generation), communication (e.g. language assistance, translation), emotional support (e.g. conversational agents) and presentation (e.g. video production with synthetic avatars) [4]. The emphasis was placed on the educational potential of these tools rather than their technical features.

Workshops also addressed ethical and critical aspects of AI use, including data privacy, algorithmic bias, and the implications of machine learning and autonomous systems. Students were encouraged to reflect on how these technologies shape teaching and learning, and to consider both their possibilities and limitations.

Such inclusive and flexible approaches also align with recent findings on the importance of coaching-based support for children's mental health and well-being in educational contexts [10].

AI was presented as a tool that can enhance educational accessibility and creativity, not as a replacement for the teacher. The initiative laid the groundwork for responsible AI integration in teacher education. It also highlighted the need for continuous professional development in a rapidly evolving technological landscape [4].

Redesigning Assessment Approaches in Light of Digital Competence Development

As part of the curriculum reform, assessment methods were redesigned to support the development of digital competences, learner autonomy and reflective practice. The process was guided by the DigComp 2.2 and DigCompEdu frameworks [1,3], which highlight the need for formative, process-oriented and inclusive approaches.

Traditional exams were supplemented by diverse formats such as digital quizzes, video presentations, screencasts, e-portfolios and reflective assignments. These methods enabled students to actively demonstrate understanding, engage in self-assessment and document learning over time.

Assessment focused on three dimensions: the learning process, the final product and students' ability to reflect and manage their own learning. To support implementation, guidelines were developed with examples of digital tools, task types and links to competence areas [3].

Special attention was paid to accessibility, fairness and authenticity. The revised system promotes original student work and helps prepare future teachers to become independent, digitally literate and critically engaged professionals.

PROGRAMME EVALUATION

Analysis of Curricula in Subject Teacher Education Programmes

An important part of the reform was a comprehensive analysis of syllabi across six teacher education programmes. The goal was to understand how digital and sustainability-related elements [1,2] are embedded in curricula and to identify areas for improvement.

We carried out the analysis using a unified methodology. The evaluation focused on three key components: learning outcomes and competences, course content, and teaching and learning methods. We assessed each component using a structured evaluation matrix. This matrix included a range of thematic dimensions, such as environmental literacy, digital skills (e.g. artificial intelligence, data security) [1,4], professional development, critical thinking, innovation, and other areas relevant to contemporary education.

This approach enabled reviewers to assess not only the presence of specific topics, but also the extent to which they were meaningfully integrated into the pedagogical process. The results revealed considerable variation in the inclusion of key content. This variation appeared both across different programmes and within individual courses of the same programme. Some syllabi had already incorporated essential competences in a systematic way, while others included them only partially or not at all.

Based on the findings, we formulated recommendations to enhance alignment between learning objectives, course content, and assessment methods. We also recommended strengthening horizontal consistency across courses within each programme. The analysis was compiled into an internal strategic document that now serves as a planning tool for further curriculum reform and for supporting long-term quality development at the faculty level [1–3].

CONCLUSION

The activities presented in this paper reflect a comprehensive approach to reforming subject teacher education in response to the changing needs of higher education and society. The project focused on digital competences, sustainability-related content, innovative assessment, and the pedagogical use of artificial intelligence [1,2,4]. Its aim was not only to update individual courses, but also to establish a coherent and competence-oriented teacher training system.

The implementation of the reform revealed that the main challenges were related to differing interpretations of the new guidelines and limited time for preparing revised syllabi. We found that regular meetings and ongoing coordination were essential. We recommend that other institutions include more opportunities for collaborative planning and sharing of good practices.

Although the project was implemented in the context of Slovenian higher education, many of the approaches and findings are transferable to other countries. The use of EU-level frameworks, competence-based curriculum design, and the integration of digital and sustainability content offer relevant insights for teacher education reform more broadly.

While this paper highlights work carried out within the programmes coordinated by the Faculty of Natural Sciences and Mathematics at the University of Maribor, similar activities were also implemented at other faculties. These faculties collaborated within the teacher education modernisation project. This indicates a broader systemic effort to align teacher education with the goals of digital transformation and sustainable development.

The next phase of the project will focus on implementing the revised curricula and monitoring their effects on teaching and learning. It will also include further development of institutional conditions that support reform. These efforts aim to ensure that future teachers are not only competent in subject knowledge but also equipped to navigate the digital, environmental, and pedagogical challenges of contemporary education.

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Reusing Post-Consumer Textiles for Decorative and Insulating Panels: A Sustainable Design Approach

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Abstract. In the context of the climate crisis and the growing amount of textile waste, this paper explores the reuse of post-consumer materials for the production of composite panels with both decorative and insulating functions. The research builds on the principles of circular economy and proposes an experimental methodology based on combining recycled textile fibers with ecological binders. The study analyzes the stages of selection, processing, and performance testing for thermal and acoustic properties, compared with conventional materials. Expected results indicate the potential of these solutions to reduce environmental impact while opening new aesthetic directions in interior design and sustainable architecture.

Keywords: recycled textiles, composite materials, sustainable design, circular economy, green architecture

INTRODUCTION

The issue of post-consumer textile waste represents one of the most pressing current challenges in the field of environment and sustainable design [1]. Global statistics indicate that millions of tons of clothes are thrown away annually, most of which end up in landfills or are incinerated. The alarming increase in textile waste, generated by the fashion industry and accelerated consumption, has become a major environmental problem. In this context, the reuse of post-consumer materials is not only an ecological necessity, but also an opportunity for innovation in contemporary design. The sustainable approach involves overcoming the traditional aesthetic paradigm and integrating functional criteria, such as thermal and acoustic insulation, into decorative and architectural objects.The article proposes applied research on the transformation of post-consumer textiles into materials with a dual function: decorative and insulating, using an interdisciplinary methodology that combines decorative arts, materials science and the principles of the circular economy.

THEORETICAL FRAMEWORK

The specialized literature reveals the use of alternative materials in architecture and interior design as a response to the demands of sustainability. According to Fletcher [2], sustainability in fashion and interior design is no longer optional, but a moral obligation, and the concept of circular economy becomes the pivot of innovation. Recycling and upcycling practices have experienced an accelerated evolution in the textile field, but most current solutions aim either at the production of fibers for spinning or household products. In this study, the innovation consists in the transformation of textiles into rigid and semi-rigid structures for constructive and decorative applications. The reintroduction of textile materials into the productive circuit reduces the consumption of virgin resources and minimizes carbon emissions.

Circular economy and reducing textile impact

The textile industry is considered the second most polluting industry globally, contributing significantly to CO_2 emissions and intensive water consumption [3]. Traditional "take-make-dispose" production models have led to the massive accumulation of post-consumer textile waste, most of which comes from clothes discarded after a short use cycle. The concept of the circular economy proposes closing material loops through reuse, recycling and upcycling, aiming to extend the life of products and reduce waste.

Textile upcycling – the creative reinterpretation of used materials to obtain products with increased aesthetic and functional value – is becoming a central strategy in sustainability. In this context, the transformation of post-consumer textiles into composite materials represents a logical extension of circular principles, with direct benefits in reducing the consumption of primary resources and in creating innovative solutions for construction and interior design.

Properties of textiles and their relevance in rigid compositions

Textile fibers (cotton, polyester, wool) possess physicomechanical characteristics that make them compatible with composite structures [4]. Natural fibers, such as cotton, offer good binder absorption and a porous structure, ideal for air retention, which confers insulating properties. Synthetic fibers, such as polyester, add mechanical strength and elasticity, reducing the risk of cracking.

These properties can be optimized by techniques such as:

• Chopping the materials to obtain an optimal ratio between long fibers and short particles.
• Homogenization with natural binders (starch, latex) or bio-resins to ensure structural cohesion.
• Pressing at controlled temperature for dimensional stabilization.

In the specialized literature, it has been observed that the integration of textile fibers into composite matrices leads to materials with low thermal conductivity (0.04–0.06 W/mK) and good acoustic capacity [4], due to the fibrous structure that absorbs vibrations.
At the same time, the chromatic and textural diversity gives them a high aesthetic potential for integration into decorative arrangements.

Current approaches and research gaps

Recent studies in the field of green materials have explored the use of plant fibers (hemp, flax, coconut) in bio-polymer compositions for construction [5], but post-consumer textiles remain insufficiently exploited on an industrial scale. Most existing projects focus on mechanical recycling to obtain renewable fibers in the textile industry, while their application in architecture is still limited.

Another critical aspect is the aesthetic impact: unlike standardized industrial materials, textiles offer a chromatic and textural variety that can be creatively exploited, transforming the final product into a unique decorative element. Thus, an interdisciplinary research area opens up, at the intersection of design, materials engineering and architecture.

RESEARCH METHODOLOGY

Research Design

The study adopts an experimental approach to validate the feasibility of converting post-consumer textiles into decorative and insulating materials. The design integrates literature review, laboratory tests for material fabrication, and comparative evaluation of thermal and acoustic performance.

Research Stages

Material Preparation: Selection of cotton, polyester and blends; cutting fibers (5–15 mm); washing and disinfecting.

Composition Formulation: Mixing fibers with ecological binders (modified starch, natural latex, bio-resins) in proportions of 60–70% fibers and 20–30% binder, with additives for safety.

Shaping: Hot pressing at 90–120°C into panels (20 mm for decorative, 40 mm for insulation).

Testing: Thermal conductivity (ISO 8302), acoustic absorption (ISO 354) and mechanical strength (EN 826).

Data analysis methods

The experimental results will be compared with the values of conventional materials (expanded polystyrene, MDF boards). Descriptive and correlational statistical analyses will be used to evaluate the variations depending on the type of fiber and the proportion of binder.

PRACTICAL APPLICATIONS AND REFERENCE STUDIES

The integration of post-consumer textiles into new productive flows is essential for reducing waste and stimulating the circular economy. The construction materials industry and interior design represent areas with huge potential for capitalizing on these resources [6], due to the need for sustainable products with a reduced ecological footprint.

Technologies for transforming textiles into insulating and decorative materials

Fiber shredding and agglomeration

The collected textiles are chopped and homogenized, then mixed with ecological binders (bio-based resins, modified starch or natural latex). By pressing at controlled temperatures, panels with variable density result, usable for thermal and acoustic insulation. The average thermal conductivity of these materials is between 0.035–0.045 W/mK, comparable to expanded polystyrene [6, p.132].

Decorative composite panels

By combining textile fibers with natural pigments and protective layers, panels with an aesthetic function can be created for interior cladding, ventilated facades or modular furniture. The resulting visual appearance is customizable by controlling recycled colors and textures [7, p.95].

Acoustic treatment with recycled textiles

Textile fibers have a superior sound absorption capacity, especially at mid-frequencies, which makes them suitable for conference rooms, theaters and offices. These panels reduce ambient noise and provide an aesthetic addition [8, p.214].

