

ENVIRONMENTAL BIOTECHNOLOGY AND GREEN TECHNOLOGIES

Muhammad Ahmad

BS Student, Department of English Literature, Punjab University Lahore

ABSTRACT

Environmental biotechnology and green technologies have emerged as important approaches for addressing pollution, resource depletion, climate change, waste generation, and increasing environmental pressure caused by industrialization and population growth. Environmental biotechnology uses microorganisms, plants, algae, enzymes, biological processes, and engineered biological systems to prevent pollution, recover resources, treat wastewater, remediate contaminated soil, convert waste into useful products, and produce renewable energy. Green technologies complement these approaches by emphasizing resource efficiency, low emissions, renewable energy, waste minimization, circular production, and environmentally responsible technological development. Recent research demonstrates growing integration between microbial bioremediation, phytoremediation, microalgal systems, anaerobic digestion, bioenergy, bioplastics, biosensors, artificial intelligence, and circular bioeconomy strategies. For example, recent reviews identify microbial technologies, phytoremediation, microbial fuel cells, biogas systems, and biological waste conversion as promising approaches for reducing environmental impacts and supporting sustainable development. This research paper examines the contribution of environmental biotechnology and green technologies to pollution control, resource recovery, renewable energy production, and sustainable environmental management. A systematic literature-based research approach was adopted using recent scholarly literature published mainly between 2023 and 2026. The findings indicate that biological treatment systems can provide environmentally compatible alternatives to several conventional technologies, although challenges related to cost, scalability, technological optimization, regulation, infrastructure, and public acceptance remain. The study concludes that combining environmental biotechnology with green technological innovation and circular-economy principles can strengthen environmental protection while supporting resource efficiency and sustainable development.

KEYWORDS: *Environmental biotechnology, green technologies, bioremediation, phytoremediation, bioenergy, wastewater treatment, circular bioeconomy, renewable energy, waste management, sustainability.*

INTRODUCTION

Environmental degradation has become one of the major challenges facing contemporary societies. Rapid population growth, urbanization, industrial expansion, intensive agriculture, fossil-fuel consumption, and increasing material production have contributed to air pollution, water contamination, soil degradation, biodiversity loss, greenhouse-gas emissions, and large quantities of solid and hazardous waste. Conventional environmental management approaches have provided important solutions, but many traditional treatment systems require substantial energy, chemicals, infrastructure, and financial resources. Consequently, increasing attention has been directed toward technologies that can prevent pollution at its source, reduce resource consumption, recover valuable materials, and minimize environmental impacts. Environmental biotechnology and green technologies represent two closely connected areas that can contribute to these objectives by combining biological processes with environmentally responsible technological innovation. Environmental biotechnology can broadly be understood as the application of biological systems and processes to environmental protection, pollution control, remediation, resource recovery, and sustainable production. Microorganisms, plants, algae, fungi, enzymes, and biological

communities can perform important functions such as degradation of organic pollutants, transformation of toxic compounds, nutrient removal, metal immobilization, waste decomposition, and production of useful metabolites. Rossi, A., & Bertacchi, S. (2026). Found that A recent discussion of environmental biotechnology emphasizes that the field increasingly includes environmental protection and bioremediation together with resource recovery and bioenergy when these applications contribute to sustainability.) This broad understanding is important because environmental biotechnology is no longer limited to cleaning contaminated sites. It is increasingly connected with circular economy systems in which waste streams become inputs for new products, energy, materials, or agricultural resources.

