

AZERBAIJAN STATE OIL AND INDUSTRY UNIVERSITY



ECO-SYNERGY 2026

International Scientific Conference
on Environmental Synergies:

Waste Valorization, Water Resource
Sustainability and Energy Efficiency

ABSTRACT BOOK



WASTE
VALORIZATION



WATER RESOURCE
SUSTAINABILITY



ENERGY
EFFICIENCY

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Azerbaijan State Oil and Industry University

International Scientific Conference:

ECO-SYNERGY 2026

Environmental Synergies: Waste Valorization,

Water Sustainability and Energy Efficiency

23 September 2026

Baku, Azerbaijan



ECO-SYNERGY 2026

International Scientific Conference

on Environmental Synergies:

Waste Valorization, Water Resource
Sustainability and Energy Efficiency

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PREFACE

In 2026, Azerbaijan State Oil and Industry University (ASOIU) hosted the UI GreenMetric World University Rankings Results & Awards Ceremony 2026, an international event bringing together the global university community around the shared values of sustainability, environmental responsibility, and international cooperation.

On 23 September 2026, as part of this major international event, ASOIU held ECO-SYNERGY 2026 — the International Scientific Conference on Environmental Synergies: Waste Valorization, Water Resource Sustainability and Energy Efficiency.

The conference was jointly organized with the Tashkent Institute of Irrigation and Agricultural Mechanization Engineers National Research University (Uzbekistan), Al-Farabi Kazakh National University, Yessenov University, and Mukhtar Auezov South Kazakhstan Research University (Kazakhstan). Additional co-organizers included Professor Ulysbek Besterekov's Research Laboratory "EcoGreenLab" (Kazakhstan) and the Institute of Geography of the Ministry of Science and Education of the Republic of Azerbaijan.

ECO-SYNERGY 2026 brought together scientists, researchers, and representatives of leading educational and research institutions from different countries. Its scientific programme addressed current sustainability challenges and explored innovative scientific and technological solutions.

The geographical reach of the conference spanned Azerbaijan, Germany, Türkiye, Pakistan, Malaysia, Indonesia, Kyrgyzstan, Georgia, and the Philippines, reflecting its international scope and creating opportunities for scientific dialogue, knowledge exchange, and new academic partnerships.

The main research areas included waste valorization and the circular economy, sustainable water resource management, renewable energy and energy efficiency, artificial intelligence and digital solutions, advanced materials, and environmental technologies.

This book of abstracts brings together the research contributions presented within the framework of ECO-SYNERGY 2026. We hope that these contributions will encourage further interdisciplinary research, strengthen international cooperation, and support the development of practical solutions for a sustainable future.

We extend our sincere gratitude to our co-organizers, members of the scientific and organizing committees, speakers, authors, and participants for their contributions to the conference.

***The Organizing Committee
ECO-SYNERGY 2026***

ECO-SYNERGY 2026 : Environmental Synergies: Waste Valorization, Water Resource Sustainability and Energy Efficiency : book of abstracts of the International Scientific Conference (Baku, September 23, 2026) / Azerbaijan State Oil and Industry University (ASOIU). – Baku : - 2026. – p.64

Materiallardan istifadə zamanı jurnala istinad zəruridir.

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ENVIRONMENTAL MONITORING



FIRST RECORDS OF GRASSHOPPER SPECIES (ORTHOPTERA: ACRIDIDAE) FROM THE FAUNA OF AZERBAIJAN

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Abstract: This study evaluates the distribution, biological characteristics, potential damage to agricultural crops, and phytosanitary significance of several grasshopper species (Orthoptera: Acrididae) recorded for the first time in the fauna of Azerbaijan. The investigated species included *Ramburiella turcomana*, *Paracyptera microptera turanica*, *Calliptamus barbarus*, *Dericorys tibialis*, *Dociostaurus brevicollis*, *Locusta migratoria migratoria*, *Oedipoda miniata*, and *Heteracris pterosticha*. The results demonstrated that none of these species currently has quarantine phytosanitary status in Azerbaijan. These grasshoppers are primarily distributed across the foothill, steppe, semi-desert, and coastal ecosystems of the country and exhibit a high degree of adaptation to diverse ecological conditions. Most species feed on cereal crops, pasture and hay plants, cotton, tobacco, potato, alfalfa, tomato, eggplant, and other cultivated plants, with the potential to cause economically significant damage during periods of population outbreaks. In particular, *Locusta migratoria migratoria* is recognized as one of the most hazardous swarm-forming species in the region and, under favorable climatic conditions, is capable of migrating into Azerbaijan from neighboring countries, posing a serious threat to extensive agricultural areas. The remaining species generally occur as localized populations and become economically important only when their population density increases substantially. The findings indicate that regular monitoring of population dynamics, early spring field surveys, implementation of control measures during the nymphal stage, mechanical destruction of egg pods, and, when necessary, the targeted application of chemical control against adult individuals are essential components of effective crop protection. The obtained results contribute to a better understanding of the grasshopper fauna of Azerbaijan and provide a scientific basis for improving the national phytosanitary surveillance system and developing future monitoring and pest management programs (Figure 1-2, table 1).

Keywords: Grasshopper, fauna, monitoring, pest, biological distribution.

SUSTAINABLE MANAGEMENT OF WATER RESOURCES AS A FOREIGN POLICY STRATEGY

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Abstract: Water management has traditionally fallen under the purview of domestic infrastructure, agricultural, and environmental policy. However, growing water scarcity, transboundary river disputes, and climate-driven hydrological instability have increasingly positioned water governance within the domain of foreign policy. With more than 60 percent of the world's freshwater flows crossing international borders and over 150 countries sharing transboundary river or aquifer basins, water resource management has evolved from a technical and environmental concern into a strategic instrument of statecraft. This article employs case study and comparative analysis of major transboundary basins — including the Nile, Tigris-Euphrates, Indus, Mekong, and Aral Sea — alongside institutional analysis of multilateral water governance bodies, drawing on hydro politics/hydro-hegemony theory and securitization theory to examine how physical scarcity and political power transform water into an instrument of statecraft. Particular attention is given to Azerbaijan, where roughly two-thirds of water resources originate outside its borders via the Kura and Aras rivers. The analysis examines Azerbaijan's response through its extensive reservoir network of over 140 reservoirs, including the 15.7 billion cubic meter Mingachevir Reservoir, alongside agricultural efficiency reforms addressing the sector's 70-75 percent share of national water consumption, and its international positioning as host of COP 29. The findings suggest that shared water resources more often catalyze cooperation than conflict, though this outcome is not automatic: it depends on the deliberate construction of institutions, information-sharing mechanisms, and diplomatic frameworks capable of managing tensions arising from asymmetric hydrological dependence. As climate change intensifies hydrological variability, foreign policy actors who invest early in cooperative, transparent, and adaptable water governance frameworks are better positioned to prevent scarcity from driving regional instability, converting shared vulnerability into a foundation for durable diplomatic engagement. The study contributes to the literature on hydro politics and resource diplomacy, offering both theoretical and practical insight, with Azerbaijan's experience as an illustrative case.

Keywords: *Water diplomacy, transboundary water management, hydro-hegemony, securitization theory, water security, foreign policy strategy, climate change adaptation, Azerbaijan water resources, river basin governance, water-energy-food nexus.*

INSTITUTIONALISING SUSTAINABILITY IN HIGHER EDUCATION: A WHOLE-INSTITUTION FRAMEWORK FROM UNIVERSITI SULTAN ZAINAL ABIDIN (UNISZA)

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Abstract: Higher education institutions are increasingly expected to embed sustainability in their core functions to support the Sustainable Development Goals (SDGs) and address environmental, social, and economic challenges. Although many universities have introduced green campus initiatives, sustainability is often implemented in a fragmented manner across governance, education, research, and campus operations. This study examines how Universiti Sultan Zainal Abidin (UniSZA), Malaysia, has institutionalised sustainability through a whole-institution approach that integrates governance, teaching and learning, research and innovation, campus operations, and community engagement. A qualitative case study was conducted using systematic document analysis of institutional policies, strategic plans, sustainability reports, operational guidelines, and official university documents. Data were analysed using thematic content analysis and mapped against the UI GreenMetric World University Rankings framework and the Sustainable Development Goals (SDGs). The findings reveal that effective sustainability implementation extends beyond operational environmental management and is driven by institutional governance, strategic leadership, stakeholder engagement, and continuous organisational learning. Based on these findings, this study proposes the Whole-Institution Sustainability Framework (WISF), which positions governance as the central mechanism linking education, research and innovation, campus operations, community engagement, and continuous improvement. The framework complements existing sustainability assessment systems by explaining the organisational processes that underpin long-term institutional transformation rather than focusing solely on performance indicators. The UniSZA experience demonstrates that embedding sustainability within institutional governance and culture enhances organisational resilience, strengthens alignment with the SDGs, and provides a practical and transferable model for higher education institutions seeking to institutionalise sustainability and improve their sustainability performance.

Keywords: *sustainable university; whole-institution approach; sustainability governance; higher education; UI GreenMetric; Sustainable Development Goals; green campus.*

HYDROGEOLOGICAL RISK ASSESSMENT OF A LEGACY AGROCHEMICAL STORAGE SITE IN HORADIZ, FUZULI DISTRICT, AZERBAIJAN

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Abstract Legacy agrochemical contamination associated with persistent organic pollutants (POPs) remains a significant environmental issue in agricultural regions due to the long-term persistence, mobility, and potential toxicity of these compounds. This study assesses the environmental risks associated with an abandoned agrochemical storage site in the town of Horadiz, Fuzuli district, Azerbaijan, focusing on the potential migration pathways of contaminants through soil, groundwater, and surface water systems. The study area covers approximately 4.05 hectares and is situated within the sensitive hydrogeological environment of the Kura-Aras Lowland. The contaminated site lies at an elevation of approximately 151 meters above sea level, while the nearby Mil-Mughan hydraulic system and the Aras River are located at lower elevations, indicating conditions conducive to the potential migration of contaminants. An integrated assessment approach combining climatic, hydrogeological, soil, and hydrochemical characteristics was applied. Monitoring of surface waters in the Quruchay, Kondalanchay, and Gozluchay river systems revealed generally acceptable physicochemical conditions, although seasonal variations in dissolved oxygen, mineralization, and nutrient concentrations reflected hydrological and agricultural influences. Low soil humus content (2–5%) and a heavy clay-loam texture indicate limited pollutant retention capacity and increased potential mobility during infiltration and irrigation processes. The findings suggest that the Horadiz area is a potential source of long-term contamination, necessitating further site-specific investigations, groundwater monitoring, and risk-based remediation planning. The study highlights the importance of integrated hydrogeological assessment for managing the risks of legacy agrochemical contamination in semi-arid agricultural landscapes.

Keywords: *Persistent organic pollutants (POPs) from past periods; Agrochemical pollution; Contaminated area in Horadiz; Aras River basin; Groundwater vulnerability; Surface water pollution; Soil contamination; Hydrogeological risk assessment; Pollutant transport due to irrigation; Semi-arid environment*

ULTRASTRUCTURAL ALTERATIONS IN GRAPEVINE LEAVES INDUCED BY GRAPEVINE LEAFROLL-ASSOCIATED VIRUS 3 (GLRAV-3)

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Abstract: Grapevine leafroll-associated virus 3 (GLRaV-3) is one of the most widespread grapevine viruses worldwide and is recognized as the most economically significant causal agent of grapevine leafroll disease. To assess its distribution and symptomatology in Azerbaijan, comprehensive phytopathological surveys were conducted across the major grape-growing regions, including Absheron, Salyan, Jalilabad, Masalli, and Lankaran, during the 2016–2022 growing seasons. Symptomatic leaf samples collected from vineyards were analyzed using immunostrip assays and double-antibody sandwich enzyme-linked immunosorbent assay (DAS-ELISA) for GLRaV-3 detection. Furthermore, anatomical and ultrastructural alterations associated with GLRaV-3 infection were investigated in naturally infected field-grown grapevines to elucidate the cytopathological effects of the virus.