International reference cases

-*Isolena Naturfasern* (Austria) - Uses recycled wool to produce natural insulation, with hygroscopic properties that maintain the optimal microclimate in homes, being certified for passive construction [9].
-*Planq* (Netherlands) - Transforms post-consumer denim into rigid boards for furniture and decorative finishes. The technology includes shredding, combining with biopolymers and pressing, resulting in products with high mechanical strength and a unique design through the texture of the jeans fibers [10].
-"*Soundproof Textiles*" project (Germany) - Developed sound-absorbing panels made of recycled textile fibers, used in co-working spaces. The results indicate high acoustic performance in the frequencies used in office environments [8, p.214].

Relevance for sustainable design

These applications demonstrate that post-consumer textiles can overcome the status of waste and be transformed into materials with dual value: functional and aesthetic [1]. In addition, they offer opportunities for: regenerative interior design, sustainable architecture, experimental collections of decorative objects with a reduced ecological footprint.

By integrating this type of materials into architectural and design projects, the premises of a circular economy are created that reduces the impact on the environment and encourages responsibility in artistic and industrial creation.

The valorization of post-consumer textiles to obtain decorative and insulating materials represents a viable solution to the problem of global textile waste. In an era marked by climate change and pressure on natural resources, this approach not only reduces pollution, but also generates innovative products that combine technical performance and visual expressiveness. The studies presented show that materials obtained from textile fibers can successfully compete with conventional alternatives in terms of energy efficiency, acoustic comfort and aesthetic impact.

In addition, this research direction favors the synergy between arts, design and science, opening up possibilities for interdisciplinary projects with economic and social impact. From a creative perspective, transforming used textiles into high-value-added products brings an ethical and poetic dimension to contemporary design, converting fragments of the past into solutions for the future.

EXPECTED RESULTS

It is expected to obtain panels with thermal conductivity < 0.06 W/mK and low density (< 400 kg/m³), suitable for interior walls and decorative systems [6]. In parallel, the materials will have a valuable aesthetic impact, thanks to the textures generated by the textile fibers, integrating the original chromaticity and structure of the source materials.

CONCLUSIONS AND IMPLICATIONS

Post-consumer textiles represent one of the most challenging and at the same time promising resources for environmental sustainability and the creative industry [1-3]. In the context where the volume of textile waste continues to grow globally, and disposal solutions through incineration or landfill generate significant ecological impacts, their transformation into materials with a dual function – decorative and insulating – opens a new interdisciplinary horizon. This approach is not only a technical alternative, but a cultural and aesthetic strategy, which reconciles design with the principles of the circular economy.

Theoretical analysis and experimental results suggest that materials obtained from recycled textile fibers can achieve relevant performances in reducing noise and heat loss, while maintaining a high expressive potential for interior design and sustainable architecture. Natural fibers, especially wool and cotton, due to their hygroscopic properties and structural elasticity, lend themselves to configurations that confer superior insulating capacities, while synthetic fibers contribute to mechanical resistance and dimensional stability. By mixing these types of fibers and using ecological binders (bio-resins, natural latex or biodegradable polymers), sustainable composites can be obtained, adaptable to different functional contexts.

Beyond technical aspects, this approach addresses an ethical and educational need by promoting a shift in consumption patterns. Revalorizing textiles becomes both social responsibility and artistic innovation, encouraging designers to rethink materiality. Pilot projects show its practical integration, with economic and image benefits. This direction fosters synergy between arts, design, and science, enabling interdisciplinary collaborations. Transforming used textiles into high-value products adds an ethical and poetic layer to contemporary design, turning waste into resources. Ultimately, it is not only a waste-reduction strategy but a catalyst for dialogue between sustainability and creativity, with potential to become a standard in construction and interior design.

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Sustainable Fashion and Educational Design as a Tool for Environmental and Social Change

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Abstract. The paper examines the potential of educational design on clothing through the reversible hoodies of the Student Company Hoody, which combine aesthetics, functionality, and an ecological message. Educational design is considered as a visual communication tool for conveying messages on important social topics, particularly ecology, with an analysis of relevant literature revealing the impact of different visual stimuli on youth awareness and behavior. Reversible design, merging two garments into one, offers potential for reducing textile waste but raises the question of whether it changes purchasing habits in the long term or creates new demand. The paper theoretically and critically addresses ethical, ecological, and economic aspects, emphasizing the need for further empirical research to assess the actual effectiveness of this approach.

Keywords: educational design, sustainable fashion, visual communication, reversible hoodies, Student Company Hoody

INTRODUCTION

The fashion industry, especially through the dominant fast fashion model, represents one of the greatest environmental and social challenges of the modern era. Fast fashion is a business model in the fashion industry based on very rapid production and placement of cheap clothing, designed according to current runway trends, with a short product life cycle. This model is characterized by short production and sales cycles, affordable prices, intensive market responsiveness, and low product durability, all for the purpose of maximum turnover and meeting consumers' immediate demand [1].

The fashion industry is responsible for a significant share of global greenhouse gas emissions, water resource pollution, and the accumulation of textile waste in landfills. It is estimated that the textile industry is the second-largest polluter of the water industry, while less than 1% of textiles are recycled, and as many as 80 billion garments are discarded and incinerated annually. According to systematic reviews, this sector is responsible for approximately 8% of global carbon dioxide emissions, with water pollution amounting to 20% of total industrial consumption, and emissions expected to rise by 50% by 2030 [2]. This is due not only to intensive production but also to accelerated consumption. Fast fashion further exacerbates these consequences. Clothing production doubled between 2000 and 2014, while the average number of times a garment is worn is only 7–10 times before disposal, highlighting the problem of overconsumption and a throwaway culture [3]. These facts point to an urgent need to transform consumer patterns toward sustainable and circular models.

Socially, the fast fashion model fosters inequality between consumers and workers in the fashion industry. While consumers in highly developed countries enjoy cheap trends, workers and local communities bear the full costs of pollution and exploitation. Waste, polluted water, and chemicals negatively affect the health of these communities even after production. The situation is especially critical in low- and middle-income countries (LMICs), where producers lack the capacity for waste treatment or legal worker protection [4].

In the global context, the need for changing consumer patterns and introducing a sustainable fashion model based on circular principles is evident: reduce waste, extend clothing life through repairs and reuse, and support recycling. These are not only environmental imperatives but also social and ethical necessities [5].

These concerning facts require innovative and creative engineering solutions that effectively connect the aesthetic and functional aspects of products with educational goals. In this context, educational design in fashion offers the potential to influence consumer behavior through attractive and thoughtful visual messages, encouraging reflection on the consequences of consumption and promoting more sustainable choices [6]. This approach combines design with a clear social mission, creating a product that simultaneously communicates, educates, and motivates action.

The aim of this paper is to present, through theoretical analysis and thematic synthesis of literature, how sustainable fashion integrated with educational design can contribute to environmental and social transformation, especially among young people, through the lens of the Student Company of Zrenjanin Gymnasium "Hoody." It also aims to show how visual communication on clothing can enhance awareness of the planet's condition, increase engagement in responsible consumption, and support circular practices, not only at the individual level but also as a driver of broader cultural change.

THEORETICAL FRAMEWORK

The role of the image in education and message transmission

Clothing is a powerful communicator that influences the first impression of a person as well as social interactions [7]. Good design is design that correlates with the social, i.e., current context, as well as design that solves real problems [8]. Considering the initial definition of good design and looking at the bigger picture, good design is that which conveys a message in the form of emotion, information, etc. If the goal is to convey a message well through illustration, the medium of transmitting design can be: 1. image, 2. text, or 3. image+text. In choosing between image and text, sources state that for this purpose it is more appropriate to use image rather than text, including better memorization and faster processing [9-11, 13]. Specifically, Paivio and Csapo [9] write that free recall is higher for information conveyed through image compared to word. They prove this with the dual-coding theory, which says that verbalization of images necessarily occurs, but not vice versa [10]. The better recognizability of images compared to text, as well as their better memorization, is also confirmed by Nelson, Reed, and Walling [11]. Furthermore, even in people with cognitive dysfunction, i.e., Alzheimer's disease and mild cognitive impairment, image superiority occurs [12]. However, recall can be hindered when two similar stimuli appear one after the other [13], which must be considered when creating designs. Moreover, regarding the elicitation of certain emotions, research shows that emotion differentiation is more pronounced when interpreting images than text, with the stimulus being positive, negative, or neutral [14]. When choosing design orientation on the positive-negative scale, studies show that evoking negative emotions through negative stimuli (e.g., a polluted planet, as negative, compared to a clean planet, as positive stimulus, where, roughly, the positive and negative stimulus evoke positive and negative feelings respectively) — specifically about environmental protection — more strongly and effectively encourages the intention to act for nature conservation [15]. The same applies to certain types of advertisements, where negative ads increase the desire to purchase products when it comes to ecological products [16], which includes sustainable fashion.

How and why clothing is bought?

When it comes to purchasing, logically, buying garments is determined by personal traits, preferences, and attitudes, and it explicitly reflects them [17]. Thus, people predominantly buy clothes they like and/or that reflect their attitudes. Also, as expected, studies show that consumer awareness of environmental issues significantly affects their behavior [18], which implies a greater willingness to buy ecological products. Moreover, people generally choose to buy and wear pro-ecological clothing believing it reflects higher status and benevolence, but only if the products are more expensive than the non-ecological alternative [19], which is important to consider when building a brand.

Youth and ecology

Young people are significant actors in every society. However, studies show that youth tend to participate more outside institutions [20, 21] and take actions in non-institutional ways, which may correlate with their (non)integration into institutions by decision-makers. Compared to older generations, youth are more oriented toward sustainability [22]. These two facts mean that young people are willing to use activism to change the negative environmental picture. Most young people gather information about eco-fashion on social media [23]. This makes social media the largest medium for transmitting environmental messages [24]. Consequently, it is potentially also the largest medium for purchasing. The literature does not explicitly define which method of purchase (online or traditional) is less or more harmful to the planet [25,26]. However, among the processed respondents, online shopping is perceived as a choice that does not contribute to climate change [27], so logically, ecological products should be sold online, since potential buyers would look for them there, and there are no sources indicating whether environmentally conscious individuals are aware of the impact of online versus traditional shopping — which, accordingly, does not diminish the hypothesis that online shopping is more suitable for the stated goals. Nonetheless, online platforms create a FOMO effect (Fear of Missing Out) [28]. The FOMO effect creates a need for compulsive shopping behavior [29], and the synthesis of the FOMO effect and consumer compulsive behavior results in depression and social anxiety, as well as pronounced hyper-consumption [29], which represents a huge problem for the fashion industry. The question of creating the FOMO effect is primarily an ethical one and varies from brand to brand, but the above statements serve as a kind of warning to fashion trend creators.

DISCUSSION

Analyzed literature shows that visual communication on clothing, especially through images and the combination of image and text, has significant potential for conveying ecological messages and encouraging sustainable consumer patterns. Within the Student Company Hoody, this principle is applied through double-sided (reversible) hoodies with educational illustrations, which simultaneously provide both aesthetic and informational content. This approach aligns with the concept that design is not merely an aesthetic choice, but also a means of social change. Reversible design also has an ecological dimension — by combining two garments into one, textile waste and the need for producing another item are reduced, which in theory can lower resource consumption and CO_2 emissions. This potentially achieves a 100% waste reduction compared to purchasing two separate products.

