DOI: http://doi.org/10.21698/simi.2025.ab49

BIO-BASED INNOVATION AND CIRCULAR BIOECONOMY SOLUTIONS DRIVING GREEN TRANSFORMATION TOWARDS CLIMATE-RESILIENT SOCIETIES

Alina Butu[1,2,3], Steliana Rodino[1,4], Audrone Ispyrian[3], Marian Butu[1,4]

[1]National Institute of Research and Development for Biological Sciences, 296 Splaiul Independentei, district 6, Bucharest, alina_butu@yahoo.com, Romania
[2]National University of Science and Technology Politehnica of Bucharest, 313 Splaiul Independentei, district 6, Bucharest, Romania
[3]Vytautas Magnus University, Studentų str. 11, LT- 5336, Kaunas, Lithuania
[4]Research Institute for Agricultural Economics and Rural Development, Marasti 61, Bucharest Romania

Keywords: *ecosystem regeneration, environmental monitoring, pollution management, renewable resources, societal transformation*

Introduction

Addressing pollution, climate change, and resource scarcity requires systemic approaches that move beyond incremental improvements. Bio-based solutions, grounded in circular economy principles, provide effective pathways for green transformation by restoring ecosystems, lowering fossil dependence, and supporting prosperity within planetary boundaries.

Worldwide, material extraction now exceeds 92 billion tonnes annually, while only 7–9% of resources are reintegrated into productive cycles. Within the European Union, more than 2.2 billion tonnes of waste are generated each year, with nearly half ending up in landfills or incineration. These figures underline the urgency of rethinking production and consumption systems. Anchoring solutions in renewable resources and circular principles is therefore essential for reducing environmental pressures and building climate-resilient societies. Such a transformation also requires a shift in cultural and economic paradigms, where innovation is not treated as an isolated technological fix but as part of a holistic redefinition of how societies produce, use, and value natural resources.

Materials and methods

The analysis builds on insights from European initiatives, case studies, and applications of renewable resource valorisation. The framework identifies innovative feedstocks for pollution prevention, applies circular strategies that transform residues into valuable products, and evaluates digital and bio-based monitoring tools to ensure transparency and decision support. A multi-criteria sustainability assessment integrates ecological, economic, and societal indicators, providing an integrated view of impacts and trade-offs. This approach remains relevant from laboratory to policy levels and demonstrates both technological efficiency and systemic contributions to sustainability transitions.

Results and conclusions

The findings confirm that the bioeconomy is not limited to technological advances but represents a comprehensive societal transformation. Positioned at the core of the European Green Deal and the forthcoming Bioeconomy Strategy, it connects innovation directly with climate neutrality, biodiversity restoration, and sustainable food and energy systems.

Evidence demonstrates that renewable and bio-based solutions deliver both immediate and systemic benefits. Bioremediation techniques can reduce heavy metal concentrations in soils by 40 - 70%, biodegradable packaging lowers plastic pollution with 30 - 60% fewer lifecycle emissions, and microbial biofertilisers replace up to 25% of synthetic fertilisers while improving soil health. Waste valorisation further strengthens circularity by converting agricultural and forestry residues into biogas, bio-based chemicals, and advanced materials. Europe produces over 900 million tonnes of agricultural residues annually, representing a largely untapped feedstock for such innovations.

Innovations in monitoring technologies enhance governance. Biosensors and digital platforms provide real-time data with up to 90% faster detection than conventional methods, enabling transparent reporting and citizen participation. Coupled with adaptive policies, these tools transform monitoring from a compliance mechanism into an enabler of sustainability.

Beyond the technological dimension, the circular bioeconomy generates systemic societal value. It restores degraded ecosystems, fosters biodiversity, and creates green jobs. According to recent estimates, the EU bioeconomy sustains over 17 million jobs and contributes up to €750 billion annually to the economy. By diversifying supply chains and reducing fossil dependence, it enhances resilience against climate and geopolitical challenges. Educational initiatives and citizen science further embed sustainability values, turning circularity into a cultural norm.

The transition depends on collaborative innovation ecosystems. Universities generate knowledge, companies scale applications, policymakers ensure coherent frameworks, and citizens engage in co-creation. Living labs and open innovation platforms provide spaces to accelerate adoption and replication across regions.

Clear policy alignment and targeted financing are essential for scaling solutions from pilots to industrial deployment. Harmonised standards, sustainability-oriented procurement, and international cooperation further reinforce Europe's global leadership in sustainable innovation.

In conclusion, bio-based innovation and circular solutions are not complementary options but essential foundations for Europe's transformation. Anchoring them at the core of sustainability agendas delivers measurable pollution control, climate resilience, and societal prosperity, positioning Europe as a frontrunner in shaping a fair, inclusive, and future-oriented model of development.

Acknowledgements

This work was supported by the Program NUCLEU 7N/2023 within the framework of the National Research Development and Innovation Plan 2022-2027, as well as by the Horizon Europe projects BOOST4BIOEAST and BEAMING.