Keywords: *grapevine, GLRaV-3, SEM, TEM*

SUSTAINABLE NANOMODIFIED PF-115 ALKYD COATINGS FOR RESOURCE-EFFICIENT CORROSION AND ANTIFOULING PROTECTION IN MARINE ENVIRONMENTS

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Abstract: Marine steel structures are continuously exposed to aggressive chloride-containing environments, moisture, and biological activity, resulting in corrosion processes and biofouling that reduce their operational lifetime. This study investigates the development of a multifunctional PF-115

alkyd coating modified with nanocalcite, ZnO, and Cu₂O nanoparticles for improved corrosion protection and antifouling performance under simulated marine conditions.

Nanomodified coatings were prepared by mechanical mixing followed by ultrasonic dispersion to ensure uniform distribution of functional additives within the alkyd matrix. The influence of nanoparticle incorporation on coating morphology, elemental composition, water resistance, storage stability, and antifouling behavior was evaluated using scanning electron microscopy (SEM), energy-dispersive spectroscopy (EDS), and standardized coating performance tests.

The results demonstrated that the incorporation of nanocalcite, ZnO, and Cu₂O significantly improved the structural characteristics of PF-115 coatings. SEM observations revealed a denser and more homogeneous coating microstructure with reduced defects compared with the unmodified system. EDS analysis confirmed a decrease in corrosion-related iron content after modification, with no iron detected on the surfaces of Cu₂O-containing coatings after marine exposure. The modified coatings also exhibited improved storage stability, reduced water-related degradation, and lower delamination tendency. The hybrid nanocomposite formulation containing nanocalcite, ZnO, and Cu₂O demonstrated the highest protective performance, providing a reduction in microbial adhesion of approximately 60–70% compared with the unmodified coating.

The developed nanomodified PF-115 coating combines barrier protection, antimicrobial activity, and improved durability while maintaining economic feasibility. The calculated material cost of the developed coating was 9.76 AZN/kg, which is lower than the cost of comparable commercial marine coating systems. The obtained results indicate that nanomodified alkyd coatings represent a promising resource-efficient solution for corrosion and biofouling protection of marine steel structures.

Keywords: *PF-115; alkyd coatings; nanocalcite; ZnO; Cu₂O; marine corrosion; antifouling coatings; nanocomposite coatings; SEM; sustainable protection.*

THE FILIZCHAY POLYMETALLIC MASSIVE SULFIDE DEPOSIT (THE GREATER CAUCASUS, AZERBAIJAN): GEOLOGY, CRITICAL RAW MATERIALS, AND ENVIRONMENTAL IMPLICATIONS

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Abstract: The Filizchay polymetallic massive sulfide deposit, located in the Balakan–Zagatala ore district on the southern slope of the Greater Caucasus, northwestern Azerbaijan, is one of the major polymetallic sulfide systems of the region. Although its geology, mineralogy and geochemistry have been investigated for decades, information on ore-forming processes, mineral-specific distribution of minor and critical elements, and environmental implications has remained dispersed among different studies.

Objectives. This review integrates published geological, mineralogical and ecological–geochemical evidence to provide a unified assessment of the deposit.

Methods. Published ecological–geochemical data demonstrate pronounced species-specific differences in the accumulation of Cu, Ni, Pb, Zn, Mn and other potentially toxic elements in cultivated plants and natural vegetation. These observations indicate that vegetation can provide complementary information on the biologically available fraction of trace elements, although plant concentrations should not be interpreted as direct measures of total environmental contamination.

Results. The integrated evidence supports interpretation of the principal stratiform mineralization within a SEDEX framework, while subsequent hydrothermal, metasomatic, tectonic and metamorphic processes contributed to the present mineralogical and structural characteristics of the ore system. From an environmental perspective, sulfide weathering and historical exploration exposures may influence element mobility. A combined geological–mineralogical–environmental approach is therefore recommended for future resource assessment, environmental monitoring and sustainable development of the Filizchay deposit.

Keywords: *the Filizchay deposit, polymetallic massive sulfide, Greater Caucasus, SEDEX, mineralogy*

ENGINEERING - ECOLOGICAL DEVELOPMENT OF PROTECTION, MANAGEMENT AND CLEANING OF WATER BODIES AGAINST NATURAL AND TECHNOGENIC INFLUENCES

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Abstract. The presented scientific article analyzes and studies the engineering-ecological development of protection, management and purification of water bodies from natural and technogenic impacts, as well as environmental parameters. Water is the basis of human life on Earth. Water is not only the main component of all living things, but also plays an important role in important biological processes. Here, water and soil pollution are treated, as well as wastewater treatment projects, landscape design, land reclamation works are developed, and a plan of measures is developed to reduce harmful emissions into the atmosphere. Here, researchers analyze environmental documents on the protection of water bodies from natural and technogenic impacts, conduct research on environmental safety issues, and implement engineering-ecological development measures in this regard. First of all, the analyzes conducted in various directions during the research show that the quality of water in water bodies should be determined by the chemical, physical and hygienic state of groundwater and surface water. Currently, the term "water quality" is defined in a broader sense. It also protects water bodies, as well as their function as an important habitat for animals and plants, from natural and man-made impacts. When we say protection of water bodies from natural and man-made impacts, we can include wastewater treatment, reduced use of fertilizers, plant protection products and pesticides in agriculture, restoration of the natural state of rivers or economically efficient use of valuable resources, etc. Protection of water bodies from natural and man-made impacts is a complex of legal, engineering and environmental principles aimed at preventing pollution, water depletion and protecting the ecosystem.

TOWARD RESTORATIVE UNIVERSITY BUILDINGS: A BIOPHILIC SPATIAL AUDIT AND USER PERCEPTION STUDY— THE CASE OF AZERBAIJAN UNIVERSITY OF ARCHITECTURE AND CONSTRUCTION

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Abstract. Modern university buildings are typically designed around normative insolation and capacity standards, while overlooking their occupants' psycho-emotional well-being. This study addresses this gap by evaluating the spatial prerequisites for a restorative environment at the educational buildings of the Azerbaijan University of Architecture and Construction. A visual-spatial expert audit of 134 spaces across three campus buildings assessed the presence of 14 patterns of biophilic design, yielding a Spatial Biophilic Availability Index (SBAI_k) for four space categories (classrooms, corridors, stair/elevator cores, and public halls). In parallel, a survey of 200 students and faculty members measured subjective restorative perception (R_k) for the same categories. Comparing SBAI_k and R_k via Spearman's rank correlation revealed notable discrepancies between expert-assessed biophilic provision and users' actual perceptions, most pronounced in classrooms and public halls, where formal pattern presence and perceived restorative quality diverge sharply. Results show corridors and stair/elevator cores as the most biophilically deprived zones by expert audit, while classrooms, despite the highest measured biophilic provision, paradoxically received the lowest restorative ratings from users. Based on these findings, differentiated design recommendations are proposed, offering a practical framework for improving the restorative quality of educational building stock.

Keywords: *Biophilic design, Restorative environment, University building, Spatial audit, Patterns.*

ADVANCING WATER RESOURCE SUSTAINABILITY THROUGH SMART IRRIGATION AND ADAPTIVE WATER MANAGEMENT

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Abstract: Sustainable water management has become a strategic priority due to increasing water scarcity, climate change, and rising agricultural demand, which are putting increasing pressure on freshwater resources. This study investigates the determinants of water sustainability by examining the effects of Government Water Support, Water Management Knowledge, and Water Infrastructure Quality, while also evaluating the mediating role of Smart Irrigation Applications and the moderating role of Climate Change Adaptation Capacity. Survey data was collected from 355 agricultural producers in Azerbaijan and analyzed using Structural Equation Modeling. The findings reveal that Government Water Support and Water Infrastructure Quality have significant positive effects on water sustainability, while Water Management Knowledge has no statistically significant effect. The results also show that Smart Irrigation Applications play a significant partial mediating role, accounting for approximately 59.9% of the total effect of Government Water Support on water sustainability. Furthermore, Climate Change Adaptation Capacity significantly strengthens the positive relationship between Water Infrastructure Quality and water sustainability. This study expands the sustainable water management literature by integrating institutional, technological, and adaptive perspectives into a unified conceptual framework. The findings also offer practical implications for policymakers by supporting government incentive programs aimed at long-term water resource sustainability, investments in digital irrigation technologies and modern irrigation infrastructure, and climate adaptation initiatives.

Keywords: Circular water management; Agricultural resilience; Digital agriculture; Sustainable development; Public policy.

PHILOSOPHICAL ANALYSIS OF THE RELATIONSHIP BETWEEN NATURE AND SOCIETY IN THE CONTEXT OF SUSTAINABLE DEVELOPMENT

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Abstract: The ecological crisis of the twenty-first century is not merely a technical or managerial problem — it is, at its root, a crisis of the philosophical categories through which human beings understand their place in the natural world. This paper offers a systematic philosophical analysis of the nature–society relationship as it bears on the concept of sustainable development. It traces the historical evolution of this relationship from pre-modern cosmologies through the Cartesian-mechanistic break, examines the major twentieth- and twenty-first-century philosophical positions — anthropocentrism, biocentrism, ecocentrism, deep ecology, social ecology, and eco-Marxism — and evaluates how each reframes the meaning of “sustainability.” It argues that the Brundtland Commission's influential definition of sustainable development, while politically indispensable, rests on an unresolved philosophical tension between instrumental and intrinsic conceptions of nature, and that resolving — or at least clarifying — this tension is a precondition for coherent environmental policy. The paper concludes by proposing that a dialectical, relational ontology of nature and society, informed by the ethics of responsibility, offers the most promising philosophical foundation for sustainable development in the Anthropocene.

Keywords: *Sustainable development, nature–society relationship, environmental philosophy, Anthropocene, ethics of responsibility, anthropocentrism, biocentrism, ecocentrism, deep ecology, social ecology, Eco-Marxism, metabolic rift, planetary boundaries, Brundtland Report, intergenerational justice.*

EFFICIENT WATER USE AND SUSTAINABLE CAMPUS WATER MANAGEMENT: A CASE STUDY OF BAKU ENGINEERING UNIVERSITY

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Abstract: Universities are important settings for evaluating practical sustainability measures because they combine buildings, laboratories, green spaces, student activities, and substantial daily resource consumption. This study evaluates water-use efficiency and sustainable water management at Baku Engineering University (BEU) in Azerbaijan and develops a practical proposal for expanding greywater reuse on campus. The research uses a descriptive case-study approach based on institutional evidence compiled by the researcher to UI GreenMetric water and setting-infrastructure indicators, supported by campus photographs, facility records, and relevant recent literature. Findings indicate that BEU's 200,000 m² campus comprises approximately 85% open space and 152,000 m² of planted vegetation. The water-management evidence indicates the presence of five storage reservoirs with a total capacity of about 635,000 L, rainwater collection, water recycling infrastructure, flow monitoring, and non-potable reuse applications. The documents also show that water efficiency, maintenance, pollution prevention, and sustainability awareness are part of the university's environmental management approach. However, some internal evidence descriptions are not fully consistent, especially for wastewater routing and the exact share of water-efficient fixtures; therefore, these values should be technically verified before any official ranking claim is made. Based on the literature and campus conditions, the paper proposes a pilot system that separately collects light greywater from hand- and face-washing basins, treats it through filtration and biological treatment followed by disinfection, and reuses it first for landscape and tree irrigation. The proposed approach can reduce potable-water demand, increase circular water use, and provide a visible educational demonstration of sustainable water management on campus.