However, the question arises whether such a concept truly reduces the need for purchasing additional clothing in the long run or, conversely, creates new demand and the desire to buy a Hoody hoodie even when another garment is not necessary. This balance between ecological benefit and possible consumerist effect requires further research.

An ethical question also remains: is it acceptable to manipulate the emotions of young people in order to motivate them to protect the environment, or is it more correct to limit oneself solely to informing them? According to the cited research, negative visual stimuli (e.g., an image of a polluted planet) more strongly encourage the intention for ecological action than positive ones (e.g., an image of a clean planet). This indicates that the goal — ecological transformation — may justify the use of emotionally powerful, even negative, messages. However, there is a risk of excessive manipulation that could undermine trust or cause feelings of ecological anxiety, especially among younger populations. Therefore, the ethical boundary must be carefully defined so that the design motivates, rather than demotivates or overwhelms.

The potential of educational design on clothing lies in its mobility and visibility — a “walking billboard” can reach audiences that are not active consumers of ecological messages through other channels. Considering that young people obtain most of their ecological information via social media, Hoody designs can function simultaneously in physical space (on clothing) and in digital space (through photos and sharing on networks). This creates a synergy between offline and online communication.

However, the limitations are numerous. Perception of the design itself is highly subjective — what seems inspiring to one observer may appear unattractive or unclear to another. Furthermore, there is insufficient research on the reach of educational design on clothing or on the long-term impact of such visual messages on changing consumer behavior. There is also an economic aspect — studies show that consumers are more likely to purchase ecological products when they are more expensive, associating them with status and altruism, but at the same time, an excessively high price can limit accessibility to a wider circle of young people.

Theoretically, such design contributes to merging aesthetics, education, and social responsibility into a single product. Practically, Hoody hoodies offer a model that can be adapted to various themes (ecology, human rights, health) and that allows the consumer to become an active carrier of the message. Still, further empirical research is necessary to measure the actual effectiveness of this approach — from message recall levels to real behavioral changes, as well as understanding whether reversible design truly reduces long-term purchases or merely changes their form.

CONCLUSION

Sustainable fashion with educational design, as developed by the Student Company Hoody, shows potential to combine aesthetic value, social responsibility, and ecological messaging in a single product. This approach can contribute to strengthening awareness of environmental protection, especially among young people, and create new forms of engagement through everyday wearing of clothing with clear messages.

To confirm this potential, it is necessary to conduct concrete empirical research focused specifically on Hoody designs. It would be particularly useful to compare reactions, message recall, and possible changes in consumer attitudes when exposed to a Hoody hoodie versus a regular hoodie without educational content. Such comparisons could provide a clearer picture of the real power of visual communication on clothing and its impact on consumer behavior.

Further development of the Hoody concept should also include testing different types of messages (positive and negative), as well as assessing their effect in various contexts — in schools, at public events, and on social media. This would enable more precise design shaping that not only attracts attention but also triggers action toward more sustainable lifestyle habits.

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Increasing Oil Production by Polymer Injection – Repair and Isolation Operations (RIO)

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Abstract. Excessive water influx in oil wells constitutes a major technical and economic issue, especially in the advanced stages of well exploitation. This paper presents the application of repair and isolation operations (RIO) involving polymer gel injection as an effective method for controlling unwanted water production and enhancing oil recovery in the "V" oil field. The study focuses on the selection of candidate wells, assessment of cement sheath integrity, and interpretation of production logging data. A detailed case study of well V-153 is presented to illustrate the effectiveness of the applied methodology. The results confirm that proper planning and execution of RIO operations can significantly reduce water cut and improve oil output.

Keywords: repair and isolation operations (RIO), water influx, polymer injection, oil fields, production enhancement.

INTRODUCTION

Extended exploitation of oil reservoirs often leads to increased water influx into production wells, which directly reduces the efficiency and economic viability of hydrocarbon recovery [1]. Phenomena such as bottom water breakthrough, the formation of water cones, and inadequate cementing of the casing represent key challenges in fluid flow management [2]. To ensure stable production and prolong well life, it is necessary to apply targeted methods for the selective isolation of water-bearing zones [3].

One of the effective techniques in modern practice is the application of repair and isolation operations (RIO) through the injection of polymer gels into water-saturated zones [4]. These operations enable the formation of low-permeability barriers that redirect flow toward oil-saturated portions of the reservoir [5]. Compared to traditional mechanical approaches, chemical methods such as polymer injection allow for deeper intervention into the formation and offer long-term solutions for controlling unwanted water influx [6,7].

This paper presents the methodology for planning and executing RIO operations at the "V" oil field, with special emphasis on the analysis of geological and production data, selection of candidate wells, evaluation of cement sheath integrity, and implementation of production logging. The results of the intervention on a specific well are presented, along with a multi-year field-wide efficiency analysis. The aim of the study is to highlight the potential of this method in improving reservoir performance and reducing operational costs through effective water control [8–10].

MATERIALS AND METHODS

The research was conducted in the “V” oil field, which is characterized by a water drive exploitation regime. In order to restrict water inflow into the production intervals and enhance oil production, workover and isolation interventions were carried out. The main objective of these operations was to reduce the influence of bottom water and the occurrence of water coning, both of which lead to an increased water content in the produced fluid.

Wells that exhibited a sudden rise in water content, along with the presence of sufficient formation space below the production interval, were selected as candidates for intervention. The candidate selection process was based on cement bond log (CBL) analysis to assess the quality of the cement sheath, production logging (PL) measurements to characterize inflow profiles, and a comprehensive review of historical production data.

The core method applied involved injecting polymer gels below the production interval to create an impermeable barrier between oil-saturated and water-saturated zones. Depending on geological and technical conditions, two operational techniques were employed: the installation of a retainer followed by the perforation of technical injection ports, or the pressure cementing of the production interval, hermeticity testing, and subsequent perforation of technical ports.

The design and implementation of polymer injection were guided by carefully defined parameters, including polymer viscosity and concentration (starting with a lower concentration), total volume and fluid density, gelation time, water quality for mixing and compatibility with formation water, and the appropriate selection of crosslinking agents. Operational constraints were strictly observed throughout the process; injection pressure did not exceed the formation fracture pressure, which was typically kept below 40 bar, and injection capacity was limited to a maximum of 200 dm^3/min.

If injectivity was found to be below 300 m^3/day at a pressure of 60 bar, chemical treatment of the formation was conducted to enhance permeability. The full injection sequence included a two-stage polymer injection (starting with a lower concentration followed by a higher one), the placement of a cement barrier, and displacement with a flushing fluid, typically water.

After gel solidification, the planned production interval was perforated. In certain cases, this interval corresponded to the original one, while in others, it was adjusted slightly upward to include previously unperforated upper reservoir sections.

The efficiency of the remedial isolation works was evaluated based on post-intervention production dynamics. In all treated wells, an increase in oil production of up to 2 tons per day was observed, accompanied by a noticeable reduction in water cut. These results led to a significant decrease in water disposal costs and an overall improvement in production economics.

RESULTS AND DISCUSSION

The application of repair and isolation operations (RIO) using polymer gels at the “V” oil field has yielded quantifiable technical and economic results. In order to assess the effectiveness of the method, three key performance indicators were analyzed: the reduction in total fluid production, the increase in oil output, and the decrease in the water cut of the produced fluids.

The results are presented over a three-year period and cover multiple wells treated using this method (Table 1, Figure 1). A significant decrease in total fluid production was recorded following the RIO interventions, indicating successful isolation of zones characterized by dominant water influx. This trend confirms that the implemented measures effectively redirected flow away from water-saturated regions.

The increase in oil production further validates the efficiency of the intervention. By eliminating preferential water pathways, the reservoir was compelled to contribute from oil-saturated zones. In some wells, oil production increased by as much as 210%, clearly demonstrating the high efficiency of the polymer injection approach under the given reservoir conditions.

The reduction in water cut serves as a direct indicator of the method's success. In several wells, a substantial decline in water content was observed, which varied depending on the reservoir's heterogeneity and the accuracy in selecting the injection interval. This highlights the importance of detailed pre-treatment diagnostics and precise execution.

Table 1. Annual reduction in total fluid production, increase in oil production, and decrease in water cut (%)

Year	Annual Reduction in Fluid Production (%)	Annual Increase in Oil Production (%)	Annual Percentage Reduction in Water Cut (%)
2016	47	378	13
2017	10	730	15
2018	46	296	19

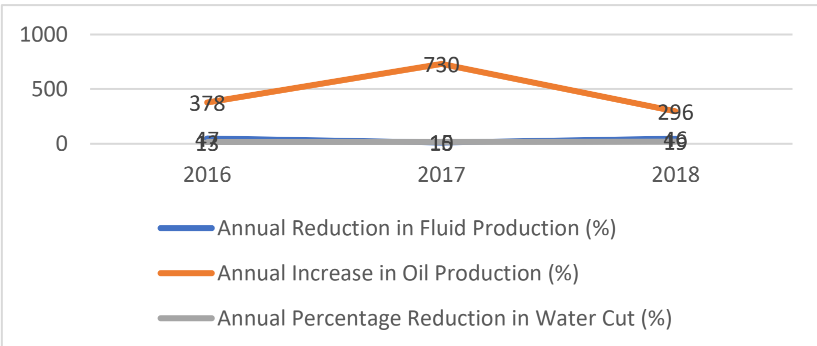

Figure 1. Annual Percentage Reduction in Total Fluid Production, Decrease in Water Cut, and Increase in Oil Production

Figure 2 presents a comparative analysis of production decline trends, illustrating projected production behavior in the absence of repair and isolation operations (RIO), versus the actual production outcomes following intervention on well V-153 [11].

The production dynamics were analyzed using Arps' decline curve model. Theoretical decline curves, representing scenarios without intervention, were compared with actual post-treatment production data. For well V-153, a clear divergence in production trends was observed. While continuous decline would have been expected without intervention, polymer injection resulted in production stabilization and, in some instances, even an increase. This contrast strongly supports the effectiveness of the RIO approach.

The cumulative oil production gain for the analyzed period amounted to 25,886 metric tons, representing a substantial contribution to the overall recovery efficiency of the reservoir. Notably, this production increase was achieved despite the mature stage of the reservoir and the high water cut observed in the wells prior to treatment. This further underlines the robustness and practical viability of the applied method.

The discussion of results suggests that the success of the RIO operation critically depends on accurate calculation of the polymer volume and properties, the quality of the pre-existing cement sheath, and the appropriate selection of candidate wells. These parameters must be carefully optimized in order to achieve sustainable improvement in production performance and water management.