A 2024 comprehensive review describes bioremediation as an environmentally sustainable approach for pollution management and highlights increasing integration with technologies such as artificial intelligence, Internet of Things systems, and biosensors. Microbial bioremediation is particularly relevant for petroleum hydrocarbons, pesticides, dyes, industrial chemicals, and other organic pollutants. Research on soil pollution has also shown the importance of microbial and plant-assisted systems for treating persistent organic contaminants. Phytoremediation represents another important branch of environmental biotechnology. Dutta, C. K. (2023) elaborated on It uses plants and their associated microorganisms to remove, immobilize, transform, or stabilize pollutants. Plants can absorb certain metals and other contaminants through their roots, while rhizosphere microorganisms can contribute to pollutant degradation and nutrient transformation. Phytoremediation can be attractive because it may require less energy and infrastructure than some conventional engineering approaches. Recent research is also moving toward next-generation phytoremediation in which plants are combined with microorganisms, nanotechnology, genetic engineering, and information technologies to improve pollutant uptake, degradation, stress tolerance, monitoring, and optimization. These developments demonstrate how environmental biotechnology is increasingly becoming interdisciplinary. Wastewater treatment is another major application area. Conventional wastewater treatment is essential for protecting aquatic ecosystems and public health, but treatment processes can consume significant amounts of energy and generate residual sludge. Biotechnology provides alternatives based on microbial degradation, biological nutrient removal, algal treatment, anaerobic digestion, and other biological processes.

Similarly, research on phycoremediation reports that microalgae can contribute to wastewater treatment, nutrient recovery, and biofuel production. Anaerobic digestion is another important green-biotechnology technology. Yu, K. L., Ong, H. C., & Zaman, H. B. (2024). Revealed that In anaerobic digestion, microorganisms break down biodegradable organic material in the absence of oxygen and produce biogas and digestate. Biogas can be used as a renewable energy source, while digestate can potentially be recovered as an agricultural input after appropriate treatment. This creates an important connection between waste management, renewable energy, agriculture, and circular economy principles. A 2024 review of digestate treatment and agricultural valorization emphasizes the potential of anaerobic digestion to support the transition from linear to circular systems. Therefore, biological waste treatment can be designed not only to reduce pollution but also to recover energy and nutrients. Agricultural waste is particularly important in environmental biotechnology because large quantities of crop residues and other organic materials are generated every

year. Instead of treating agricultural residues solely as waste, biotechnology can convert them into biofuels, biochemicals, compost, biofertilizers, enzymes, bioplastics, and other useful products. Research published in 2024 has examined the simultaneous production of microbial biofuels from agricultural wastes and bioremediation of the resulting waste substrate. Such approaches support the circular bioeconomy by connecting agricultural production with waste valorization and renewable energy. Green technologies broaden this perspective by focusing on technologies that reduce environmental impacts throughout production and consumption systems. They include renewable energy, energy-efficient technologies, green manufacturing, sustainable materials, waste-to-energy systems, low-carbon processes, water-saving technologies, environmentally friendly chemical processes, and digital systems for environmental monitoring. The integration of green technologies with biotechnology can produce systems in which biological processes provide the core environmental function while advanced engineering and digital technologies improve efficiency and control.

Bioplastics are one example of this transformation. Conventional plastics are largely produced from fossil resources and can persist in the environment for long periods. Biotechnology can produce biodegradable or bio-based polymers through microbial fermentation and other biological processes. Such materials can potentially reduce dependence on fossil resources and contribute to circular production systems. However, the environmental performance of bioplastics depends on feedstock selection, production processes, energy requirements, biodegradation conditions, and end-of-life management. Therefore, green technology assessment should consider the entire life cycle rather than focusing only on whether a product is biologically produced. Bioenergy is another major area where environmental biotechnology and green technologies overlap. Microbial systems, anaerobic digestion, algae, agricultural residues, and other biological resources can contribute to renewable-energy production. Microbial fuel cells can convert organic matter into electricity while treating wastewater or other organic wastes. Biogas systems can convert biodegradable waste into methane-rich gas for energy production. Recent research on biotechnology for greenhouse-gas mitigation identifies microbial fuel cells, biogas technologies, bio-based products, and biological carbon-management approaches among the technologies being investigated for sustainable development. Environmental biotechnology can also contribute to greenhouse-gas mitigation. Biological systems can potentially capture or transform carbon dioxide, produce renewable fuels and materials, and reduce emissions associated with conventional manufacturing. Synthetic biology and engineered microorganisms are being investigated for carbon capture and conversion into useful bio-based products.