Keywords: *water efficiency; greywater reuse; university campus; water recycling; sustainability; UI GreenMetric; Baku Engineering University*

GREEN CHEMISTRY & CATALYSIS



PRODUCTION TECHNOLOGY OF WHITE CHEESE AND COTTAGE CHEESE: ANALYSIS OF TECHNOLOGICAL PARAMETERS AND QUALITY INDICATORS

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Abstract: This study systematically monitored and evaluated key technological parameters and product quality indicators across nine production batches of white cheese and fourteen cottage cheese production runs at a dairy processing plant in January 2025.

In white cheese production, the volume of raw milk processed per batch ranged from 7,700 to 7,720 L, and milk with a fat content of 2.8–4.0% was standardized to 3.0% fat in a normalized volume of 4,400 L. Milk was pasteurized at 89°C for 36–37 seconds, followed by enzymatic coagulation at pH 6.0 for 60 minutes. The mean cheese yield was 671 kg per batch, with a yield efficiency of 8.70%. The sequential pH decrease observed at the coagulation (pH 6.0), pressing (pH 5.0), and maturation (pH 4.4–4.5) stages demonstrates the controlled acidification process essential for texture development and microbiological safety.

For cottage cheese production, skim milk ranging from 1,000 to 8,000 L was used as the primary raw material. Following pasteurization at 94.8–96.0°C, fermentation with mesophilic starter cultures was carried out at 34.0–35.5°C, with coagulation acidity recorded in the range of 62–90°T in the majority of production runs.

Correlation analysis revealed a positive association between the fat content of normalized milk and cheese yield ($r = 0.401$), as well as a strong negative correlation between acidity and pH in cottage cheese production ($r = -0.84$). The findings provide important quantitative benchmarks for dairy processing facilities and demonstrate the critical importance of precise control of pasteurization temperature, pH progression, and fermentation conditions in ensuring consistent product quality and high yield efficiency. The results contribute to the scientific-practical optimization of traditional cheese production technologies.

Keywords: white cheese, cottage cheese, dairy processing technology, quality indicators, process optimization, traditional cheese production, fermentation technology

GREEN ANALYTICAL SYNERGIES FOR FOOD SAFETY, WATER QUALITY, AND WASTE MONITORING

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Abstract: The convergence of food safety, water quality preservation, and sustainable waste management represents one of the most pressing challenges of the twenty first century, requiring integrated approaches that transcend traditional sectoral boundaries. Conventional analytical methodologies, although robust and precise, are heavily dependent on resource-intensive practices that impose substantial environmental burdens-including excessive solvent consumption, high energy demands, and the generation of large volumes of hazardous waste. Such practices are increasingly incompatible with global sustainability objectives and the urgent need to reduce the ecological footprint of monitoring activities. This review examines the transformative potential of green analytical chemistry (GAC) as a unifying framework capable of simultaneously addressing these interconnected challenges across the food water waste nexus. We systematically evaluate recent progress in sustainable sample preparation techniques, such as solvent-free extraction, microextraction, and the use of alternative green solvents, alongside eco-friendly instrumentation designed for lower power consumption and reduced reagent usage. Special emphasis is placed on greenness assessment metrics-including the Analytical Eco-Scale, the Green Analytical Procedure Index (GAPI), and the RGB model which provide quantitative tools for evaluating and optimizing the environmental sustainability of analytical methods. Emerging technologies are critically discussed, particularly deep eutectic solvents (DESs), dispersive liquid-liquid microextraction (DLLME), solid-phase microextraction (SPME), electrochemical and optical biosensors, and white analytical chemistry approaches that effectively balance analytical performance, environmental friendliness, and economic feasibility. The synergistic integration of these innovative tools enables the reliable, cost-effective, and rapid monitoring of diverse contaminants-ranging from heavy metals and pesticides to pharmaceuticals and pathogens-across different sample matrices. Ultimately, the adoption of GAC-based strategies within a circular economy framework not only minimizes resource consumption and waste production but also strengthens the resilience and responsiveness of monitoring systems. This review concludes that such integrated green analytical synergies offer a viable and scalable pathway toward more responsible, efficient, and sustainable environmental and food safety practices, directly contributing to the achievement of the Sustainable Development Goals (SDGs) related to clean water, responsible consumption, and climate action.

Keywords: *Green analytical chemistry; food safety; water quality; waste monitoring; sample preparation; deep eutectic solvents; microextraction; biosensors; white analytical chemistry; sustainability metrics*

SELECTION OF NANOMATERIAL AND ARCHITECTURE OF AN AMMONIA CONCENTRATION SENSOR FOR INTEGRATION INTO AN ENDOSCOPE

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Abstract: Real-time detection of *Helicobacter pylori* during gastrointestinal endoscopy remains a significant clinical challenge, as traditional biopsy and breath tests are either highly invasive or result in delayed results. The aim of this study was to rationally select nanomaterials and design a sensor architecture optimized for endoscopic monitoring of ammonia (NH_3) concentrations. A three-component nanostructure consisting of commercially available few-layer molybdenum disulfide (MoS_2) nanoplatelets modified with tin oxide (SnO_2) nanoparticles and encapsulated with a selective Nafion polymer layer using a drop-coating technique was selected as the optimal gas-sensing matrix. The selected heterojunction topography reduces the activation energy of NH_3 adsorption at a human body temperature of 37°C , while the hydrophobic Nafion layer effectively repels gastric liquid and blocks interfering gastrointestinal gases (CH_4 , H_2 , CO_2). Linux-embedded software was developed to control the sensor integrated onto a subminiature MEMS substrate and provide continuous monitoring of sub-ppm ammonia concentrations, synchronized with a high-speed HD video stream. To eliminate natural material degradation during long-term operation, an adaptive exponentially weighted moving average (EWMA) algorithm with a rate-of-change locking mechanism was developed for mathematical compensation of baseline drift. Furthermore, a fast microthermal desorption profile is integrated, ensuring full baseline recovery within 10 seconds through automatic air purging. The proposed architecture opens a non-invasive, accurate and instant digital pathway for *H. pylori* screening during routine examinations, generating structured clinical data (JSON/CSV) for medical information systems.

Keywords: *Helicobacter pylori*, ammonia sensor, $\text{MoS}_2/\text{SnO}_2$ / Nafion nanostructure, Linux Embedded platform, baseline drift compensation.

INVESTIGATION OF THE PROPERTIES OF COMPOSITIONS BASED ON PVA FILLED WITH MINERAL AND ORGANIC FILLERS

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Introduction. One of the most widely used polymers for creation of smart materials is ecologically harmless polyvinyl alcohol (PVA). The functionalization of PVA macromolecules improves its initial properties, and the introduction of the organic or inorganic fillers into the composition of the polymer matrix of PVA is used for increasing flexibility, physical and thermal stability, chemical inertness and for improvement of the mechanical and barrier properties of the end material.

The purpose of work is the development and investigation of the strength and thermal properties of the filled PVA compositions and revealing areas of their possible application.

Methodology.

PVA of mark 6/4 with characteristic viscosity of 0.62 dl/g was chosen for the investigations. The natural mineral of the Absheron deposit of Azerbaijan was used as a mineral filler (MF). The mineral was crushed in a ball mill to obtain particles sized 98-586 mcm. The mineral contains about 5 mass % of nanoclays with particle size of 14-59 mcm and oxides of various elements. The almond shell powder was used as an organic filler (OF).

For preparation of the compositions, PVA was first mixed with glycerin used as a plasticizer. The obtained mixture was treated on rollers at 120°C for 4-5 min; the calculated amounts of the mineral filler and almond shell powder were introduced, and mixing was continued for 10 min. until melt homogeneity was achieved. The strength properties of the compositions were studied on samples as blades.

Results

The tests showed that the strength indices and heat resistance of the filled compositions are improved, and the water absorption is slightly changed. The compositions in the form of films can be used as durable, ecologically pure and biodegradable packages.

BIOACTIVE COMPOUNDS IN GRAPES: A TRIAD APPROACH TO HEALTH BENEFITS, ANTIVIRAL PROPERTIES AND DISEASE PREVENTION

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Abstract: Grapes are a rich source of phytochemicals, including phenolic acids, flavonoids, anthocyanins, stilbenes, and essential lipids, which collectively contribute to their significant health-promoting properties. These bioactive compounds exhibit strong antioxidant, antimicrobial, and anti-inflammatory effects, playing a crucial role in disease prevention and overall well-being. In particular, grape-derived polyphenols have gained increasing attention for their cardiovascular benefits, particularly in modulating blood pressure and reducing the risk of hypertension, a major global health concern. The polyphenol-rich compounds and lipid substances found in grapevines are known to improve endothelial cell function, regulate lipid metabolism, and mitigate oxidative stress, thereby supporting overall cardiovascular health and reducing the risk of atherosclerosis. Beyond cardiovascular protection, recent studies highlight the antiviral properties of grape-derived compounds, demonstrating their potential in inhibiting viral replication and modulating immune responses. Certain bioactive molecules, such as resveratrol, quercetin, and proanthocyanidins, have shown promising antiviral activity against a range of pathogens, including respiratory viruses, and other emerging infectious agents. These compounds exert their effects through multiple mechanisms, such as inhibiting viral entry, blocking replication, and enhancing host immune defense. Additionally, the antioxidant properties of grape phytochemicals contribute to reducing inflammation and oxidative stress, both of which play key roles in the progression of viral infections. Given the increasing interest in natural therapeutics, grape-based products are being actively explored as functional dietary interventions for cardiovascular and immune health. This review provides a comprehensive overview of the diverse health benefits of grape-derived bioactive compounds, with a particular focus on their antiviral mechanisms and broader applications in disease prevention. By elucidating the molecular pathways through which these compounds exert their effects, this research aims to advance our understanding of their therapeutic potential. The evidence supporting the role of grape bioactives in health underscores the integrating these natural compounds into dietary and clinical strategies for disease management.

Keywords: Grape, bioactive compounds, polyphenols, hypertension, cardiovascular health, lipid metabolism

RENEWABLE ENERGY & ENERGY EFFICIENCY



DEVELOPMENT AND EXPERIMENTAL EVALUATION OF A MACHINE VISION–BASED ROBOTIC SYSTEM FOR SUSTAINABLE CHEMICAL LABORATORY AUTOMATION

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Abstract: The increasing demand for precision, repeatability, and operational safety in chemical laboratories has accelerated the adoption of intelligent automation technologies. Among these technologies, machine vision integrated with robotic manipulation systems offers an effective approach for reducing human intervention in analytical procedures while improving measurement reliability. This study presents the design and evaluation of a machine vision–based robotic manipulation system developed for the automation of selected chemical laboratory operations, including liquid dosing, endpoint detection, and pH monitoring. The proposed system combines a robotic manipulator, an industrial camera, image processing algorithms, a pH sensor, and an automated liquid delivery mechanism within a unified control framework. Visual information acquired during the titration process is processed to identify color transitions associated with the reaction endpoint, whereas sensor measurements are used to monitor pH variation in real time. The integration of these components enables continuous process observation and supports accurate control of liquid dispensing throughout the experiment. Experimental investigations conducted under laboratory conditions demonstrated stable system performance, high repeatability of dosing operations, reliable endpoint identification, and low measurement deviation. The obtained results indicate that the integration of machine vision with robotic manipulation improves analytical accuracy and contributes to the standardization of laboratory procedures. In addition to the experimental evaluation, the study discusses current technical challenges affecting the development of machine vision systems, including illumination variability, sensor calibration, computational requirements, and the robustness of visual analysis under changing operating conditions. Possible research directions related to adaptive image processing, multimodal sensing, and intelligent process monitoring are also considered. The proposed framework provides a practical basis for the development of autonomous laboratory platforms and demonstrates the potential of machine vision technologies in modern chemical process automation.