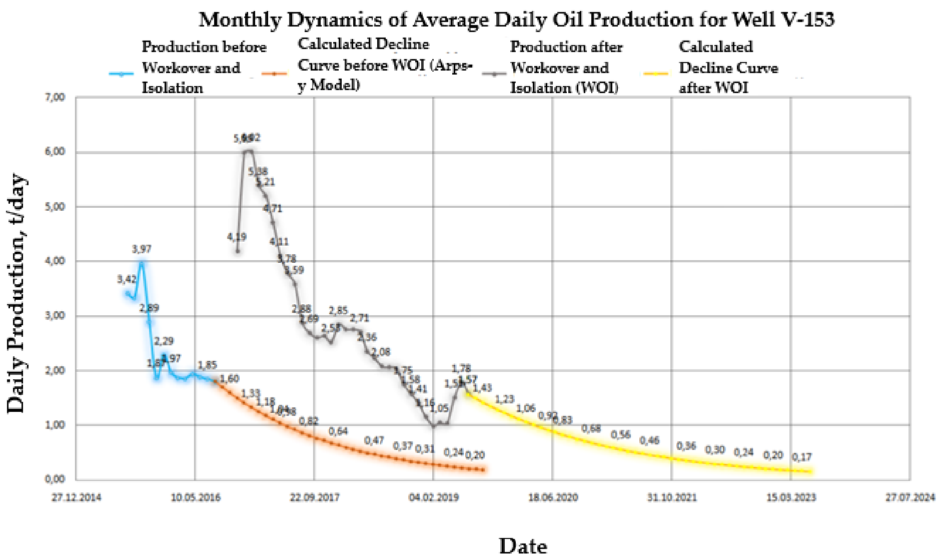

Figure 2. Oil production before and after repair and isolation operations (RIO) for Well V-153

CONCLUSION

Repair and isolation operations (RIO) using polymer gels have proven to be an effective and applicable method for reducing water influx in production wells at the “V” oil field. A detailed analysis of geological and production data, combined with meticulous planning of operational procedures, were key factors in the success of these interventions.

The results indicate that the application of this method led to:

- a significant reduction in water content in the total produced fluid (up to 72%),
- an increase in daily oil production at individual wells (up to 210%),
- a cumulative oil gain of 25,886 metric tons during the analyzed period.

It is particularly noteworthy that positive outcomes were also achieved in wells that had been shut-in or were nearing the threshold of economic viability, highlighting the potential of this method for revitalizing production capacity in mature reservoirs.

Based on the results, it can be concluded that properly designed and executed remedial isolation operations represent a cost-effective solution for enhancing oil production and controlling unwanted water influx in petroleum wells.

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Radiative-Cooling Textiles for Passive Body Cooling – A Teaching Concept

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Abstract. In the contemporary context of climate change and increasingly frequent heat waves, the demand for technologies that enable passive body cooling without additional energy consumption has been intensified. One of the innovative solutions is represented by radiative-cooling textiles - materials designed to reflect solar radiation while simultaneously emitting heat effectively in the form of infrared radiation. These materials provide body temperature reduction and enhance thermal comfort, even under extreme conditions. The aim of this paper is to present the fundamental physical properties and operational principles of radiative-cooling textiles, as well as examples of their modern applications. The focus of the study is directed toward the possibilities of addressing this topic within a teaching context, with emphasis on fostering scientific literacy and linking theoretical knowledge with contemporary technologies.

Keywords: radiative-cooling textiles, passive cooling, infrared radiation, teaching concept, thermal comfort

INTRODUCTION

Climate change has led to an increase in average temperatures and more frequent extreme weather events, including heat waves that may seriously endanger human health [1]. In this context, growing interest has been directed toward the development of technologies that can contribute to passive thermal regulation without reliance on energy-intensive air conditioning systems. One such technology is the application of *radiative-cooling* textiles.

In this paper, the physical basis of the functioning of such materials, their applications, and the potential for introducing this topic into the educational process through the teaching of natural sciences, physics, chemistry, and engineering and technology subjects are considered. The objective is to highlight the possibility of integrating contemporary scientific achievements into teaching practice.

PRINCIPLES OF RADIATIVE COOLING

Radiative cooling refers to the process in which an object reduces its temperature by emitting heat in the form of infrared (IR) radiation. For a material to be effective in this process, high reflectivity in the visible spectrum and high emissivity in the infrared spectrum are required [2,3].

Textile materials that meet these requirements have been engineered through the use of nanostructures, coatings with metal oxides, as well as specific polymers such as modified polyethylene. These materials have been shown to reduce the temperature of the clothed body by as much as 5–13 °C in comparison with conventional cotton garments. In the work of Hasan et al. [2], the importance of nanostructures and composite materials is emphasized, whereas Jiang et al. [3] provide a broader classification of contemporary radiative-cooling solutions.

MODERN MATERIALS AND TECHNOLOGIES

Examples of successfully developed radiative-cooling textiles include three dominant approaches:

Polyethylene fabrics with ZnO nanoparticles: This type of material employs low-density polyethylene that has been modified to be transparent to radiation in the mid-infrared spectrum, thereby allowing efficient emission of body heat. At the same time, the incorporation of zinc oxide (ZnO) nanoparticles into the fabric enhances reflection of the visible and near-infrared portions of solar radiation, preventing heating. In practical tests, such fabrics have been shown to reduce skin temperature compared to conventional fabrics. An additional advantage is their lightweight structure and relatively good moisture permeability (Figure 1).

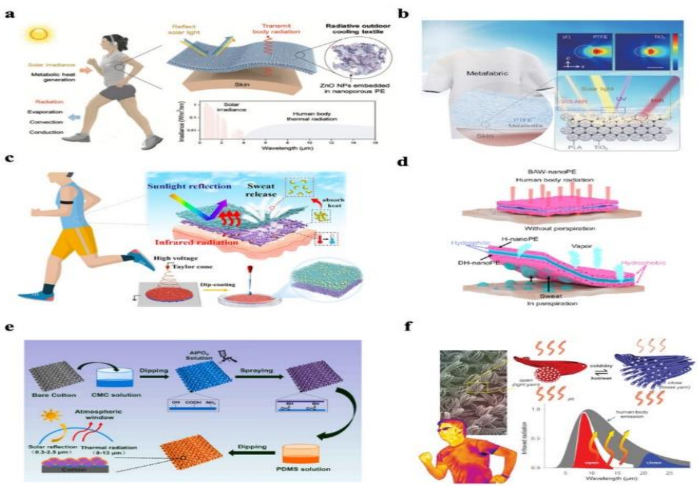

Figure 1. Structure and application of polyethylene textile with embedded ZnO nanoparticles (source: https://www.preprints.org/manuscript/202402.0087/v1)

Porous materials for passive cooling: These materials have been designed to contain micro- and nano-porous structures that enable simultaneous transfer of heat and moisture [3,4]. The porosity increases the surface area available for IR emission, while simultaneously permitting the passage of water vapor, thereby improving the regulation of the microclimate between the body and the fabric (Figure 2). For instance, fabrics produced from porous polypropylene or combinations of cellulosic fibers with porous layers have demonstrated good performance under hot and humid conditions, which further enhances the subjective perception of comfort.

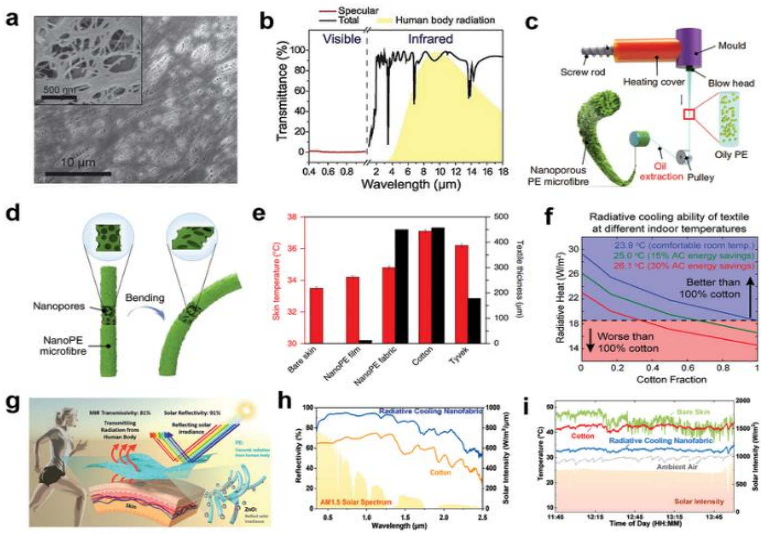

Figure 2. Structure of porous materials for passive cooling
(source: https://advanced.onlinelibrary.wiley.com/doi/10.1002/advs.202305228)

Metalized textiles with reflective layers: Metalized textiles with reflective layers are fabricated by depositing ultra-thin metallic coatings, most commonly aluminum or silver, onto the fabric surface (Figure 3). These coatings exhibit high reflectivity to solar radiation and thereby reduce overall heat gain, while appropriate adjustment of their thickness and distribution enables satisfactory emissive properties in the infrared spectrum. Recent studies on silver-coated textiles have further demonstrated enhanced infrared transmittance and measurable cooling effects, confirming their potential for passive thermal management [5].

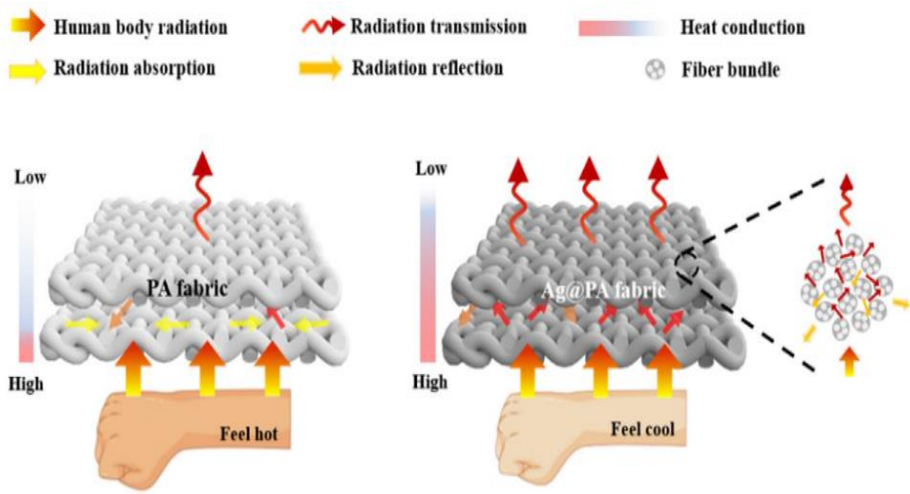

Figure 3. IR transmittance of conventional fabric (left) and silver-metalized fabric (right) (source: https://www.mdpi.com/2073-4360/14/1/147)

Commercial products based on these radiative-cooling approaches are being developed by companies and research groups, particularly for sportswear, work clothing, and garments intended for extreme environments.

TEACHING CONCEPT

The treatment of this topic within the teaching process enables the connection of theoretical knowledge with contemporary contexts and the development of ecological awareness. A teaching unit may be designed within the framework of the topic concerning heat transfer, radiation, and materials.

Proposed teaching framework:

Teaching unit: Heat transfer and material properties

Learning outcomes:

- The student is able to explain the basic modes of heat transfer.
- The role of materials in regulating body heat is recognized.
- The advantages of modern materials in comparison with conventional ones are analyzed.