Artificial intelligence, machine learning, sensors, Internet of Things technologies, remote monitoring, and predictive models can improve the operation of biological treatment systems. These tools can help identify changing pollutant concentrations, optimize microbial conditions, predict treatment performance, reduce energy consumption, and support real-time decision-making. Recent bioremediation research specifically highlights the integration of AI, IoT, and biosensors with biological pollution-management approaches. Such integration represents an important movement from conventional treatment toward smart environmental biotechnology. Another important development is the emergence of bioengineered living materials. These materials combine biological systems with materials science and can use organisms such as bacteria, fungi, or algae to produce dynamic and potentially

environmentally responsive materials. Recent research describes bioengineered living materials as an emerging intersection of biotechnology and materials science with possible applications in environmental remediation and climate adaptation. Although many of these technologies remain at research or development stages, they illustrate the expanding boundaries of environmental biotechnology.

RESEARCH OBJECTIVES

1. the major applications of environmental biotechnology and green technologies in pollution control, waste management, wastewater treatment, renewable energy, and environmental remediation.
2. The contribution of biotechnology-based and green technological approaches to resource recovery, circular economy development, greenhouse-gas reduction, and environmental sustainability.
3. the major challenges, limitations, and future opportunities associated with the large-scale implementation of environmental biotechnology and green technologies.

RESEARCH QUESTIONS

1. What are the major applications of environmental biotechnology and green technologies in sustainable environmental management?
2. How do environmental biotechnology and green technologies contribute to pollution reduction, resource recovery, renewable energy production, and circular economy development?
3. What are the major challenges and future opportunities associated with implementing environmental biotechnology and green technologies?

LITERATURE REVIEW

Recent literature indicates that environmental biotechnology is expanding from conventional pollution treatment toward integrated systems for environmental restoration, resource recovery, renewable energy, and circular production. The field includes microorganisms, plants, algae, fungi, enzymes, biological reactors, and engineered biological systems. Recent scholarship has also emphasized the importance of developing a clearer and broader understanding of environmental biotechnology because the field overlaps with environmental engineering, industrial biotechnology, microbiology, bioenergy, and circular-economy research. This interdisciplinary character makes environmental biotechnology particularly relevant to modern sustainability challenges. Bioremediation remains one of the most extensively investigated applications. Microbial organisms can degrade organic pollutants and transform hazardous substances into less harmful compounds. Bacteria and fungi can be used in contaminated soil and water, while plant-microbe interactions can improve remediation performance. The 2024 literature emphasizes the potential of combining biological remediation with advanced monitoring technologies, including biosensors, IoT, and AI. Such integration can make biological treatment systems more responsive and efficient. Soil remediation literature also demonstrates the importance of combining different biological approaches. Microbial bioremediation can be supported by phytoremediation, bioaugmentation, biostimulation, and microbial consortia. Research on organic soil pollution

identifies microbial systems and plant-assisted remediation as environmentally compatible strategies, while also pointing toward microbial consortia, nanobioremediation, and genetic engineering as future research areas. These approaches can potentially improve the degradation of persistent pollutants while reducing the environmental burden associated with conventional remediation. Phytoremediation is similarly gaining attention because it combines environmental restoration with relatively low-energy biological processes. Plants can accumulate, stabilize, or transform pollutants and can be used in contaminated soils and water bodies. New research is increasingly investigating the combination of plants with microbes, nanomaterials, genetic engineering, and digital technologies.