Keywords: *Machine Vision, Robotic Manipulation, Chemical Process Automation, Artificial Neural Networks, Image Processing, Computer Vision, pH Monitoring, Intelligent Laboratory Systems, Automated Titration, Industrial Robotics.*

NEFT SƏNAYESİNDƏ REAL VAXT MONİTORİNQİ: ÖLÇMƏ DƏQİQLİYİNİN ENERJİ DAYANIQLILIĞINA TƏSİRİ

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Xülasə: Məqalədə neft quyularında hasilatın ölçülməsi üçün tətbiq olunan ənənəvi və müasir texnologiyalar, həmçinin həmin texnologiyaların enerji dayanıqlılığının təmin edilməsinə təsiri araşdırılır. Neft quyusunun hasilat göstəricilərinin dəqiq müəyyənləşdirilməsi hasilatın uçuotu ilə məhdudlaşmır; bu proses layın davranışının öyrənilməsi, quyunun istismar rejiminin seçilməsi, avadanlıqların texniki vəziyyətinin qiymətləndirilməsi və enerji sərfiyyatının optimallaşdırılması baxımından da mühüm əhəmiyyət daşıyır. Ənənəvi periodik quyu sınaqları və separator əsaslı ölçmə üsulları müəyyən üstünlüklərə malik olsa da, məlumatların gecikmə ilə əldə edilməsi, dəyişkən axın şəraitində dəqiqliyin azalması, insan faktorundan asılılıq və texniki xidmət ehtiyacı kimi məhdudiyyətlərlə xarakterizə olunur.

Məqalədə çoxfazlı axınölçənlərin, virtual axınölçmə sistemlərinin, fiber-optik sensorların, IoT əsaslı monitoring platformalarının, süni intellekt və maşın öyrənməsi alqoritmlərinin, eləcə də rəqəmsal əkizlərin imkanları təhlil edilir. Bu texnologiyalar neft, qaz və su fazalarının daha operativ izlənilməsinə, hasilat dəyişikliklərinin vaxtında müəyyənləşdirilməsinə və avadanlıqların iş rejiminin real məlumatlar əsasında tənzimlənməsinə şərait yaradır. Dəqiq ölçmə məlumatları nasos və kompressorların səmərəsiz işləməsinin, artıq enerji sərfiyyatının, plansız dayanmanın və hasilat itkilərinin qarşısını almağa kömək edir. Eyni zamanda, suvurma prosesinin, lay təzyiqinin və quyuların qarşılıqlı təsirinin daha əsaslandırılmış şəkildə idarə olunması mümkün olur. Tədqiqatda sensorların kalibrlənməsi, məlumat keyfiyyəti, modelin tədricən sapması, kibertəhlükəsizlik, ilkin investisiya xərcləri və mütəxəssis hazırlığı əsas tətbiq problemləri kimi qiymətləndirilir. Nəticə etibarilə, müasir hasilat ölçmə sistemlərinin rəqəmsal idarəetmə platformaları ilə inteqrasiyası enerji səmərəliliyinin artırılması, hasilat proseslərinin etibarlılığının yüksəldilməsi və neft ehtiyatlarından uzunmüddətli, təhlükəsiz və dayanıqlı istifadə üçün mühüm vasitə hesab olunur.

Açar sözlər: *neft quyularının hasilatı, çoxfazlı axınölçən, virtual axınölçən, fiber-optik sensor, süni intellekt, rəqəmsal əkiz, enerji dayanıqlılığı, enerji səmərəliliyi*

APPLICATION OF THE ZERO TRUST MODEL IN THE PROTECTION OF DIGITAL RIGHTS

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Abstract: The widespread adoption of digital technologies across various areas of public and social life has led to a substantial increase in the collection, storage, processing, and transfer of personal data between different information systems. The processing of large volumes of data in e-government, higher education, healthcare, banking, e-commerce, and other digital services has created new opportunities while also making it necessary to address issues such as the protection of personal data privacy, secure user identification, prevention of unauthorized access, and the lawful use of information. In particular, the growing use of cloud services, remote working environments, mobile devices, and access to information systems through different networks requires a reconsideration of the capabilities of traditional perimeter-based security approaches. In this context, access to information resources should be determined not by whether a user is located inside or outside a particular network, but by the user's identity, the device being used, the context of access, and the specific resource being requested.

The main objective of this study is to examine the theoretical and practical potential of the Zero Trust model from the perspective of digital rights protection, to establish a relationship between its core principles and personal data protection, and to identify its potential applications in digital information systems operating in the Republic of Azerbaijan. The methodological basis of the study includes an analysis of the relevant academic literature, examination of international information security standards and methodological frameworks, comparative analysis of regulatory and legal instruments, and modelling of practical application scenarios. Within this framework, the approaches defined in the National Institute of Standards and Technology (NIST) Special Publication 800-207, *Zero Trust Architecture*, the NIST Privacy Framework, and internationally recognized principles for personal data protection are used as key methodological references.

A fundamental characteristic of the Zero Trust model is that no user, device, or network segment is automatically trusted solely on the basis of its location or presence within a particular environment. Access to a resource is granted based on the identification and authentication of the user and device, the determination of access privileges, and an assessment of the context in which the access request is made. This approach is particularly relevant to the protection of digital rights because the mere presence of a user within an information system does not provide unrestricted access to all available resources. Instead, access privileges are limited to the information and functions required for a specific task. The principle of least privilege therefore helps reduce the risk of excessive use of information and unauthorized access.

The application of the Zero Trust model to the protection of digital rights can also be considered in the context of information systems used by higher education institutions in Azerbaijan. University information systems process students' identification data, contact details, academic records, attendance information, and other personal data. Providing all employees with the same level of access to such information is neither technically necessary nor legally appropriate. Under a Zero Trust approach, a lecturer may be granted access only to the information required for the courses and student groups they teach, while a student may access only their own educational records. A head of an academic or administrative unit may be granted access to information necessary for the performance of their official responsibilities. Similarly, the technical privileges assigned to a system

administrator should not automatically provide access to the content of users' academic or personal information. Separating these functions is an important requirement for limiting unnecessary access to sensitive information.

Another important component of the model is the assessment of access requests according to their context. For example, when a user attempts to access a system from a previously unknown device or under unusual geographic or temporal conditions, additional authentication may be required. Likewise, access to particular resources may be restricted if indicators of potentially harmful or anomalous behaviour are detected. Although these mechanisms are intended to prevent account compromise and misuse of privileges, the monitoring process itself may create additional privacy risks. Therefore, the implementation of Zero Trust requires an appropriate balance between security objectives, data minimization, and the protection of individual privacy.

The findings of the study indicate that applying the Zero Trust model to the protection of digital rights should not be limited to strengthening authentication and access control mechanisms. Effective implementation requires the coordinated use of identification and authentication, least-privilege access, data segmentation, continuous access control, security event monitoring, and data protection measures within an integrated governance framework. In the context of Azerbaijan, the gradual adoption of this approach in e-government services, higher education information systems, healthcare platforms, financial institutions, and corporate information systems may contribute to strengthening the security of digital services and the protection of personal data. Thus, the Zero Trust model can be regarded not only as an information security mechanism but also as a technical and governance approach for protecting individuals' data in digital environments and ensuring that access to information resources is appropriately justified and limited.

Keywords: *Zero Trust, digital rights, personal data, information security, privacy, authentication, authorization, least privilege, digital services, information systems.*

MATHEMATICAL MODELING AND MULTI-OBJECTIVE OPTIMIZATION OF CIRCULAR ECONOMY IN ENERGY SYSTEMS

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Abstract This paper proposes an integrated multi-objective mathematical model for the implementation of circular economy principles in energy systems. The proposed model considers the interrelationships among energy generation, the integration of renewable energy sources, energy storage, waste-to-energy conversion, material circularity, and carbon emissions. For the first time, the Adaptive Circular Energy Index (ACEI), which evaluates the circularity level of energy systems, and the integrated Integrated Circular Energy Resource Optimization Model (ICEROM) are introduced.

Scientific Novelty of the Study

The scientific novelty of this paper is defined by the following contributions:

1. A new integrated mathematical model for energy systems based on circular economy principles, referred to as the Integrated Circular Energy Resource Optimization Model (ICEROM), is proposed.
2. A novel Adaptive Circular Energy Index (ACEI) is developed to assess the level of circularity of energy systems.
3. A multi-objective function is formulated that simultaneously accounts for energy costs, carbon emissions, resource circularity, and energy efficiency.
4. A system of balance equations is established to describe the interactions among energy, material, and waste flows.
5. The theoretical foundations of an optimization algorithm for the proposed model are presented, and its applicability under different scenarios is demonstrated.

The application of the proposed model provides a scientifically grounded decision-making mechanism for optimizing the utilization of energy resources, converting waste into an energy resource, improving economic efficiency, and achieving sustainable development objectives. The results obtained can be applied to the strategic planning of energy systems, green energy policy development, and resource management in industrial enterprises.

METHODS OF USING RENEWABLE ENERGY SOURCES TO IMPROVE THE EFFICIENCY OF ENERGY SUPPLY IN SOCIAL FACILITIES

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Abstract: In modern times, providing civil and social infrastructure facilities with sustainable and uninterrupted energy, as well as reducing utility costs and carbon emissions by increasing energy efficiency, are important strategic issues. In this regard, achieving carbon neutrality against the backdrop of global climate change and decarbonization of civil and social infrastructure facilities in accordance with the “Green Transition” strategies are becoming more urgent. Objective: The objective of this study is to investigate the possibilities of applying renewable energy sources (RES) in social buildings (residential buildings, administrative buildings, healthcare and educational institutions) and to offer comprehensive solutions to increase the efficiency of energy supply. The scientific novelty of the study lies in optimizing the parameters of the joint operation of social facilities of various types with hybrid renewable energy systems (RES) and intelligent energy management. Methodology: During the study, the energy consumption characteristics of social facilities of various categories were comparatively analyzed, and the integration capabilities of photovoltaic systems, solar collectors and heat pumps were evaluated. The analysis shows that the application of appropriate renewable energy sources (RES) technologies and thermal insulation measures increases energy savings by 50–70% and ensures uninterrupted operation of facilities during network failures. Conclusions: The results of the study can be used in the decision-making process during the modernization of social infrastructure and the implementation of ESCO models. Ensuring energy efficiency and reliability in social infrastructure facilities requires targeted and integrated application of (RES) technologies.