Methodology:

- Analysis of video and digital resources on radiative-cooling textiles.
- Comparison of thermal images of different materials (using IR cameras or simulations).
- Group discussion and connection with everyday experiences.

Interdisciplinary connections: physics, chemistry, engineering and technology, ecology

CONCLUSION

The integration of contemporary scientific topics into teaching can contribute to student motivation, an improved understanding of the role of science in everyday life, and the development of critical thinking skills. The introduction of topics such as radiative-cooling textiles also provides opportunities for discussions on climate challenges and environmentally responsible solutions [2,3]. Successful implementation requires the availability of resources (digital tools, measuring instruments) and adequate teacher training; however, it can also be initiated through simple analyses and comparisons based on freely available materials.

The topic of radiative-cooling textiles represents a synthesis of modern science, everyday application, and educational potential. The incorporation of such topics into teaching contributes to the modernization of the educational process, the strengthening of interdisciplinary connections, and the development of sustainability awareness. This paper offers a model of how complex scientific concepts can be brought closer to students through concrete and relevant examples. In this way, students not only gain an understanding of the fundamental principles of physics and engineering sciences but also develop awareness of the importance of sustainable technologies in everyday life.

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Ultraviolet Radiation and Human Health – A Model of an Interdisciplinary Lesson in Natural Sciences

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Abstract. In this paper, the physical properties of UV radiation and its biological effects on human health will be examined. In the introductory part, the fundamental characteristics of UV radiation will be considered, followed by a description of its positive and negative effects on human health and the possibilities of protection. In the final section, the pedagogical and methodological structure of an interdisciplinary lesson incorporating the content discussed in the paper will be presented.

Keywords: electromagnetic radiation, health, teaching

INTRODUCTION

The concept of ultraviolet (UV) radiation has been encountered in the teaching of natural sciences such as biology, physics, and chemistry since elementary education. The primary natural source of UV radiation on Earth is the Sun, while lightning, auroras, and volcanic eruptions contribute to a lesser extent. Artificial sources of UV radiation are also known. UV radiation plays an essential role in biochemical processes that occur in living organisms and are necessary for their physiological functioning (e.g., photosynthesis) [3]. It is indispensable for the survival of life on Earth. Living organisms have been adapted to natural levels of solar UV radiation; however, any increase in its intensity or alteration in the spectrum reaching the Earth's surface results in harmful effects on human health and the biosphere as a whole [7]. The intensity and spectrum of UV radiation reaching the Earth's surface are directly determined by the thickness of the ozone layer.

The ozone layer functions as a filter (absorber) of ultraviolet (UV) radiation. Ozone (O_3) is an unstable gas that is readily decomposed under the influence of artificially produced halogenated hydrocarbons (such as chlorofluorocarbons and halons), which have found wide application in industry and everyday life [3]. In addition to natural UV radiation, increasing exposure to UV radiation emitted by artificial sources is occurring today, particularly those employed for medical, cosmetic, and aesthetic purposes. The harmful effects resulting from excessive exposure to UV radiation are not limited to immediate and visible outcomes; rather, they may accumulate within the organism and manifest years later. Therefore, caution and adequate awareness regarding UV radiation are required in order to prevent unpleasant experiences and potentially serious health consequences [1].

FUNDAMENTAL CHARACTERISTICS OF UV RADIATION

Ultraviolet (UV) radiation is defined as the portion of the electromagnetic spectrum with wavelengths ranging from 100 nm to 400 nm. It is encompassed within the region of the spectrum situated between X-rays and visible radiation (light) [9]. UV radiation is invisible to the human eye. Its frequency range extends from 7.5×10^{14} Hz to 3.0×10^{15} Hz [10]. According to the standard biological and medical classification [6,7], UV radiation is subdivided into three spectral regions: UV-A (400–315 nm), UV-B (315–280 nm), and UV-C (280–100 nm).

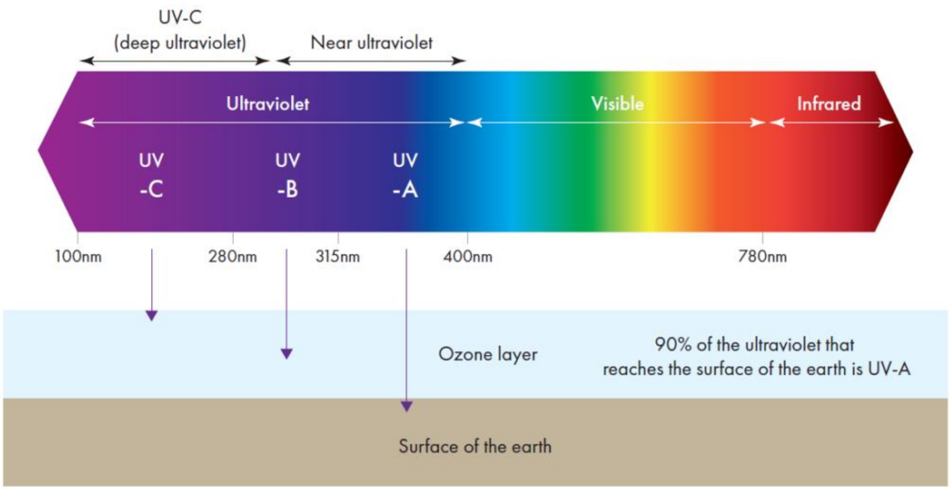

Figure 1. UV Spectrum
(source: https://knowhow.distrelec.com/medical-healthcare/an-introduction-to-uvc/)

The ultraviolet (UV) radiation reaching the Earth from the Sun (UV-A and UV-B) is classified as non-ionizing, whereas UV-C radiation, within a part of its spectrum, is ionizing and plays a crucial role in ozone formation. More than 90% of the total UV radiation that reaches the Earth's surface consists of UV-A. UV-B, possessing significantly higher energy, is capable of causing burns and DNA damage, while UV-C radiation is completely absorbed by the ozone layer and does not naturally reach the Earth's surface. UV-C radiation emitted from artificial sources is extremely harmful to living organisms [4].

POSITIVE EFFECTS OF UV RADIATION ON HUMAN HEALTH

Moderate exposure to UV-B radiation stimulates the synthesis of vitamin D, which is essential for bone health, immune function, and the regulation of cellular growth. Daylight, including UV-A, contributes to the regulation of the circadian rhythm and the secretion of serotonin. Controlled UV radiation is employed in phototherapy for the treatment of certain skin diseases, such as psoriasis, vitiligo, and atopic dermatitis (eczema). Since the late 19th century, prior to the discovery of antibiotics, UV-C and UV-B radiation have been utilized for the surface disinfection of skin and wounds [7].

NEGATIVE EFFECTS OF UV RADIATION ON HUMAN HEALTH

Excessive exposure to UV radiation results in acute skin damage (erythema, burns), chronic damage (photoaging, DNA mutations), and an increased risk of skin cancers, the most dangerous being melanoma. Immunosuppression and viral reactivation may also be induced. Furthermore, UV radiation causes ocular disorders such as photokeratitis, pterygium, cataracts, and malignancies of the ocular and periocular regions, including the eyelids [2,6,7].

UV INDEX AND PROTECTION AGAINST UV RADIATION

The UV Index is an internationally standardized numerical scale that indicates the intensity of solar UV radiation reaching the Earth’s surface, thereby reflecting the associated risk of skin damage [5].

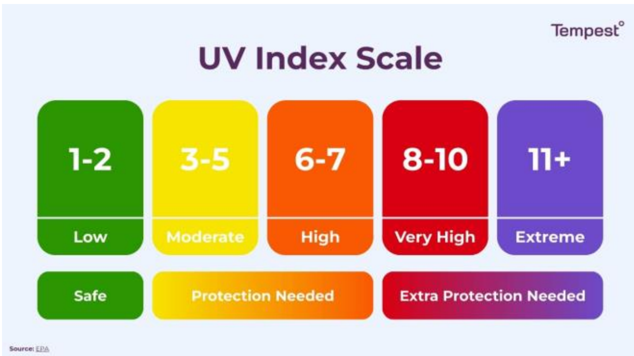

Figure 2. UV Index (source: https://tempest.earth/resources/what-is-the-uv-index/)

Protection against UV radiation includes the wearing of wide-brimmed hats, sunglasses with 100% UV-A/UV-B protection, clothing with UV shielding properties, and the application of broad-spectrum sunscreen with a minimum SPF of 30, in addition to the avoidance of direct sun exposure between 10 a.m. and 4 p.m. [7]. All of these protective measures should be followed in accordance with the relevant UV Index values and recommended guidelines. The term SPF denotes the degree of protection against UV-B radiation and is applied to skin protection products such as creams and lotions. Clothing designed to protect against both UV-A and UV-B radiation is labeled with a UPF value [8].

PEDAGOGICAL AND METHODOLOGICAL STRUCTURE OF AN INTERDISCIPLINARY LESSON

Model of an Interdisciplinary Lesson:

- **Type of Lesson:** Interdisciplinary lesson (theoretical + practical) within the field of natural sciences (biology, physics, and chemistry).
- **Objectives:** To familiarize students with the physical properties of UV radiation and its classification.To analyze the positive and negative biological effects of UV radiation. To develop awareness of the importance of preventive protection of the skin and eyes.
- **Methods and Forms of Work:** Lecture with presentation, discussion, pair/group work, case study analysis, and practical demonstration of UV Index measurement.
- **Lesson Components:** Introduction (motivation): Short video/animation on solar radiation and the UV spectrum. Main part (instruction): Explanation of the physical properties of UV radiation, with examples of its positive and negative effects. Practical work: Use of applications (e.g., SunSmart Global UV or UV Index, Forecast & Tan Info) for measuring the UV Index, and analysis of protective factors in sunscreens. Conclusion and reflection: Discussion on personal habits and preventive measures, followed by a short knowledge quiz. Teaching Aids: PowerPoint presentation, mobile application, sunscreen samples, anatomical models of the eye and skin, UV Index scale. Evaluation: Oral responses, quiz, mini-essay, or poster with recommendations for UV protection.

CONCLUSION

Ultraviolet radiation exerts significant biological effects, beneficial in moderate doses but harmful under excessive exposure. Education through a combined teaching model contributes to the understanding of associated risks and the development of preventive habits in health protection [5].

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Monitoring Microclimate Parameters in a Schoolyard Using Basic Physical Concepts

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Abstract. Modern education requires an interdisciplinary approach that links scientific disciplines with real-world environmental problems. This paper proposes a practical model for integrating physical concepts into educational activities related to ecology and environmental physics by monitoring variations in microclimatic parameters within a schoolyard setting. The research involves measuring temperature, light intensity, humidity, and wind at different locations in the schoolyard, aiming to analyze the influence of natural and anthropogenic factors on the local microclimate. The results confirm significant differences between the selected locations, highlighting the potential of such activities to foster environmental awareness and support the development of sustainable educational practices.

Keywords: environmental physics, microclimate, schoolyard.