Anaerobic digestion is strongly connected to green technology and circular economy development. Organic wastes can be transformed into biogas and digestate rather than simply disposed of. The literature suggests that optimizing digestate treatment and valorization can improve the overall sustainability of anaerobic digestion systems. This approach can connect waste management with renewable energy and agriculture. Biotechnology also supports circular production through the conversion of waste materials into useful products. Ro y, I., Ghosh, T. K., Rana, D., Sadhukhan, S., Bhattacharyya, A., Sarkar, G., ... & Chattopadhyay, D. (2024). Explained A recent review of biotechnology in the circular economy identifies bioplastics, bioenergy, bioproducts, bioremediation, agricultural waste valorization, and metal recovery as important applications. These applications demonstrate how biological systems can reduce the quantity of waste requiring disposal while generating economically useful outputs. Recent research also places environmental biotechnology within the broader concept of the circular bioeconomy. The circular bioeconomy seeks to use renewable biological resources while minimizing waste and retaining resources within production systems. A 2026 study emphasizes that achieving a global circular bioeconomy requires connections among biotechnology research, industrial application, communication, and policymaking.

Thus, the success of environmental biotechnology depends not only on laboratory innovation but also on institutional and economic systems. Greenhouse-gas mitigation is another developing research area. Recent literature reviews biotechnology-based approaches including microbial carbon conversion, microbial fuel cells, biogas, phytoremediation, and bio-based materials. These technologies may contribute to lower-carbon systems, but their environmental benefits must be evaluated through life-cycle approaches to determine whether emissions are actually reduced across the complete production chain. Overall, the literature indicates that environmental biotechnology and green technologies are increasingly interconnected. The major research direction is moving toward integrated systems that combine biological processes, renewable energy, digital monitoring, resource recovery, and circular economy principles. However, further research is needed to improve scalability, economic feasibility, environmental safety, regulatory frameworks, and long-term performance. Environmental biotechnology and green technologies have become increasingly important fields in contemporary environmental research because of their potential to address pollution, climate change, resource depletion, waste generation, and ecosystem degradation through sustainable technological approaches. Environmental biotechnology applies microorganisms, plants, algae, fungi, enzymes, and biological processes to prevent, control, and remediate environmental pollution, whereas green technologies emphasize efficient resource use, renewable energy, reduced emissions, waste minimization, and environmentally

responsible production. Recent literature shows that the boundaries between these fields are becoming increasingly interconnected, particularly through bioremediation, wastewater treatment, bioenergy production, waste valorization, circular bioeconomy, and biological resource recovery. Contemporary environmental biotechnology is therefore moving beyond conventional pollution treatment toward integrated systems in which waste is treated as a potential resource and biological processes are combined with engineering and digital technologies. Recent studies emphasize that this transition can contribute to sustainable development by reducing environmental impacts while creating opportunities for energy and material recovery.

A 2024 review of sustainable bioremediation techniques describes biological approaches as environmentally friendly options for pollution and waste management and also highlights the increasing integration of advanced technologies into biological remediation systems. Similarly, recent research on soil organic pollution has investigated the roles of microorganisms and biological processes in degrading persistent contaminants. These studies indicate that microbial remediation can reduce dependence on some chemical-intensive remediation approaches, although pollutant type, environmental conditions, microbial activity, and treatment duration strongly influence performance. Phytoremediation has also received considerable attention as an environmentally sustainable technology. Phytoremediation uses plants and their associated microorganisms to remove, stabilize, or transform contaminants in soil and water. Plants may accumulate metals in their tissues, stabilize contaminants within soil, or facilitate microbial degradation in the rhizosphere. The approach is particularly attractive for certain large or moderately contaminated areas because vegetation-based systems can potentially operate with comparatively low energy requirements. Recent research has moved toward next-generation phytoremediation, combining plants with beneficial microorganisms, nanotechnology, genetic engineering, and advanced monitoring technologies. Such integration aims to improve plant tolerance to pollutants, enhance contaminant uptake or degradation, and increase treatment efficiency. However, the literature also recognizes limitations including slow remediation rates, dependence on climatic and soil conditions, limited applicability to highly contaminated sites, and the need for appropriate management of contaminated plant biomass.