Keywords: *social facilities, energy efficiency, renewable energy, solar panels, heat pumps, energy security.*

EFFECT OF TEMPERATURE ON THE DEPOSITION PROCESS OF MO–S THIN FILMS

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Abstract: Molybdenum–sulfur (Mo–S) thin films are functional materials characterized by high electrical conductivity, chemical stability, and catalytic activity. Due to these properties, they are widely used in nanoelectronics, electrocatalysis, energy conversion and storage systems, sensors, and other modern technologies. The properties of Mo–S thin films depend significantly on the synthesis conditions, especially temperature. Since temperature directly affects the kinetics of the electrochemical deposition process and the structure of the resulting films, this work is devoted to studying the effect of temperature on the electrochemical deposition of Mo–S thin films in an anhydrous electrolyte environment.

GEOHERMY. OPPORTUNITIES AND PROSPECTS DEVELOPMENT IN THE KARABAKH REGION OF THE REPUBLIC OF AZERBAIJAN

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Abstract: The project leverages the region's thermal waters and assesses the potential of Istisu for health, tourism, and industrial thermal applications. Future geothermal electricity generation is a possibility, subject to the confirmation of high-temperature horizons.

It is recommended to develop a tourism and wellness complex and industrial thermal technologies based on geothermal energy. The next step involves geological exploration and the drilling of productive horizons to locate temperatures exceeding 125°C, as well as to assess the potential for commercial extraction and a water circulation cycle.

At the same time, there is no need to wait for the construction of a full-scale geothermal power plant; it is important to begin implementing heat pumps for buildings, wellness centers, greenhouses, public facilities, and small-scale industrial operations right away.

Heat pumps are roughly three times more efficient than gas heating systems; they run on electricity and can cut heating costs by nearly half. The notion that they are unsuitable for older homes is mistaken: in Germany, financial support for heat pump installation can reach €17,000, covering design, planning, and rapid installation.

This approach makes it possible to utilize low- and medium-temperature resources early on, reduce fuel dependency, lower heating costs, and gain experience for a future geothermal energy system. Heat pumps can serve as a transitional and complementary technology bridging the gap between thermal water sources and geothermal power plants.

Keywords: *renewable energy; deep geothermal energy; thermal waters; heat pumps; energy infrastructure.*

FROM SUSTAINABILITY RANKING TO DATA-DRIVEN ENERGY GOVERNANCE: UTEG'S GREENMETRIC TRAJECTORY AND AN AI-ASSISTED ECOMETRICS FRAMEWORK

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Abstract. Universities increasingly use sustainability rankings as benchmarking tools, yet a recurring challenge is converting annual evidence collection into continuous operational management. This paper analyzes the 2024–2026 sustainability trajectory of Universidad Tecnológica Empresarial de Guayaquil (UTEG), Ecuador, using published UI GreenMetric results, institutional sustainability records, campus energy data, and the 2026 evidence portfolio. A longitudinal case-study design compares category performance between 2024 and 2025 and examines management actions incorporated into the 2026 cycle, with emphasis on energy efficiency and digital governance. UTEG improved its total UI GreenMetric score from 4,280 to 5,240 points (+22.4%) and moved from 1,075th to 981st globally. However, its Energy and Climate Change score decreased from 1,500 to 1,260 points, revealing a discrepancy between infrastructure interventions and their continuous measurement, documentation, and management. The 2026 portfolio reports annual electricity consumption of 819,602.4 kWh, approximately 28,800 kWh of on-site photovoltaic generation, intelligent LED lighting, three smart campus buildings, and a 35.6% reduction in electricity consumption relative to the previous comparable period. To strengthen continuous management, the paper frames EcoMetrics as an institutional sustainability intelligence layer integrating energy, emissions, renewable generation, resource-use indicators, and GreenMetric evidence. A phased AI-assisted extension is proposed for anomaly detection, consumption forecasting, evidence-completeness checks, and scenario analysis. The case illustrates how sustainability rankings can evolve from ex-post reporting exercises into data-informed management architectures for continuous improvement in resource-constrained higher education institutions.

Keywords: UI GreenMetric; sustainable university; energy efficiency; smart campus; sustainability analytics; artificial intelligence; Ecuador.

INTEGRATION OF INTELLIGENT LIGHTING SYSTEMS WITH NATURAL LIGHTING IN GREEN BUILDINGS

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Abstract: Global climate change, acceleration of urbanization processes and the need for efficient use of energy resources are becoming an increasingly important trend, making the development of the green building concept one of the priority directions. In this regard, the integration of natural lighting with intelligent lighting systems in green buildings is one of the most relevant topics of modern architecture and urban planning, energy security in the direction of reducing carbon emissions, increasing energy efficiency and implementing the principles of sustainable development.

The main purpose of the article is to determine the integrative working principles, components and areas of application of natural lighting processes and intelligent lighting systems in green buildings, to analyze the requirements for natural lighting in certification systems intended for green buildings (LEED, BREEAM, etc.).

In the research process, a systematic literature review, analysis of international scientific sources, comparative analysis and conceptual assessment methodology of green building standards (BREEAM, LEED) were used, and the impact of the integration of natural lighting with intelligent lighting systems in green buildings on energy efficiency, carbon emissions reduction, consumer comfort, building performance and overall sustainability of ecosystems was comprehensively evaluated.

The scientific novelty of this study is the assessment of the complex impact of the integration of natural lighting and intelligent lighting systems in green buildings within a single conceptual model on energy sustainability and efficiency indicators. As a result of the scientific approach aimed at optimizing energy consumption based on the integration of solar energy indicators (Daylight Autonomy, Daylight Factor and Useful Daylight Illumination) with smart management technologies, it was determined that integrated lighting solutions both ensure the reduction of electricity consumption and carbon emissions, and also create conditions for increasing the comfort of energy users and the efficiency of building operation. In this regard, the practical results of the study provide scientifically and theoretically justified recommendations for power engineers, engineers, designers, architects, and building management specialists in the design and implementation of efficient lighting systems.

Keywords: *energy efficiency; green building concept; natural lighting; LED technology; BREEAM, LEED green building certificates; smart building management system; Artificial Intelligence.*

HIGHLY EFFICIENT NANOMODIFIED POLYMER COATINGS FOR THE PROTECTION OF OIL AND GAS PIPELINES

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Abstract: The oil and gas pipeline network of the Republic of Azerbaijan possesses an extensive, complex, and multifunctional structure. This system includes trunk pipelines of both national and international significance, as well as in-field pipelines that transport well products to collection, treatment, and processing stations, as well as deliver gas to domestic, industrial, and commercial consumers. The primary operational challenge facing this infrastructure is the corrosion protection of the pipeline system, which is addressed through the application of active and passive protection methods.

The article considers the application of nanomodified polymer coatings as one of the passive protection methods for metal surfaces, representing an effective means of enhancing the corrosion resistance of pipelines in the oil and gas industry. The mechanisms of corrosion-induced degradation of pipelines, the classification of nano additives, and their influence on the barrier, adhesion, and mechanical properties of protective coatings were analyzed.

The results of experimental studies confirming a significant reduction in corrosion rate and the extension of pipeline service life upon the application of nanocomposite polymer coatings are presented. Relevant scientific conclusions regarding the prospects of applying these coatings in field and trunk pipeline systems have been drawn.

Keywords: Pipeline; Corrosion protection; Polymer coatings; Nanomodification; Oil and gas industry

IMPACT OF GROUND HEAT EXCHANGER CONFIGURATION AND SOLAR THERMAL INTEGRATION ON THE SEASONAL PERFORMANCE OF RESIDENTIAL GROUND SOURCE HEAT PUMP SYSTEMS IN AZERBAIJAN

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Abstract: The decarbonization of the heating sector plays a crucial role in achieving national and global climate targets, particularly in countries with a high share of fossil-fuel-based energy systems. In this context, the integration of renewable energy technologies into building heating systems represents an important pathway for reducing greenhouse gas emissions and primary energy consumption. This study investigates the performance of solar-assisted ground source heat pump (SA-GSHP) systems under the climatic conditions of Azerbaijan by comparing horizontal and vertical ground heat exchanger configurations. Dynamic simulations were conducted to evaluate the effects of solar thermal integration on seasonal performance and annual energy balance. The results show that solar assistance leads to a substantial improvement in efficiency, with the SPF of the horizontal GSHP increasing from 3.40 to 11.72 and that of the vertical GSHP from 4.01 to 12.28. Approximately 28% of the total annual useful heat demand was covered by the solar thermal subsystem, resulting in reduced electrical consumption and shorter operating hours of the heat pump. Although vertical systems achieved slightly higher absolute SPF values, the relative improvement was more pronounced in horizontal systems due to their stronger sensitivity to ground temperature variations. Overall, the findings demonstrate that SA-GSHP systems can make a meaningful contribution to the decarbonization of Azerbaijan's heating sector.

Keywords: *Ground source heat pump systems, Ground heat exchanger configuration, Solar thermal integration, Seasonal performance factor, Azerbaijan climatic conditions*

SPECTRAL–ANGULAR OPTIMIZATION OF ANTIREFLECTION COATINGS FOR SOLAR CELLS

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Abstract. A method is proposed for determining the optimal normalized thicknesses of a two-layer antireflection coating on an absorbing substrate. Unlike approaches aimed at achieving zero reflectance at isolated parameter values, the proposed method determines the coating configuration that minimizes the mean reflectance over prescribed spectral and angular ranges for unpolarized radiation. The optimized two-layer structure provides a substantial reduction in reflectance relative to both the uncoated substrate and the corresponding single-layer coatings. The effects of layer sequence, polarization, and deviations of the layer thicknesses from their optimal values are analyzed. The optimized solution remains stable under moderate thickness variations. The results establish the conditions for effectively reducing reflection from the front surface of the absorbing system.

Keywords: *antireflection coating; solar cell; absorbing substrate; normalized wavelength; spectral–angular optimization; layered medium; polarization.*

MULTI-CRITERIA MATHEMATICAL MODELING AND OPTIMIZATION OF ENERGY SYSTEMS IN SUSTAINABLE URBAN PLANNING

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Abstract: Introduction

Rapid urbanization, increasing energy demand, and environmental challenges require advanced approaches to sustainable urban energy planning. Traditional energy management methods generally optimize a single objective and therefore cannot adequately balance economic efficiency, environmental sustainability, and system reliability in complex urban energy systems.

Objective

This study aims to develop a multi-criteria mathematical optimization framework for sustainable urban energy systems by integrating energy consumption, economic cost, carbon emissions, and system reliability into a unified decision-making model.

Methodology

The proposed framework combines graph theory, multi-criteria optimization, and artificial intelligence-supported adaptive decision-making. Urban energy infrastructure is represented as a directed graph, while optimization is performed using Pareto-based multi-objective analysis through the NSGA-II algorithm and the TOPSIS decision-making method. In addition, a novel **Urban Sustainable Energy Index (USEI)** is introduced to evaluate the overall technical, economic, and environmental performance of alternative energy management scenarios.

Results

Theoretical simulation results demonstrate that the proposed model improves energy efficiency, reduces energy losses and carbon emissions, enhances system reliability, and lowers overall operating costs compared with conventional and hybrid energy management approaches. The integration of adaptive optimization and artificial intelligence enables the model to respond effectively to dynamically changing urban energy conditions while providing more balanced and sustainable decision-making. Furthermore, the proposed framework serves as an effective decision-support tool for Smart City applications and sustainable urban energy planning by integrating graph theory, adaptive optimization, artificial intelligence, and the Urban Sustainable Energy Index (USEI) into a unified mathematical framework for evaluating and optimizing urban energy systems.