INTRODUCTION

Modern educational practices increasingly emphasize the need for an integrated approach to teaching, where scientific disciplines are not studied separately but are interconnected into functional units that reflect the real world [1]. Linking physics laws with environmental standards is one of the most effective ways to develop scientific literacy, critical thinking, and, most importantly, environmental awareness among students.

The most pressing issue that affects all living beings nowadays and complicates everyday behavior, especially for humans, is the problem of global warming and the climate changes it causes. Although all of us, including students, are constantly receiving information through various communication channels about the negative consequences of climate change, a large portion of the population does not understand the scientific background of the problem. Demonstrating simple experimental exercises, which, through the application of physical explanations of meteorological phenomena, lead to certain conclusions about the different impacts of anthropogenic factors, can address this gap. Microclimatic conditions, in particular, are the result of a complex interaction of several physical processes, such as light absorption, light intensity, humidity, temperature, air pressure, and anthropogenic factors present in the environment [2,3].

Microclimate refers to the climatic conditions of a small, localized area, which, due to spatial characteristics, can vary even at nearby points. These processes directly influence the formation and maintenance of favorable conditions for the growth, development, and distribution of plant species, as well as the migration and survival of animal species in specific locations [4]. Understanding these cause-and-effect phenomena is crucial for the development of environmental awareness and the formation of scientifically grounded attitudes among students regarding the influence of anthropogenic factors on both climate and microclimate [1].

These rapid changes in meteorological factors provide an ideal opportunity for conducting physical measurements and data analysis within regular classes [2–5], thereby creating a foundation for experiential learning among students, compatible with modern STEM techniques. Moreover, this approach enables students to be actively involved in the entire cycle of scientific research—from hypothesis formulation, through data collection and analysis, to concluding and public presentation [6,7].

METHODOLOGY

The activity proposed here is designed as an experimental, team-based activity that includes determining measurement sites, setting up measuring instruments, recording values, and analyzing and discussing the collected data. The suggested location for conducting the activity is the schoolyard and its immediate surroundings. It is proposed that students from the 8th and 9th grades in primary schools work in teams, with different levels of assigned requirements in accordance with the curriculum, while the teacher's role is to provide supervision, technical support, and mentorship.

For the measurements, instruments available in the physics laboratory of the school are used, which allows the task requirements to vary. During our demonstration of the exercise, the following parameters were measured: air temperature, relative humidity, light intensity, soil temperature, and atmospheric pressure at four different locations within the schoolyard with different anthropogenic influences, at two different times of the day. The instruments employed included a digital luxmeter, a digital thermometer with a probe designed for measuring the internal temperature of prepared food, a digital clock with a sensor for measuring relative humidity and air temperature, as well as a mobile phone equipped with a suitable software application for measuring atmospheric pressure (Figure 1).

After the measurements are carried out, the data are processed in the classroom, followed by a discussion not only on the accuracy of the measurements but also on the causes, consequences, and possible measures for reducing the observed variations of the parameters.

Figure 1. Arrangement of the instruments at the different measuring sites

RESULTS AND DISCUSSION

The results of the measurements are presented in Table 1. The measurements were conducted during a day with a rainy morning and a sunny afternoon, which immediately explains the difference in air humidity values. It should be noted that the rainfall was short-lived and therefore did not significantly affect the soil temperature, since this parameter was measured at a depth of 15 cm. As the accuracy of the instrument used for measuring soil temperature is one degree Celsius, the values are presented as whole numbers. The partly cloudy afternoon resulted in certain locations not receiving any direct sunlight during the second measurement period, which resulted in a huge decrease in light intensity.

Table 1. Summarized results of the measurements of the local climate parameters

Place of measurement/ Time of measurement	Air pressure (hPa)	Air humidity (%)	Air temp. (^0C)	Local soil temp. (^0C)	Light intensity (x100 lx)
Entrance of the school yard/11:30	932.51	82	32.2	27	1030
Entrance of the school yard/15:30	931.24	55	38.6	31	741
Entrance of the school building/11:30	932.56	76	25.7	22	669
Entrance of the school building/15:30	931.20	58	24.8	23	26
Under a tree in the school yard/11:30	932.52	69	24.3	19	72
Under a tree in the school yard/15:30	931.28	35	26.9	21	63
Open space exposed to sun/11:30	932.42	47	36.8	27	840
Open space exposed to sun/15:30	931.28	28	34.0	29	653

The measurement time at all locations was identical, since all teams began measuring simultaneously; however, due to the varying scientific abilities of the students, the duration of the measurements differed. The reasons for the variations in the values of the respective parameters at different locations, as well as their changes between the first and second measurements, were the main focus of the discussion of the results. In addition, the students identified their own mistakes made during the measurement process and their nature and extent of influence on the values of parameters such as those mentioned above. The discussion itself encouraged students to think about what is lacking in the organization of the environment to improve microclimatic parameters and avoid their negative impacts. It also led them to consider what additional steps were missing in the proposed activity to help them find answers to each of the posed yet unresolved questions.

CONCLUSION

The interconnection of physics and ecology through the study of variations in meteorological parameters of the microclimate represents an effective model for interdisciplinary education, enabling easier mastery of theoretical content by linking it to real processes in the environment.

This type of activity is recommended to be increasingly incorporated into the curriculum and even practiced regularly to foster a high level of awareness among young people about the importance of urban planning development and environmental protection. At the same time, it stimulates students' motivation for active participation in scientific research, the results of which guide changes aimed at mitigating the negative consequences of climate change caused by global warming.

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Connection Between Bio-Economy and Climate Change

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Abstract. Bio-economy is an economic system that uses biomass, renewable biological resources to produce goods, energy and services. It is an alternative to fossil-based production processes as it mainly focuses on replacing fossil fuels in combustion and the production of materials with renewable biomass. The bio-economy helps to mitigate the effects of climate change in sector ranging from primary production, to the promotion of circularity, to the innovation of industrial processes. Bio-economy can be considered as one of the possible climate factors and in the future may affect in global warming reduction.

Keywords: bio-economy, climate change, global warming

INTRODUCTION

Bio-economy is an economic system that uses biomass, renewable biological resources, such as plants, animals, and microorganisms, to produce goods, energy, and services. It is an alternative to fossil-based production processes as it mainly focuses on replacing fossil fuels in combustion and the production of materials with renewable biomass. To support this shift, it's essential to increase the availability of biomass, which involves not only cultivating more plants but also utilizing a diverse range of biological resources, including animal by-products and microbial processes. These efforts aim to enhance yields, ensure that these resources do not compete with food production, and optimize the collection and conversion processes to use all components effectively and sustainably.

It covers a broad range of sectors, from agriculture, fishery, and forestry to bio-based and traditional industries, bio-refineries, and (bio) energy. It encompasses all sectors and associated services and investments, that produce, use, process, distribute or consume biological resources, including ecosystem services. On the other hand, mainly due to the release of carbon-dioxide into the atmosphere in recent years, climate changes are taking place on global level, which implies an increase in the global temperature of the Earth and the occurrence of extreme climatic events throughout the planet Earth. In this work, we will study the connection between the use of the bio-economy as a negative feedback loop in order to control global temperature and reducing climate change.

Bio-economy includes and interlinks land and marine ecosystems and the services they provide; all primary production, sectors that use and produce biological resources (agriculture, forestry, fisheries and aquaculture); and all economic and industrial sectors that use biological resources and processes to produce food, feed, bio-based products, energy and services. Unlike fossil fuel-based systems, the bio-economy aims to close resource loops, reduce greenhouse gas emissions, and promote sustainable development. This transition has the potential to be powerful lever in mitigating and adapting to climate change.

UNDERSTANDING THE BIO-ECONOMY

The bio-economy refers to the production, utilization and conservation of biological resources. It spans sectors like agriculture, forestry, fisheries, biotechnology and bio-energy. Central to its philosophy is replacing non-renewable, carbon-intensive inputs with renewable, carbon-neutral or carbon-negative alternatives. Bio-economy can contribues to climate change mitigation:

- reducing fossil fuel dependence (bio-based materials and bio-fuels replace petroleum-based products, lowering CO_2 emissions)
- advances in cellulosic ethanol and biodiesel help decarbonize transportation
- sustainable forestry and agroforestry systems capture and store atmospheric carbon in biomass and soils
- bio char production can lock carbon in soils for centuries while improving soil health
- valorizing agricultural residues and organic waste into energy of high-value products prevents methane emissions from decomposition
- circular bio-based value chains minimize waste and enhance efficiency.

In order to best understand the bio-economy as a negative feedback loop, or as a regulator of global warming, let's explain this loop through the example of a person sweating due to an increase of body temperature.

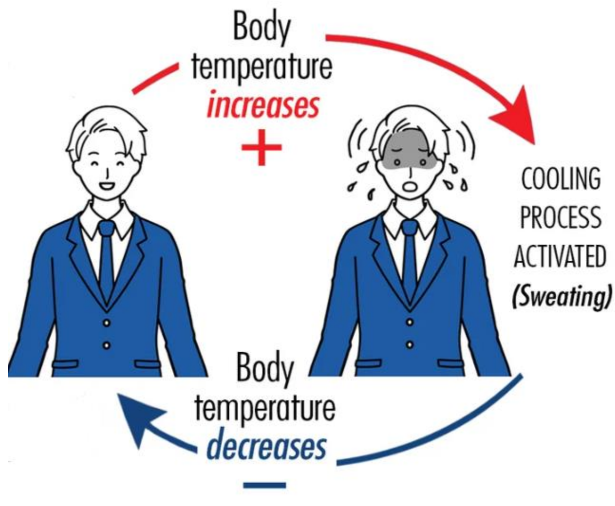

Figure 1. Biological negative feedback loop

The hypothalamus of a human reacts to temperature fluctuations and responds accordingly. If the temperature rise the body will sweat to cool down due to evaporation.

This negative feedback loop is temperature stabilizer. Similarly, the global temperature of the Earth is rising due to the greenhouse effect and other factors. Shifting society towards a bio-economy would result in the creation of another temperature stabilizer that could act as a negative feedback loop by its principles. The transition to a bio-economy requires large financial resources. We identify seven key overall challenges at the nexus of the climate crisis and the bio-economy that require proactive policy and finance interventions in the short to medium term:

- **climate vulnerability** (the climate crisis undermines the sustainability of bio-based solutions, particularly in very sensitive sectors and ecosystems, such as those for food production, coastal and riparian ecosystems for extremes protection)
- **systematic risks** (bio-economy sectors face interconnected risks, such as extreme climate events, biodiversity loss, and market volatility that threaten the long-term viability of bio-based products and services)
- **uneven access to technology and finance** (developed countries leverage financial and technological advantages to advance innovative bio-economy solutions)
- **equity and development challenges** (resource-rich but technology-limited countries remain dependent on nature-intensive segments that generate lower economic value and face greater climate risks)
- **shifting sustainability dynamics** (climate change alters not only the availability and access, but also the sustainability of bio-economy products and services, such as bioplastics, which are vulnerable to warming trends and ecosystem disruptions)
- **governance and institutional fragmentation** (bio-economy initiatives in developing countries face several challenges: institutional fragmentation, limited capacity to design and enforce integrated policies, political pressure and lobbying by extractive industries favoring short-term extraction over long term sustainability)
- **inclusive befit sharing** (a critical challenge is ensuring bio-economy initiatives deliver tangible benefits to key custodians of biodiversity)

CLIMATE CHANGE AS A CONSTRAINT ON THE BIO-ECONOMY

The link between the bio-economy and climate change is not one-way. While a sustainable bio-economy can help mitigate climate change, climate change itself can threaten the reliability of biological resources. Droughts and heatwaves can reduce crop an forest yields, pests and diseases may spread more rapidly in warmer climates and extreme weather events can damage infrastructure and supply chains. Bio-economy depends on climate adaptation. For the bio-economy to contribute positively to the climate, certain principal must guide its development.