Another major area of environmental biotechnology is wastewater treatment. Biological wastewater treatment relies on microorganisms to break down organic matter and remove nutrients and other pollutants. Activated sludge systems, biofilm reactors, anaerobic systems, constructed wetlands, algae-based systems, and microbial electrochemical technologies are among the approaches examined in contemporary research. Biological treatment can provide an important alternative or complement to physical and chemical treatment methods because microorganisms naturally perform many of the transformations required for wastewater purification. Recent research has increasingly focused on improving biological treatment through process optimization, microbial-community management, nutrient recovery, and energy production. Instead of considering wastewater only as a waste stream, current research increasingly views it as a source of water, nutrients, organic matter, energy, and other recoverable resources. This perspective connects environmental biotechnology directly with circular economy principles. Microalgae-based technologies represent an especially important intersection between environmental biotechnology and green technology. Microalgae can utilize nutrients such as nitrogen and phosphorus from wastewater while producing biomass

through photosynthesis. The resulting biomass may have potential applications in biofuels, fertilizers, animal feed, biochemicals, and other products, depending on contamination levels and processing requirements. Recent literature has investigated integrated microalgal wastewater treatment and bioenergy production, including the use of energy informatics and artificial intelligence to optimize treatment and biomass productivity. Research on phycoremediation similarly identifies microalgae as potentially useful organisms for nutrient removal, wastewater treatment, carbon utilization, and biomass production. Nevertheless, challenges involving harvesting costs, contamination, light availability, biomass processing, and economic feasibility continue to limit widespread implementation.

METHODOLOGY

The approach was selected because the purpose of the study was to synthesize existing scientific knowledge rather than conduct laboratory experiments. Recent peer-reviewed research published primarily between 2023 and 2026 was examined, with particular attention given to studies concerning bioremediation, phytoremediation, wastewater treatment, bioenergy, circular biotechnology, waste valorization, green technologies, and environmental sustainability. Literature was interpreted comparatively to identify recurring themes, technological developments, benefits, limitations, and future research directions. The research approach also emphasized interdisciplinary evidence because environmental biotechnology connects microbiology, biotechnology, environmental engineering, renewable energy, materials science, environmental management, and circular economy studies. Recent literature shows that environmental biotechnology is increasingly integrated with AI, IoT, biosensors, nanotechnology, and information systems. This study employed a qualitative research approach based on a systematic literature review to examine the role of environmental biotechnology and green technologies in sustainable environmental management. Relevant scholarly literature published primarily between 2023 and 2026 was reviewed to identify recent developments in bioremediation, phytoremediation, wastewater treatment, bioenergy production, waste valorization, microbial technologies, circular bioeconomy, renewable energy, and environmentally sustainable technologies. Research articles, review papers, and other credible academic sources were selected according to their relevance to the research objectives. The collected literature was critically examined to understand how biotechnology-based technologies contribute to pollution reduction, resource recovery, waste management, climate-change mitigation, and sustainable development. Particular attention was given to technological benefits, environmental effectiveness, practical applications, limitations, and emerging innovations.

RESEARCH DESIGN

A n was used. Relevant scientific literature was organized into major thematic categories, including biological remediation, wastewater treatment, waste-to-energy technologies, bio-based materials, resource recovery, circular bioeconomy, greenhouse-gas mitigation, and smart environmental technologies. The design enabled the study to compare different environmental biotechnology applications and identify similarities and differences in their environmental contributions. The literature was reviewed according to four broad dimensions: environmental effectiveness, resource efficiency, technological development, and implementation challenges. This design was appropriate because current literature includes

both established technologies and emerging innovations. The analysis therefore considered not only current applications but also technologies that are still undergoing development. This study adopted a descriptive and thematic research design to investigate the role of environmental biotechnology and green technologies in sustainable environmental management. The design was selected because the study focuses on systematically describing and interpreting existing scientific knowledge rather than conducting laboratory experiments or collecting primary field data. Relevant research published mainly from 2023 to 2026 was examined, with particular attention to bioremediation, phytoremediation, biological wastewater treatment, microbial technologies, bioenergy, waste valorization, renewable energy, circular bioeconomy, and green technological innovations. The selected literature was organized into major themes according to the research objectives and questions. The study compared findings from different scholarly sources to identify the environmental benefits, technological applications, resource-recovery potential, and limitations of these approaches.