Keywords: *sustainable urban planning, energy systems, mathematical modeling, multi-criteria optimization, graph theory, artificial intelligence.*

GREEN HYDROGEN POTENTIAL OF AZERBAIJAN: OPPORTUNITIES, CHALLENGES AND PROSPECTS

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Abstract: The global energy transition, rising demand for renewable energy, efforts to address climate change, and the need to reduce carbon emissions have increased the strategic importance of green hydrogen as an energy carrier. Produced by water electrolysis powered by renewable electricity, green hydrogen is increasingly viewed as a practical option for industrial sectors in which deep decarbonization is difficult to achieve through direct electrification alone. Azerbaijan has several advantages that could support the development of green hydrogen production and export, including substantial wind and solar resources, significant offshore wind potential in the Caspian Sea, an established energy infrastructure, and existing links with European energy markets. These advantages are accompanied by important constraints, notably high production costs, the need to reinforce the electricity grid, limited water resources, storage and transport requirements, certification rules, and uncertainty around long-term buyers. This article assesses Azerbaijan's green hydrogen potential from technical, economic, and strategic perspectives. The study reviews scientific literature and official information related to renewable energy resources, existing infrastructure, international energy cooperation, water supply, safety, and export opportunities. It also considers the integration of green hydrogen into ammonia production through a conceptual modelling approach. The analysis indicates that Azerbaijan's existing industrial base could provide a useful starting point for green ammonia production, domestic industrial decarbonization, and future regional export projects. Progress in this field will depend on a phased strategy that combines pilot projects, the creation of domestic industrial demand, certification aligned with international standards, infrastructure development, sustained investment, and stronger human capital.

Keywords: *green hydrogen, renewable energy, offshore wind energy, electrolysis, green ammonia, energy transition, Azerbaijan, European energy market.*

FORECASTING THE DEPENDENCE OF ARC OVERVOLTAGE ON THE GROUND FAULT INCEPTION ANGLE IN RENEWABLE ENERGY-BASED DISTRIBUTION NETWORKS

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Abstract. This paper investigates the regression modeling and forecasting of the dependence of arc overvoltage on the ground fault inception angle during transient single-phase-to-ground faults in isolated-neutral distribution networks with high penetration of renewable energy sources. The integration of renewable energy sources alters the network capacitance parameters and transient electromagnetic processes, significantly affecting the characteristics of arc overvoltages. To address this issue, a regression model describing the relationship between the arc overvoltage factor and the ground fault inception angle was developed using the least squares method. The adequacy of the proposed model was evaluated by testing the statistical significance of the regression and correlation coefficients, determining confidence intervals, and analyzing the agreement between theoretical and experimental results. Furthermore, arc overvoltage values were forecast for different ground fault inception angles. The obtained results are presented using two-dimensional graphs and demonstrate the practical applicability of the proposed approach for on-line insulation testing and improving the operational reliability of renewable energy-integrated distribution networks.

Keywords: *isolated-neutral distribution network; renewable energy sources; transient single-phase-to-ground fault; ground fault inception angle; arc overvoltage factor; regression model; forecasting.*

TRACKING AND TACKLING THE RISING ENERGY CONSUMPTION TREND OF A HIGHER EDUCATION INSTITUTION IN MINDANAO, PHILIPPINES

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Abstract: Higher education institutions play a vital role in advancing sustainable development by integrating responsible energy management into their core operations. This study examines the escalating electricity consumption at Bukidnon State University (BukuSU) from 2015 to early 2025, using descriptive statistics, trend analysis, and document review of institutional energy policies and audit reports. The results reveal a steady increase in energy use with seasonal patterns linked to academic operations, highlighting deficiencies in real-time monitoring, centralized oversight, and strategic planning. To address these challenges, the study recommends establishing a centralized Energy Management Office, deploying an Energy Management Information System (EMIS), and implementing a five-year roadmap targeting a 20% reduction in electricity consumption. Key strategies include infrastructure upgrades, such as high-efficiency HVAC systems and smart lighting, alongside behavioral change programs and robust financial planning. and presents a series of critical recommendations to enhance energy efficiency and sustainability. Aligning these initiatives with the Energy Efficiency and Conservation Act (RA 11285) and the UN Sustainable Development Goals is crucial for long-term impact. Continuous monitoring, third-party audits, and strategic benchmarking are also recommended to ensure accountability and sustained progress. The findings offer a replicable model for public universities aiming to enhance operational efficiency and environmental sustainability.

Keywords: *Energy consumption, conservation, higher education institutions, sustainable goals, environmental responsibility, institutional energy efficiency, infrastructure, financial sustainability, environmental stewardship, social impact*

DEVELOPMENT OF CDTE THIN FILMS BY ELECTRODEPOSITION FOR PHOTOVOLTAIC APPLICATIONS

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The rapid development of renewable energy technologies has increased the demand for advanced semiconductor materials with improved structural, optical, and photoelectric properties for photovoltaic applications. Among various thin-film absorber materials, cadmium telluride (CdTe) has attracted considerable attention because of its high optical absorption coefficient ($\sim 10^5 \text{ cm}^{-1}$), direct bandgap (1.45–1.50 eV), low production cost, high deposition rate, and excellent long-term stability. Owing to these advantages, CdTe-based solar cells have become one of the leading candidates for large-scale photovoltaic power generation. The theoretical power conversion efficiency of CdTe solar cells is close to 30%, while the highest experimentally achieved efficiency has already reached 22.1%. Current research on CdTe solar cells focuses on reducing material and energy consumption by fabricating thinner absorber layers at lower processing temperatures, while simultaneously improving device efficiency through low-cost fabrication techniques. Recent studies have demonstrated that selenium (Se) incorporation into CdTe reduces lattice mismatch at the CdS/CdTe heterojunction, enhances charge carrier transport, increases carrier lifetime and diffusion length, and suppresses interface recombination. Moreover, CdTe interlayers prepared by the glancing angle deposition (GLAD) technique improve heterojunction quality and photovoltaic performance.

In the present work, CdTe thin films were deposited on indium tin oxide (ITO) substrates using a simple two-electrode electrodeposition method. The influence of deposition voltage on the structural, morphological, optical, and compositional properties of the films was systematically investigated. Electrodeposition offers several advantages, including low energy consumption, high material utilization efficiency, precise control of deposition parameters, and the ability to produce uniform thin films over large areas. The obtained results demonstrate that deposition voltage strongly affects crystallinity, crystallite size, surface morphology, elemental composition, and optical bandgap. These findings provide valuable guidelines for optimizing CdTe absorber layers and developing high-efficiency, cost-effective, and environmentally sustainable thin-film solar cells.

WASTE VALORIZATION & CIRCULAR ECONOMY



DEVELOPMENT AND FEASIBILITY STUDY OF A COMPACT HOUSEHOLD PLASTIC WASTE SHREDDER FOR A DECENTRALIZED CIRCULAR ECONOMY.

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Abstract: The rapid growth of volumes of plastic waste is one of the most urgent environmental problems of our time. Despite the widespread introduction of industrial processing technologies, a significant part of plastic waste is still not returned to the production cycle due to the insufficient participation of the population in the primary sorting and preparation of secondary raw materials. In this regard, the development of technical solutions that allow to organize the primary processing of plastic directly at home is of special interest. This paper presents the concept, engineering rationale and technical design of a compact household shredder of plastic waste, intended for obtaining secondary plastic raw materials directly in the places of waste generation. The design scheme of the two-shaft cutting mechanism was developed, the engineering calculations of the torque and power of the drive were performed, and the basic design and operational parameters of the equipment were determined. On the basis of the accepted calculation parameters, a scenario assessment of the technical, economic and ecological efficiency during the mass implementation of such devices was performed. This research is at the stage of conceptual design: the production of a physical prototype and its experimental testing are considered as the next stage of the work and are indicated in the limitations section. The paper proposes the concept of a decentralized circular economy system based on the active participation of households in the preparation of secondary plastic raw materials. It is shown that the use of household shredders can potentially reduce the volume of plastic waste sent to landfills, increase the return of polymeric materials to the production cycle, reduce the need for the production of primary polymers from oil and gas raw materials, and reduce the negative impact on the environment. The obtained results allow us to consider the developed concept of a household shredder not only as an engineering solution for the primary processing of plastic waste, but also as a technological element for the implementation of the principles of circular economy, resource conservation and sustainable development, which requires further experimental verification.

Key words: *plastic waste; household grinder; primary processing of plastic; secondary polymer raw material; circular economy; decentralized processing; engineering design; scenario analysis; technical and economic evaluation.*

ECOTWIN - AI: AN INTEGRATED DIGITAL TWIN AND ARTIFICIAL INTELLIGENCE FRAMEWORK FOR SUSTAINABLE SMART CAMPUS RESOURCE MANAGEMENT

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Abstract: Introduction: Higher education institutions are increasingly adopting smart technologies to improve environmental sustainability and resource efficiency. Although Artificial Intelligence (AI), Digital Twin (DT), and Internet of Things (IoT) technologies have been widely investigated in smart campus research, existing studies primarily address energy, water, and waste management as independent domains. The absence of an integrated decision-support framework limits the implementation of holistic sustainability strategies and reduces the effectiveness of campus resource optimization.

Objectives: This study proposes EcoTwin-AI, a novel AI-driven Digital Twin framework that integrates waste valorization, sustainable water management, and energy optimization into a unified intelligent platform for smart university campuses. The framework aims to support real-time monitoring, predictive analytics, and evidence-based decision-making while promoting circular resource management and environmental sustainability.

Methodology: The study follows a Design Science Research (DSR) approach combined with systems engineering principles and a comprehensive review of recent literature. The proposed framework consists of five interconnected layers: physical infrastructure, IoT-based data acquisition, Digital Twin modelling, AI-powered analytics, and sustainability assessment. A proof-of-concept case study based on a university campus environment is used to demonstrate the applicability of the framework. Resource flows related to electricity consumption, water use, and waste generation are mapped into a virtual campus model to evaluate operational scenarios and intelligent optimization strategies.

Results: The proposed EcoTwin-AI framework demonstrates how heterogeneous environmental data can be integrated into a single intelligent management platform capable of supporting predictive monitoring, scenario analysis, and sustainability-oriented decision-making. The framework establishes a scalable architecture for optimizing campus resources, improving operational efficiency, facilitating waste valorization, and strengthening circular economy practices. It also provides a practical foundation for future implementation of AI-enabled Digital Twin technologies in higher education institutions and contributes to achieving the United Nations Sustainable Development Goals (SDG 6, 7, 11, 12, and 13).

Keywords: Artificial Intelligence; Digital Twin; Smart Campus; Sustainability; Waste Valorization; Water Management; Energy Optimization; Internet of Things.

A CIRCULAR ECONOMY FRAMEWORK FOR REGIONAL END-OF-LIFE TRACTION-BATTERY MANAGEMENT IN AZERBAIJAN

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Abstract: Road-transport electrification shifts environmental responsibility from fuel use to the stewardship of long-lived electrochemical assets. This article develops an ex-ante circular-economy framework for Azerbaijan integrating traceable take-back, diagnostic grading, second-life allocation, material recovery and controlled residual treatment. The method combines a value-retention hierarchy, route-specific net circular value, a throughput condition and bounded cohort scenarios. Azerbaijan imported 13,409 plug-in vehicles in 2024 and 58,822 in 2025. If annual inflow reverts to the 2024 level, remains at the 2025 level or expands by 5%, the cumulative 2024–2030 imported cohort reaches 139,276–413,511 vehicles. This is an exposure indicator, not end-of-life tonnage. The result supports early investment in a modular national centre for registration, safe consolidation, diagnosis, second-life qualification and pre-treatment, while deferring irreversible metallurgical capacity until retired mass and regional supply contracts are verified. PPP is treated solely as an implementation solution for allocating risk, mobilising finance and remunerating audited circular services. The contribution is an Azerbaijan-specific investment sequence that preserves functional and material value without manufacturing feedstock or profitability assumptions. The framework also emphasizes that registration and diagnostic capacity should precede large-scale recycling investment, allowing future decisions to be based on verified retirement volumes, battery chemistry, process yields and regional logistics. This staged approach reduces the risk of underutilised capacity while maintaining traceability throughout the battery life cycle.