- <u>principle one</u> - avoiding deforestation and protecting carbon-rich ecosystems;
- <u>principle two</u> - using agricultural residues, algae and organic waste instead of relying solely on dedicated crops.
- <u>principle three</u> - aligning bio-economy policies with biodiversity protection and ecosystem restoration.
- <u>principle four</u> - minimizing waste and reusing materials to keep biomass in use for as long as possible.

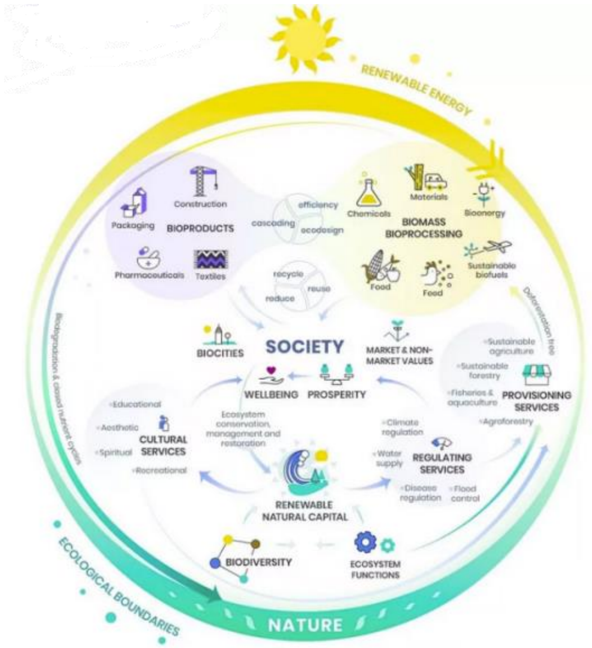

Figure 2. Circular bio-economy: 10 solutions to tackle global warming

For the bio-economy to contribute meaningfully to climate goals, coherent policies are essential: agreements such as the Paris Agreement and the UN sustainable development goals, the European Union's bio-economy strategy and similar initiatives in different countries.

Figure 3. The UN sustainable goals

The United Nations sustainable development goals provide a blueprint for achieving a better and more sustainable future for all by addressing global challenges such as poverty, inequality, climate change, environmental degradation, peace and justice. Bio-economy can be recognize in several goals.

CONCLUSION

The global bio-economy is a cornerstone in the transition to a more equitable, low-carbon and climate-resilient, nature-positive economy. The changing world around is resetting our appreciation of an equitable and sustainable bio-economy's pivotal role in sustainable development. The clean tech revolution has provided one viable pathway, especially for decarbonisation. The bio-economy provides the complementary basis through which we can secure an equitable, sustainable use of nature, particularly biodiversity, a precondition to a just transition to sustainable development. We need to turn the vision of an equitable, sustainable bio-economy into practice. At its core, it is about how we use biological resources in sustainable ways that advance an equitable global economy. The bio-economy holds immense economic potential for significant job creation and economic growth. Beyond such quantitative potential, efforts must support the development of socioeconomically that are localized and sustain cultural diversity embodied by the role of Indigenous Peoples and Local Communities, including farmers, in stewarding the world's biodiversity

The bio-economy holds significant promise as a tool in the fight against climate change, offering pathways for emission reductions, carbon storage and resilience building. However, its success depends on a sustainable-first approach that avoids land-use conflicts, safeguards biodiversity, and prioritizes circularity. As the world accelerates its transition toward net-zero emissions, the bio-economy must be seen not as an automatic climate solutions, and integration with broader climate policies.

If implemented responsibly, the bio-economy could form one of the keystones of a climate-resilient and low-carbon global economy. In the future, the bio-economy may represent a significant negative feedback loop, that is, it may become a powerful temperature stabilizer.

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Modeling Global Warming with En-Roads Simulator

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Abstract. The Earth's climate is influenced by a large number of factors and in this paper we will analyze global warming with En-roads simulator. This simulator is divided into six categories with a total of nineteen factors affecting global warming. The existing model predicts that if the status quo of these factors is maintained, the temperature will increase 3.4°C by year 2100. Simulator allows us to analyze, for example, the impact of higher taxation of carbon dioxide emissions on global warming, as well as the impact of higher carbon dioxide emissions than the model predicts.

Keywords: modeling, En-roads simulator, global warming, climate change

INTRODUCTION

Global climate change is one of the biggest challenges of our time. Rising temperatures, more frequent natural disasters, melting icebergs and rising seas, point to the urgency of solving climate problems. Given that this topic is current, especially during the summer months, the need for tools that can help in understanding the consequences of global warming and other climate changes is recognized. One of the most accessible and powerful tools of this type is the En-ROADS climate simulator, developed by the organizations Climate Interactive and the MIT Sloan Sustainability Initiative. En-Roads (Energy-Rapid Overview And Decision Support) is an interactive climate simulator that enables research into various parameters that affect global warming and other climate parameters. The parameters are divided into the following groups: energy supply, transport, buildings and industry, growth, carbon dioxide removal, other sources of greenhouse gases. Parameters can adjust in the following areas:

- energy supply (coal, oil, natural gas, bioenergy, renewables, nuclear, new zero-carbon, carbon price)
- transport (energy efficiency, electrification)
- buildings and industry (energy efficiency, electrification)
- growth (population, economic growth)
- carbon dioxide removal (nature-based, technological)
- other sources of greenhouse gases (agricultural emissions, waste and leakage, deforestation).

This simulator can be used as a education tool used in schools, universities and public workshop. Can help politicians and corporate leaders to better understand the consequences of their decisions about reducing climate change.

Figure 1. Home page of En-roads climate simulator

As can be seen in the figure one, if all parameters remain at the same level by year 2100, global temperature will increase by 3.3°C. The image also shows two graphs. The graph on the left is a graph that predicts global primary energy sources up to year 2100. The graph on the right is a graph that predicts greenhouse gas emissions up to year 2100. By changing the parameters, these graphs will look different.

CHANGE ANALYSIS OF ENERGY SUPPLY

Let's analyze the graph of global primary energy sources in more detail. A prediction of the use of various forms of energy until the year 2100 is presented. (expressed at 10^{18} Joule/year) A large part of energy is obtained from non-renewable sources such as oil, coal and natural gas. Energy needs are expected to increase from $400 \cdot 10^{18}$ to $800 \cdot 10^{18}$ Joule/year. The authors of the simulator do not take two parameters into account at all when modeling the current scenario: new zero-carbon and carbon price. New zero-carbon typically refers to advancements and innovations aimed at achieving zero carbon emissions, either in a specific product, service, or across broader systems like buildings or entire cities. This concept focuses on eliminating carbon emissions entirely during the production or operation of a product or service. For example, a building powered entirely by renewable energy and using no fossil fuels can be considered zero carbon. Carbon pricing is a policy mechanism that puts a price on greenhouse gas emissions, primarily carbon dioxide. It's designed to make polluters pay for the environmental damage caused by their emissions, such as the costs associated with climate change impacts like rising sea levels, extreme weather events, and air pollution.

Modeling global warming: scenario one

Let's assume that very highly taxes are introduced on the use of non-renewable energy sources: coal, oil, bio-energy, natural gas. On the other hand, we have maximized the use of renewable energy sources, nuclear energy, new zero-carbon and carbon-price. Although nuclear energy is a non-renewable energy source, it has zero greenhouse gas emissions. (although some other effects can pollute the environment) The results are very devastating, which is that we still have an increase of global temperature by 2.4°C.

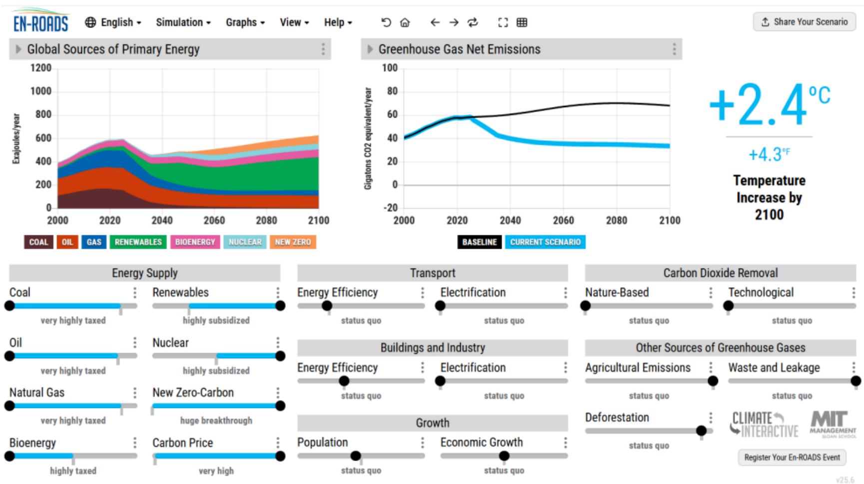

Figure 2. Changes in energy supply (scenario one)

It is already clear from scenario one that changing only the energy supply parameters is not enough. We can emphasize that an increase in external temperatures affects people's health in various ways, such as dehydration, heat rash, and heat stroke, and sometimes even leads to death. People are threatened by food and water shortages, stronger and more frequent floods, extreme heat, diseases and economic losses. It should also be noted that this simulator has the ability to change the global warming graph. One of them is the graph called deaths from extreme heat.

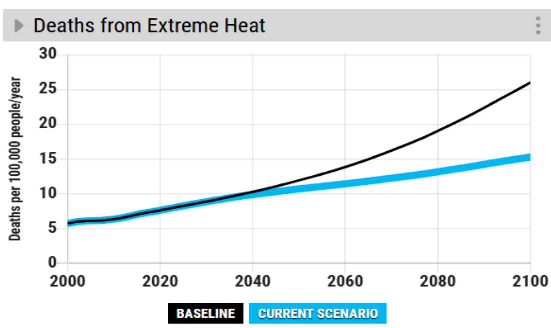

Figure 3. Death from extreme heat by 2100 year

The black line in the previous graph shows that if the parameters remain the same until year 2100, $25 \cdot 10^5$ people/year will die, but blue line represent our scenario one and shows that $5 \cdot 10^5$ people/year will die by 2100, which can be considered a positive development.