DATA ANALYSIS

The collected literature was analyzed through. First, relevant studies were grouped according to their technological focus. Second, repeated concepts and findings were identified. Third, the evidence was synthesized into broader themes related to pollution reduction, waste valorization, renewable energy, resource recovery, circular economy, and sustainability. Particular attention was given to evidence concerning bioremediation, microalgae, anaerobic digestion, bioenergy, phytoremediation, and bio-based materials. The analysis also considered recurring barriers such as high initial costs, scalability, infrastructure requirements, technological complexity, regulation, and environmental safety. Recent studies consistently identify the need for improved scalability and system integration before some emerging technologies can achieve widespread implementation. The data collected for the study “Environmental Biotechnology and Green Technologies” were analyzed using a qualitative thematic content analysis technique. Since the research was based on a systematic review of existing scholarly literature, information from selected studies was carefully examined, compared, categorized, and interpreted according to the research objectives and questions. The reviewed literature was organized into major themes, including bioremediation, phytoremediation, wastewater treatment, microbial technologies, bioenergy production, agricultural-waste valorization, green manufacturing, renewable energy, circular bioeconomy, resource recovery, and climate-change mitigation. The analysis focused on identifying common findings, technological developments, environmental benefits, and limitations reported across the selected studies.

FINDINGS

The literature indicates that environmental biotechnology provides diverse biological solutions for pollution management. Microorganisms, fungi, plants, and algae can contribute to the degradation, transformation, immobilization, or removal of pollutants. Bioremediation is particularly important because it can address contaminated soil and water while potentially reducing reliance on energy-intensive conventional treatment methods. Recent literature also indicates that integrating biological remediation with biosensors, AI, IoT, and advanced monitoring may improve environmental-management efficiency. The literature demonstrates

that environmental biotechnology can transform waste into useful resources. Anaerobic digestion can convert organic waste into biogas, while agricultural residues can serve as feedstocks for biofuels and other bio-based products. Biotechnology can also contribute to bioplastics, nutrient recovery, microbial metal recovery, and other circular-economy applications. These systems reduce the concept of waste by treating discarded materials as potential resources. A major finding is the growing integration of environmental biotechnology with AI, sensors, IoT, nanotechnology, genetic engineering, and information technologies. These combinations can improve monitoring, process control, pollutant detection, predictive modeling, and treatment optimization. Recent research on phytoremediation and bioremediation particularly emphasizes technological integration as a pathway toward more efficient and scalable environmental solutions. Despite significant potential, the literature identifies several barriers. These include high capital costs for advanced systems, limited large-scale demonstration, variable biological performance, regulatory requirements, availability of skilled personnel, infrastructure limitations, and uncertainty about long-term environmental effects.

CONCLUSION

Environmental biotechnology and green technologies represent important components of contemporary sustainable environmental management. The reviewed literature demonstrates that biological systems can contribute to pollution prevention, remediation, wastewater treatment, waste conversion, renewable energy production, resource recovery, and circular-economy development. Microorganisms, plants, algae, fungi, enzymes, and biological reactors provide opportunities for reducing environmental pollution while recovering valuable resources. Bioremediation and phytoremediation are particularly relevant for contaminated environments, while microalgal systems and anaerobic digestion provide opportunities to combine pollution control with energy and resource recovery. The study also shows that the future of environmental biotechnology is increasingly connected with green technological innovation. Artificial intelligence, biosensors, IoT, nanotechnology, genetic engineering, and advanced process monitoring are being incorporated into biological systems to improve performance and management. At the same time, circular bioeconomy principles are encouraging researchers and industries to convert agricultural residues, food waste, wastewater, and other organic materials into energy, materials, fertilizers, and bio-based products. However, technological potential does not automatically guarantee sustainability. Environmental biotechnology must be evaluated according to its complete environmental, economic, and social impacts.