Keywords: *circular economy; traction battery; value retention; second life; regional recycling; Azerbaijan*

WASTE-FREE EXTRACTION TECHNOLOGY FOR WASTEWATER PURIFICATION FROM ORGANIC POLLUTANTS WITH REGENERATIVE RECOVERY OF EXTRACTANT AND SOLVENTS

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Abstract: A comprehensive wastewater treatment scheme for removal of organic contaminants is presented and theoretically substantiated. The proposed methodology is based on liquid-liquid extraction from the aqueous media utilizing isopropyl ether, followed by phase separation and regenerative recycling of the extractant for continuous cyclic utilization. Experimental results detailing the kinetic characteristics of organic component extraction are discussed.

Special emphasis is placed on pigment-containing electrolyte systems comprising compounds such as TiO_2 and TiCl_2 , which are extensively applied in protective coating technologies to form anticorrosive films. To enhance the physical and mechanical properties of these coatings, electrolyte compositions containing both highly soluble and sparingly soluble hydrophobic organic components—including butyl glycol gel, phenylisopropanol, acetic acid, and acetone—are employed, with total mass fractions reaching 25–35 wt.%.

Accounting for the specific physical-chemical characteristics of the investigated systems, an optimized extraction approach for water-emulsion organic mixtures is proposed. This approach employs high-boiling isostructural ethers, specifically isopropyl ether ($(i\text{-C}_3\text{H}_7)_2\text{O}$) and isobutyl ether ($(i\text{-C}_4\text{H}_9)_2\text{O}$), which are industrially manufactured and readily available.

The primary objective of the work is development of a waste-free, environmentally sustainable technological framework for recovering organic components from paint and varnish industry wastewater via liquid-phase extraction. This process ensures the recovery and recycling of both solvent and purified water—meeting maximum permissible concentration (MPC) standards for toxic substances—back into the production cycle. A comprehensive AGREEprep evaluation index score of 0.89 demonstrates the high environmental sustainability of the developed technology, confirming its alignment with green chemistry principles.

Keywords: *extraction, solvent, purification, extractant, recycling, rectification, waste-free technology.*

DETERMINATION OF PUMP INPUT DEPTH TAKING INTO ACCOUNT LIQUID-GAS MIXTURE IN MECHANIZED OPERATION METHOD

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Abstract: Introduction. The Republic of Azerbaijan is rich in oil and gas fields with large reserves. For this purpose, existing technologies are being enriched and, thanks to newly created technologies, great prospects are created in the development of oil and gas fields. In general, the study of the characteristics of oil and gas wells is of great importance. The study of the general characteristics of the gas-liquid mixture in the body of oil and gas wells, as is known, allows you to determine many parameters. There are various methods for determining the depth of pumping in the mechanized exploitation of oil and gas fields.

Objectives. The main objective of the presented research work is to determine the pump discharge depth, taking into account the liquid-gas mixture in wells drilled in mechanized oil and gas fields.

Methods. To achieve the main goal, analysis, synthesis and calculation methods were used. As a result of the application of these methods, the pump discharge depth was determined, taking into account the liquid-gas mixture.

Results. It has been found that taking into account the liquid-gas mixture in the mechanized operation process plays an important role in determining the pump discharge depth. Taking into account the liquid-gas mixture will reduce pump overload and help to significantly reduce energy consumption.

Keywords: oil, water, pump, methods, wells

INTEGRATED ORGANIC WASTE MANAGEMENT MODEL FOR SUSTAINABLE UNIVERSITY CAMPUSES: THE CASE OF SULEYMAN DEMIREL UNIVERSITY

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Abstract: Higher education institutions play an important role in achieving the Sustainable Development Goals (SDGs), not only through education and research activities but also through the environmental management systems implemented on their campuses. This study evaluates the integrated organic waste management model developed at Süleyman Demirel University (SDU) within the framework of the circular economy and examines its contribution to sustainable campus management.

The organic waste generated at the university mainly consists of food waste, kitchen waste, plant-based waste, and animal manure. Food waste is separately collected and processed through a shredding system for the production of animal feed, which is subsequently used to feed stray animals. Kitchen waste, plant residues generated from campus landscaping activities, and animal manure are directed to the composting facility. Following a controlled composting process, the resulting compost is intended to be utilized in university landscaping areas, thereby enabling organic materials to be recirculated within the campus ecosystem.

Through this integrated system, the amount of organic waste sent to landfills is significantly reduced, contributing to the mitigation of greenhouse gas emissions, reduction in chemical fertilizer use, conservation of natural resources, and sustainable management of campus green areas. Furthermore, the system functions as a Living Laboratory, providing opportunities for students and researchers to conduct applied education, scientific research, and community awareness activities related to waste management, circular economy, and sustainability.

The Süleyman Demirel University case demonstrates that organic waste generated on university campuses can be transformed into valuable resources while reducing environmental impacts. The integrated model also illustrates how circular economy principles can be incorporated into sustainable campus management and provides a potentially replicable approach for higher education institutions seeking to strengthen their environmental performance and contribution to the SDGs.

Keywords: *Organic waste management, circular economy, sustainable campus, compost production, animal feed production, Living Laboratory, UI GreenMetric, Sustainable Development Goals.*

DATA-DRIVEN CIRCULAR CAMPUS TRANSITION AT AZERBAIJAN STATE PEDAGOGICAL UNIVERSITY: UI GREENMETRIC 2024-2025 BENCHMARKING AND AN INTEGRATED WASTE-WATER-ENERGY ROADMAP

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Abstract: This study examines how publicly available UI GreenMetric data can be converted into an uncertainty-aware decision-support framework for Azerbaijan State Pedagogical University (ADPU). Official 2024 and 2025 category scores are analysed through normalized performance, absolute and relative change, contribution to improvement, residual weighted gaps, a balance index, and distance to the ideal profile. The methodological novelty is a dual-axis diagnostic that separates historical contribution from future weighted need, combines structural validation with one-at-a-time sensitivity analysis, and connects campus operations to a pedagogical living-lab multiplier. Scenario recovery rates are used to compare strategic pathways and quantify assumption sensitivity. ADPU's score increased from 2,400 to 4,320 points (+80.0%), while its world rank improved by 163 places. Transportation generated 40.5% of the gain, whereas Energy and Climate Change, Waste, and Water represented 59.0% of the residual gap. In the selected national benchmark, ADPU recorded the largest percentage increase, signalling accelerated institutional progress from a developing baseline. The integrated scenario produced a modelled score of 6,232.3 points. Sensitivity tests produced 6,097.3 points when the Energy recovery rate changed from 40% to 30%, and 5,972.3 points when the Waste rate changed from 45% to 25%; a uniform ± 10 -percentage-point perturbation generated a range of 5,664.3-6,800.3. The study therefore offers a reproducible methodological base for data-driven prioritization, forecast-ready sustainability strategies, environmentally responsible policy design, and future longitudinal research as audited campus data become available.

Keywords: *UI GreenMetric; Azerbaijan State Pedagogical University; circular campus; waste valorization; water sustainability; renewable energy; teacher education; sustainability benchmarking*

WOMEN OF KYRGYZSTAN IN THE CONTEXT OF THE SYNERGY OF SUSTAINABLE DEVELOPMENT: ENVIRONMENTAL, ECONOMIC, AND SOCIAL DIMENSIONS

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Abstract: This article examines the role of women in Kyrgyzstan in the context of the synergy of sustainable development, integrating environmental, economic, social, and gender dimensions. The relevance of the study is determined by the growing impacts of climate change, the degradation of natural resources and ecosystems, glacier retreat, water scarcity, land and pasture degradation, the increasing frequency of natural disasters, as well as rising poverty and migration. For Kyrgyzstan, a mountainous country characterized by high climate and geographical vulnerability, these challenges have significant socio-economic implications. The article identifies the key areas of women's contribution to sustainable development, including agriculture, the rational use of natural resources, food and environmental security, environmental education, entrepreneurship, civil society, and local governance. Particular attention is paid to women's vulnerability to climate change, the increasing burden of unpaid domestic and care work, poverty, migration, and the risks associated with natural disasters. The study concludes that a gender-responsive approach should be systematically integrated into national climate and environmental policies. Expanding women's participation in decision-making and improving their access to resources, education, innovation, and environmental governance are considered essential conditions for building a sustainable, inclusive, and competitive development model for the Kyrgyz Republic.

Keywords: *sustainable development, women of Kyrgyzstan, gender equality, climate change, environmental security, sustainable communities, Sustainable Development Goals (SDGs), social policy.*

DIGITAL TRANSFORMATION OF REVENUE ACCOUNTING AND AUDITING SYSTEMS IN THE SERVICE SECTOR

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Abstract: In modern economic conditions, the formation of digital business models, the increase in complex contractual relationships, and the expansion of the service sector have made it necessary to reassess traditional approaches to accounting and auditing systems. In this regard, the purpose of the study is to study the theoretical and methodological foundations of the mechanisms for recognizing, measuring, and conducting audit audits in the service sector in the context of digital transformation, and to identify the mechanisms of impact of new technologies on audit and accounting systems. The article examines the impact of digitalization on revenue accounting systems in service enterprises, the application directions of cloud-based accounting platforms, AI and analytical audit tools, and the impact of digital technologies on real-time tracking of revenue transactions, recognition of revenues in the correct periods, and more effective assessment of audit risks.

The theoretical and methodological basis of the study is formed by the analysis of International Accounting Standards, digital accounting theories, digital economy concepts, and scientific approaches to the topic. A systematic approach, comparative analysis, normative legal, and documentary analysis methods were used in the research work.

As a result of the study, it was determined that the digital transformation of revenue accounting and audit systems in the service sector provides not only the automation of revenue accounting, but also the intellectualization of audit and accounting processes, risk-based management, as well as the optimization of information flow. The scientific novelty of the conducted research is the systematic analysis and conceptual substantiation of new management models based on the integration of traditional accounting and audit approaches and digital technologies for the digital transformation of revenue accounting and audit systems in the service sector.

Increasing the efficiency of revenue accounting and audit processes in enterprises operating in the service sector is determined by expanding the possibilities of applying digital management mechanisms and improving the quality of financial statements. In this regard, the scientific novelty of the research is the formation of a single conceptual approach to the digital transformation of audit systems and revenue accounting in the service sector.