MULTIPLE CHANGES OF PARAMETERS WITH EN-ROAD SIMULATOR

Given that by changing the parameters of the energy supply in scenario one, we only reduced the temperature by 1°C, we should try, in scenario two, to change other parameters in order to reduce global warming. So we should make the best scenario for the humanity, global temperature reduce compare with predicted values of baseline scenario.

Figure 4. Scenario two (maximum reduction of global warming)

We get a line of slight increase in greenhouse gas emissions until year 2020. After that we have exponential decrease in greenhouse gas emissions, and thus by 2100 the temperature would increase by only 1.3°C with a tendency to further decrease. This result indicates two things:

- first: global warming has gained so much momentum that even the best possible scenario of its reduction by the year 2100 does not imply a decrease in temperature. The global temperature would increase even in that best scenario.
- second: if we did everything in our power to prevent global warming as in scenario two, global emissions of greenhouse gases would be in a exponential decline, which would lead to a further decrease in temperature at some point after 2100.

In this simulator we can create whatever scenarios we want and now we can create the worst possible scenario. I took these most extreme cases to show all the power of this climate simulator. Therefore, let's reduce the use of renewable energy sources, let's increase the use of non-renewable energy sources, (those that produce greenhouse gases) let's maximize the population and economic growth as well as deforestation.

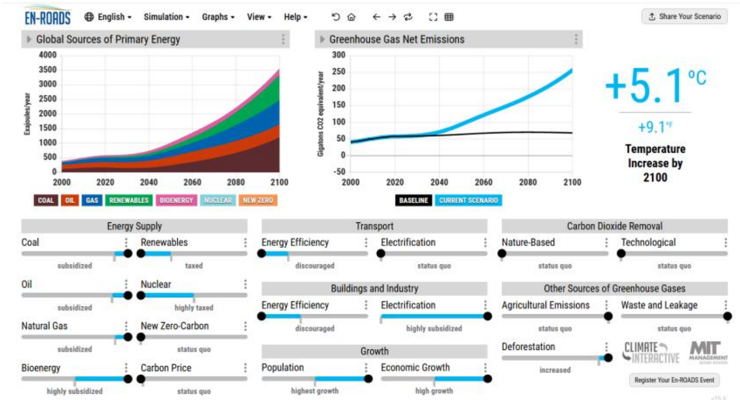

Figure 4. Scenario three: the worst possible scenario

In worst possible scenario temperature will increase by 5.1°C by year 2100. This lead to approximately $80 \cdot 10^5$ deaths from extreme heat in one year. Also 450 million of people will be exposed to hurricanes and typhoon. Sea level increase by 0.8 m, and in the Arctic summer would happen without the presence of ice.

CONCLUSION

Modeling global warming with En-roads simulator shows that if we do our best, the temperature will rise by year 2100. At this point, all we can do is to reduce the predicted temperature rise by 3.3°C. This motivates us to ask the following questions:

- first: How did we get into this position?
- second: Can we as individuals do anything to prevent global warming?
- third: If global warming continues beyond year 2100, what to do to survive?
- fourth: Are we worried enough about continued global warming?

There are certainly those among us who will say that raising the temperature by 3.3°C is nothing terrible. But if we look at the Earth as our baby, all of us who know that it is not the same if it has 39°C or 40°C body temperature. On the other hand a temperature of 42°C indicates a significant infection of our baby and urgent hospitalization. If the predictions of the En-road simulator come true, in the year 2100 the Earth will need urgent hospitalization!

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Artificial Intelligence (AI) in Physics Concept Visualization: Advancing Understanding of Abstract Phenomena

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Abstract. Understanding abstract concepts in physics persists as a challenge for students. Traditional visualization methods, including static diagrams and pre-designed simulations, often fail to adapt to diverse learning needs. Recent advances in technology, more concretely in artificial intelligence, offer dynamic, personalized visualization tools that can generate interactive simulations. This paper explores the potential of AI-supported visualization in enhancing conceptual understanding in physics education. This literature review aims to analyze current AI-supported visualization applications in physics education and to identify the benefits and limitations of AI usage in physics education. The goal is to provide insights for educators and researchers on how AI can be effectively integrated to improve conceptual understanding. It examines existing AI applications, reflecting on integration challenges. The findings suggest that AI has significant potential to transform physics education by making invisible phenomena more accessible, engaging, and comprehensible for students. Additionally, it is essential to state that careful implementation and educator training remain crucial for its effective adoption.

Keywords: AI, education, physics, interactive simulation, engagement

ARTIFICIAL INTELLIGENCE IN PHYSICS EDUCATION

Motivation and academic performance may suffer as a result of challenges in understanding complex physical phenomena or interpreting experimental data. In light of this, current developments in artificial intelligence (AI) present fresh ideas for enhancing physics education [1]. A revolutionary era in education has begun with the introduction of AI, which has had a significant impact on how disciplines like physics are taught and mastered. AI is being more widely used in educational systems due to its potential to improve engagement, personalize learning experiences, and enable more efficient learning. AI tools like virtual simulations, adaptive learning platforms, and intelligent tutoring systems are becoming increasingly popular in physics education in particular [2].

Machine learning algorithms can be used to analyze data, build models, and help students draw insightful conclusions from their experiments. AI can provide sophisticated modeling and simulation tools that are used to create interactive virtual simulations and models that let students investigate complex physical phenomena, facilitate the analysis of complex data, and enable interactive virtual experiments [1].

AI-powered learning resources can adjust to different learning preferences and speeds, providing a distinctive educational experience that conventional approaches frequently fall short of [3]. Enhancing reasoning and general learning outcomes can be achieved through the use of metacognitive training in physics education. Furthermore, research indicates that using computer-based simulations and interactive learning settings can significantly improve students' physics reasoning abilities by facilitating the investigation of complex subjects and offering instant feedback [3].

CONCEPT VISUALIZATIONS IN PHYSICS CLASSES

Diagrams, graphs, symbols, and computer-aided visualization tools, including video clips, animations, and simulations, are just a few of the representations used in physics education. These representations are essential to the explanations of natural events that physics offers [4].

The use of AI in physics education for the representation of complex concepts through visualization has a strong theoretical background. The experiential model, which David Kolb created, provides an experience-based philosophy of learning. Four different learning styles are proposed as a result of people's preferences for particular phases of the cycle, concrete experience, reflective observation, abstract conceptualization, and active experimentation: divergent, assimilative, convergent, and accommodating [1]. It can be interpreted as the basis for the valuation of AI usage for the visualization of complex phenomena.

Abstract reasoning requires the ability to visualize, and teachers have a hurdle when students struggle to visualize relativistic phenomena. Research on students' visualization skills is crucial in this regard to fully comprehend the idea [5]. In addition to improving information delivery, the integration of AI and virtual simulations in physics education has changed conventional teaching methodologies. AI and other cutting-edge technologies have the power to drastically alter traditional educational frameworks and encourage a move toward more technologically oriented teaching approaches. This change also affects how students interact with physics-related material [2].

Students can interact with the content in a way that would be difficult in a traditional classroom setting by experimenting with and seeing the results of different physics concepts in a controlled virtual environment, thanks to AI-driven simulations. These tools encourage active learning and have the potential to change how students view physics by making it seem less daunting and more approachable [2].

Thus, tools that support the externalization of students' imagery processes as well as the depiction of relativistic effects become important, and AI-generated images are one such tool with a lot of promise. This innovative tool not only aids in students' visualization but also offers a glimpse into their mental and visual processes, which enables teachers to recognize students' challenges and misconceptions [5].

AI-based simulations, such as those for kinematics, wave propagation, thermodynamics, electromagnetism, or quantum physics, allow students to do virtual experiments in an interesting, risk-free, and repeatable way within the context of experimental learning. Through interactive, visual, and aural clues, these simulations enable conceptual understanding by making abstract events visible and less abstract. Furthermore, AI makes it possible to model intricate systems that could be hard or impossible to duplicate in conventional labs because of equipment, safety, or financial constraints. AI-powered virtual labs can be an essential tool in remote learning settings for maintaining the continuity and caliber of science instruction [6].

BENEFITS AND LIMITATIONS

AI has helped physics education to move away from rote memorization and toward an immersive, problem-solving-based approach [2]. The quality and accessibility of science education could be significantly improved by integrating AI into physics instruction [6]. Particularly with the advent of cutting-edge technologies, the change in educational techniques has become more noticeable. Among these, integrating AI technologies and virtual simulations into physics courses has the potential to revolutionize education by bridging the gap between theory and practice [7]. Furthermore, using AI-powered simulations fosters a more dynamic learning environment by enabling students to visualize complex ideas in real-time. With these developments, teachers may turn physics from a complex subject into an interesting and approachable one, encouraging students' curiosity and critical thinking [7].

These artificial intelligence tools offer a highly customized experience that can be tailored to the needs of the students, improving comprehension and retention. Research has demonstrated the effectiveness of the AI characteristics, which went beyond the conventional parameters of physics instruction and improved students' engagement with physics-related materials [8].

AI makes abstract physics ideas more approachable and enjoyable by presenting them in interactive, visual form [8].

Improved conceptual understanding, individualized training, increased motivation and engagement, and practical assessment and feedback are just a few advantages of integrating AI into physics education. The use of AI in physics education also presents difficulties, including the requirement for technical infrastructure, teacher training, data security and privacy, and ethical considerations. Strategies like offering instructors professional development, ensuring data protection regulations are in place, encouraging cooperation between educators and AI developers, and addressing ethical issues with appropriate guidelines can all be used to overcome these obstacles [9].

Personalized, interactive learning is promoted when AI is incorporated into physics instruction. Its adaptive training and immediate feedback improve problem-solving and critical thinking skills. While educators can customize lessons, encourage collaboration, and support inquiry-based learning, AI-driven simulations pique students' interest, which represents one of the most significant benefits [10].

However, it is crucial to remember that because children are interacting with new external resources, a whole new set of abilities is needed in addition to visual literacy and critical thinking. For students to effectively engage with the AI through the chatbot, they must be able to compose prompts, edit and analyze generated visuals, and so on. Even though the chatbot uses natural language (NL) for conversation, programming-style thinking is required [5].

Pre-service teachers often lack expertise with AI technology, which makes it difficult for them to use it efficiently. Furthermore, significant obstacles to broader adoption are raised by worries about the veracity and moral ramifications of AI-generated material, including bias and transparency [11].

These aspects need to be addressed to foster wider usage of AI in physics education.

CONCLUSION

The integration of artificial intelligence into physics education, particularly through concept visualization, represents a significant step forward in making abstract phenomena more accessible and comprehensible. Current research demonstrates that AI-powered tools, such as interactive simulations, adaptive diagrams, and personalized explanations, enhance student engagement, support individualized learning, and help reduce common misconceptions in physics. Looking ahead, future developments may include the incorporation of immersive technologies like virtual and augmented reality, more sophisticated adaptive learning algorithms, and collaborative AI-driven learning environments. The relevance of this topic is underscored by the increasing need for innovative educational strategies that respond to diverse student needs and learning styles. Continued exploration and careful implementation of AI in physics education have the potential to transform traditional teaching methods, foster deeper conceptual understanding, and prepare students for a technologically advanced future.

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