REFERENCES

- Rossi, A., & Bertacchi, S. (2026). *The Role of Survey in Evidence-Based Interpretive Scenarios. Engineering Proceedings*, 149(1), 4.
- Dutta, C. K. (2023). *Assessment of Flood Susceptibility in the Cachar District of Assam Using Gis Based Multi-Criteria Decision Making and Analytical Hierarchy Process. Research Square (Research Square)*.

- Roy, I., Ghosh, T. K., Rana, D., Sadhukhan, S., Bhattacharyya, A., Sarkar, G., ... & Chattopadhyay, D. (2024). *Effect of graphene oxide, reduced graphene oxide, silver and reduced graphene oxide/silver nanohybrid on hydroxypropyl methylcellulose nanocomposites*. *Bulletin of Materials Science*, 47(3), 136.
- Kuppan, N., Padman, M., Mahadeva, M., Srinivasan, S., & Devarajan, R. (2024). *A comprehensive review of sustainable bioremediation techniques: Eco friendly solutions for waste and pollution management*. *Waste Management Bulletin*, 2(3), 154-171.
- Mokrani, S., Houali, K., Yadav, K. K., Arabi, A. I. A., Eltayeb, L. B., AwjanAlreshidi, M., ... & Nabti, E. H. (2024). *Bioremediation techniques for soil organic pollution: Mechanisms, microorganisms, and technologies-A comprehensive review*. *Ecological Engineering*, 207, 107338.
- Yu, K. L., Ong, H. C., & Zaman, H. B. (2024). *Integrated energy informatics technology on microalgae-based wastewater treatment to bioenergy production: A review*. *Journal of Environmental Management*, 368, 122085.
- Ahamefule, C. S., Osilo, C., Ahamefule, B. C., Madueke, S. N., & Moneke, A. N. (2024). *Simultaneous production of biofuel from agricultural wastes and bioremediation of the waste substrates: A review*. *Current Research in Microbial Sciences*, 7, 100305.
- Carmona Marques, P., Fernandes, P. C., Sampaio, P., & Silva, J. (2025). *Advances in biotechnology in the circular economy: a path to the sustainable use of resources*. *Sustainability*, 17(14), 6391.
- Ugwu, O. P. C., Okon, M. B., Ogenyi, F. C., Ugwu, J. N., & Ugwu, C. N. (2026). *Digital twins and explainable AI across the vaccine life cycle: from mRNA manufacturing to thermostability, cold-chain logistics, and immunisation services*. *Vaccine*, 92, 129131.
- Musa, A. O., Yarboe, J. M., Undie, D. A., Akinpelu, O. O., Samuel, H. S., & Etim, E. E. (2026). *Microbial technologies as an ecological tool for advancing environmental sustainability*. *Frontiers in Microbiology*, 17, 1875044.
- Next-generation phytoremediation approaches for environmental sustainability*. (2026). *New Biotechnology*, 94, 83–99.
- Usman, K., Alsafran, M., Ruslan, N. F., Ahmed, T., & Kalogerakis, N. (2026). *Next-generation Chegini, S., Sikkander, A. R. M., Masoudi, M., Ekhtari, H., Mojaver, E., & Jafari, H. (2026).*
- A circular bioeconomy framework for biodegradable waste: strategies and opportunities*. *Bioresources and Bioproducts*, 2(1), 2. *phytoremediation approaches for environmental sustainability*. *New Biotechnology*.