Keywords: *audit systems; digital transformation; service sector; revenue accounting; IFRS 15; digital audit.*

NOVEL JELLY MARMALADE BASED ON BLACK ELDERBERRY (*SAMBUCUS NIGRA* L.) JUICE: PHYSICOCHEMICAL AND MICROBIOLOGICAL QUALITY ASSESSMENT

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Abstract: This study investigated the feasibility of using black elderberry (*Sambucus nigra* L.), a wild-growing berry widely distributed in Georgia, as a functional raw material for jelly marmalade production. The study aimed to develop a black elderberry juice-based marmalade with improved nutritional characteristics while maintaining acceptable technological, sensory, and microbiological quality. Black elderberry berries were selected due to their high content of biologically active compounds, including polyphenols, pectin, natural pigments, vitamins, and macro- and microelements. The developed marmalade was evaluated in terms of organoleptic, physicochemical, rheological, and microbiological characteristics and compared with a conventional control product. The developed marmalade demonstrated organoleptic and physicochemical characteristics that complied with the relevant standard requirements. Its plastic strength was within the acceptable range and comparable to that of the control sample. The shelf life of the elderberry-based marmalade increased from 60 to 70 days, as confirmed by microbiological analyses, while the microbiological parameters remained within the established safety limits. The observed improvement in storage stability may be associated with the presence of antioxidant and potentially antimicrobial compounds naturally occurring in elderberry. Furthermore, reducing the sugar content of the formulation by 14.9% resulted in a 50 kcal (15.3%) reduction in caloric value compared with the control, without adversely affecting the sensory characteristics of the product. The use of gelatin as a gelling agent additionally contributed to the protein content and overall nutritional value of the marmalade.

Keywords: Black elderberry; Biologically active substances; Functional food; Microbiological indicators; Gelatin.

PREPARATION OF POLYMERIC SORBENTS BASED ON A STYRENE-MODIFIED MALEIC ANHYDRIDE–HEPTENE COPOLYMER AND INVESTIGATION OF THEIR PROPERTIES

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Abstract: In the present study, a maleic anhydride–heptene-1 copolymer (MA-co-HP) was synthesized by free-radical copolymerization in benzene solution using benzoyl peroxide as the initiator. The polarity and reactivity of the monomers were evaluated according to the Alfrey–Price Q–e scheme, confirming the feasibility of alternating copolymer formation. The obtained copolymer was subsequently modified with styrene to improve its physical, physicochemical, and sorption properties. The structure of the styrene-modified maleic anhydride–heptene-1 copolymer (St-modified MA-co-HP) was confirmed by Fourier transform infrared (FTIR) spectroscopy. Turbidimetric titration demonstrated that the synthesized product was a true copolymer rather than a mixture of the corresponding homopolymers. The intrinsic viscosity of the initial MA-co-HP copolymer was 0.20 dL g⁻¹, whereas after styrene modification it increased to 0.22 dL g⁻¹, indicating changes in the macromolecular chain structure. The sorption properties of the synthesized material were investigated by static adsorption using methylene blue as a model organic dye. The adsorption capacity increased from 8.0 to 27.2 mg g⁻¹ with an increase in the initial dye concentration from 10 to 50 mg L⁻¹, while the removal efficiency decreased from 80.0% to 54.4% due to the gradual saturation of the active adsorption sites. The high sorption performance of the obtained St-modified MA-co-HP is attributed to the presence of anhydride functional groups and aromatic styrene fragments, which provide effective interactions with dye molecules. The obtained results indicate that St-modified MA-co-HP is a promising polymeric sorbent for the removal of organic dyes from aqueous solutions and may serve as a basis for further studies on adsorption processes and the development of new materials for wastewater treatment.

Keywords: maleic anhydride; heptene-1; styrene; free-radical copolymerization; polymeric sorbent; methylene blue.

SYNTHESIS AND PROPERTIES OF OPTICALLY TRANSPARENT NANOCOMPOSITES BASED ON STYRENE–BUTYL METHACRYLATE COPOLYMER MODIFIED WITH TiO_2 NANOPARTICLES

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Abstract: An optically transparent polymer material with an improved combination of performance properties was prepared by radical copolymerization of styrene (St) and butyl methacrylate (BMA) at different comonomer molar ratios. The structure, optical, and physicomechanical properties of the obtained copolymer were investigated. It was established that an equimolar ratio of the monomers results in the formation of a copolymer possessing high optical transparency, good mechanical properties, and a refractive index of 1.5870. The obtained copolymer was modified with 1 and 2 wt.% titanium dioxide (TiO_2) nanoparticles. The effect of nanoparticle content on the optical, thermal, and physicomechanical properties of the resulting nanocomposites was investigated. It was found that the incorporation of TiO_2 nanoparticles increases the Vicat softening temperature, Brinell hardness, tensile strength, adhesive strength, and refractive index of the polymer material while maintaining high optical transparency. It was shown that the incorporation of 2 wt.% TiO_2 increases the Vicat softening temperature from 120 to 134 °C, the tensile strength from 70 to 89 MPa, and the Brinell hardness from 17 to 21 kg/mm². At the same time, the refractive index increases from 1.5870 to 1.5890, while the light transmittance in the visible region reaches 90%, compared with 88% for the unmodified copolymer. The obtained results confirm that the modification of the styrene–butyl methacrylate (St-co-BMA) copolymer with TiO_2 nanoparticles is an effective approach for tailoring its structure and performance properties. The developed nanocomposites combine high optical transparency with enhanced thermal and physicomechanical characteristics and can be recommended for the fabrication of transparent protective coatings, optical components, and optoelectronic devices.

Keywords: *styrene; butyl methacrylate, styrene, radical copolymerization, TiO_2 nanoparticles, optically transparent nanocomposites.*

GENERATIVE AI CAPABILITY AND ESG PERFORMANCE IN PAKISTANI HIGHER EDUCATION: A PROPOSED MODERATED SEQUENTIAL MEDIATION MODEL OF GREEN INNOVATION AND CIRCULAR ECONOMY PERFORMANCE

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Abstract: Generative Artificial Intelligence (GenAI) is emerging as an institutional capability with the power to transform the way organizations process information, make decisions, and manage resources. Due to these unique pressures growing digital-transformation mandates from the Higher Education Commission (HEC), unequal digital infrastructure across HEIs, resource limitation, and increasing demands for environmental, social and governance (ESG) accountability Pakistan's higher-education institutions (HEIs) are a theoretically rich context where digital transformation and AI are underexplored in relation to ESG issues. This paper investigates a moderated sequential mediation model with Generative AI Capability affecting Green Innovation, further strengthening Circular Economy Performance, which then influences institutional ESG Performance. Digital Readiness is suggested as a boundary condition that will be the basis to achieve the potential for Generative AI Capability to be translated into Green Innovation. Using the three theoretical frameworks of Dynamic Capabilities Theory, the Natural Resource Based View, and Circular Economy Theory, the paper proposes testable propositions, specificizes each construct for the higher education sector and not applies to the corporate sector and has largely explained a future empirical research agenda by including knowledgeable academic and administrative respondents in diverse Pakistani universities. The paper's contribution is conceptual, in that it moves the discussion on GenAI away from a tool-adoption variable to discuss it as an institutional capability; extends the theorizing of green-innovation and circular-economy into the higher-education sector; and provides Digital Readiness as a contingency that helps explain the inconsistent sustainability outcomes of similar investments in GenAI across institutions. The proposed model has not yet been empirically tested and is suggested to be used for guiding future research using survey-based research or mixed methods design in the Pakistani context of higher education system and similar contexts of emerging economies.

Keywords: *Generative AI Capability; Green Innovation; Circular Economy Performance; ESG Performance; Digital Readiness; Pakistani Higher Education; Sequential Mediation; Dynamic Capabilities*

ZERO WASTE MANAGEMENT AT BINGÖL UNIVERSITY CAMPUS CHARACTERIZATION OF RECYCLABLE WASTE AND ASSESSMENT OF RECOVERY POTENTIAL

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Abstract: Effective waste management on university campuses is important for returning recoverable resources to the economy and for supporting sustainable campus goals. This study aimed to determine the quantity and composition of paper-cardboard, plastic, glass, and metal waste generated at the Vocational School of Health Services of Bingöl University and, based on the data obtained, to estimate the recyclable waste potential of the main campus. Recyclable waste was monitored and weighed weekly over nine months during the 2025-2026 academic term. The recyclable waste generation rate, normalized to the number of students, was determined to be 235 g person⁻¹.day⁻¹ on average. In the waste characterization, paper-cardboard had the highest share at 43%, followed by plastic (37%), glass (16%), and metal (4%). Paper-cardboard and plastic together accounted for 80% of the total recyclable waste. Based on the measured per-capita value, the recyclable waste potential was estimated at approximately 91 tonnes for the Vocational School of Health Services and approximately 647 tonnes per academic term for the Bingöl University main campus. The findings indicate that paper-cardboard and plastic waste in particular should be prioritized in the planning of collection, temporary storage, and recovery. Regular monitoring, correct separation at source, and direct measurements across the whole campus are important for improving the performance of the zero waste management system.

Keywords: Zero waste, waste characterization, recycling, recovery potential, sustainable campus, source separation

DIGITAL FINANCIAL LITERACY, FRAUD PREVENTION AWARENESS AND FRAUD DETECTION: A CONCEPTUAL FRAMEWORK FOR RURAL WOMEN OF PAKISTAN

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Abstract: The development of digital banking has created opportunities for financial inclusion while simultaneously exposing more people to digital financial fraud. Vulnerable, financially illiterate individuals may be at higher risk due to their lack of knowledge and access to relevant financial information. Rural women may be at greater risk due to a lack of digital financial literacy, limited financial education, and insufficient knowledge of fraud techniques. The conceptual paper focuses on the importance of digital financial literacy in fostering fraud-prevention awareness. Based on Protection Motivation Theory, this study develops a theoretical framework describing how digital financial literacy increases awareness of the risks associated with digital fraud and prompts protective actions through enhanced understanding, threat perception, and coping strategies. The theoretical framework views fraud awareness as an important tool through which digital financial literacy leads to fraud detection and protection for rural women engaged in digital banking. The contribution of the study is to develop a model of digital financial literacy and fraud prevention grounded in protection motivation theory and to recognize the need to examine the rural women segment in the digital financial security literature, which has been under-examined in prior research. The proposed framework has important implications for the design of financial literacy, cybersecurity education, and fraud-prevention initiatives for financially vulnerable users of digital banking services. Further research may focus on validating the relationships in the proposed framework empirically, through longitudinal studies, comparisons, and interventions.

DETERMINANTS OF HOUSEHOLD WASTE VALORIZATION BEHAVIOR IN AZERBAIJAN: AN INTEGRATED MODEL

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Abstract: As waste generation continues to increase alongside urbanization and changing consumption patterns, promoting household recycling has become a critical component of sustainable waste management and the development of a circular economy. Therefore, understanding the behavioral and contextual factors motivating households to extract value from waste is an important research priority. The aim of this study is to examine the influence of environmental awareness, waste sorting capabilities, and accessibility of recycling infrastructure on household waste valorization behavior, as well as to explore the mediating role of economic incentives. Using survey data collected from 375 households across Azerbaijan, structural equation modeling was applied to test the proposed research model. The results show that waste sorting capabilities and accessibility of recycling infrastructure have a positive and significant impact on household waste valorization behavior, while environmental awareness does not have a significant positive impact. The results also demonstrate that economic incentives partially mediate the relationship between waste sorting capability and household waste valorization behavior, suggesting that financial incentives facilitate the conversion of waste sorting capability into actual recycling practices. This study contributes to the literature on household waste management and the circular economy by demonstrating that practical opportunities, supporting infrastructure, and incentive mechanisms play a more important role than mere environmental awareness in promoting household waste recycling. These findings have important implications for policymakers, highlighting the need for a combination of behavioral strategies, accessible recycling infrastructure, and well-designed economic incentive schemes to increase household participation in sustainable waste management throughout Azerbaijan.

Keywords: *Environmental awareness; Waste sorting capability; Recycling infrastructure accessibility; Economic incentives; Circular economy.*