

Editorial

Advancing Healthy and Sustainable Environmental Stewardship: Reimagining Strategies for Air, Water, Food, and Waste Management

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Given the pervasive impacts of global climate change and environmental degradation, there is an urgent need to develop innovative approaches to establish a trajectory towards a healthy and sustainable environment. The worldwide response to the COVID-19 pandemic has revealed significant vulnerabilities in critical environmental resource management [1]. While the significance of air, water, food, and waste management has long been recognized, the pandemic has underscored the fragility of the systems supporting these resources. Air pollution, contaminated water sources, food insecurity, and unsustainable waste management practices collectively contribute to a broader crisis in public health and environmental sustainability. In response to global challenges, nations and communities have acknowledged the need for innovative and comprehensive crisis resolution and reconstruction approaches.

The Earth is at a critical juncture with formidable challenges related to clean air, pure water, sustainable food systems, and efficient waste management [2–4]. In this context, it is imperative to adopt forward-looking solutions to address these issues and to facilitate a harmonious relationship with the environment. Consequently, the Special Issue entitled ‘Innovative Approaches towards Healthy and Sustainable Environment: Air, Water, Food, and Waste Treatment’ has been established. The Special Issue solicited papers exploring emerging innovative air, water, food, and waste management approaches. The aim was to elucidate how recent technological advancements, policy shifts, and community-driven solutions could be leveraged to create more sustainable and healthier environments. These approaches are particularly crucial in light of the ongoing environmental degradation and the increasing threats of climate change, population growth, and urbanization.

This Special Issue was initially structured into four sections, each addressing one of the key elements of environmental sustainability: air quality, water management, food security, and waste management. The papers accepted for each element aimed to discuss the challenges, innovative solutions being implemented, and potential of the solutions to contribute to long-term environmental sustainability.

Air pollution is a significant concern because it adversely affects human health and the environment. These issues are now being addressed through innovative technologies such as artificial intelligence (AI) and Internet of Things (IoT) applications, which have emerged as transformative solutions [5]. Smart sensors facilitate real-time air quality monitoring and provide critical information for the timely intervention of urban authorities. Recent initiatives, including urban greening strategies for vertical gardens and green roofs, have also demonstrated efficacy in enhancing air quality while promoting biodiversity [6]. These



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methods reduce pollutants and contribute to healthier urban environments conducive to community well-being.

Water contamination and scarcity pose significant risks to millions of people worldwide [7]. Advanced filtration systems utilizing nanotechnology are being developed to treat wastewater for potential reuse, thereby maximizing the utilization of available water resources. Rainwater harvesting systems and modular water treatment plants represent scalable solutions, particularly for underserved communities [8]. Traditional conservation practices, such as watershed restoration, complement technological advancements by providing sustainable approaches to ensure universal access to clean water.

The current food production systems exhibit unsustainable characteristics. With the intensive and potentially harmful pesticides in monocultures and land overexploitation, every aspect of the food chain requires urgent revision. This necessitates the implementation of landscape-scale criteria for soil health, crop diversification, and ethical animal husbandry. Agroecological methods such as permaculture and agroforestry enable farmers to enhance biodiversity, sequester carbon, and mitigate the effects of erratic weather patterns associated with climate change [9]. Emerging trends in urban agriculture and vertical farming are gaining prominence, facilitating localized food production, reducing transportation emissions, and providing fresh produce for urban populations [10].

Novel waste treatment methodologies are imperative as waste generation rates increase. The circular economy concept has garnered significant attention because it aims to reduce waste generation and maximize resource recovery through product and process redesign [11]. Anaerobic digestion and composting technologies enable the conversion of organic waste into valuable resources including energy- and nutrient-rich soil amendments. Furthermore, advancements in recycling technologies have facilitated the production of high-quality output from mixed materials. These approaches contribute to reducing the burden on landfills and promoting responsible consumption behaviors among consumers.

The submission deadline for the Special Issue was 30 June 2024. More than twenty manuscripts were submitted for publication as of this date. Among these submissions, 15 papers successfully passed the peer-review evaluation process and were published. An alphabetically ordered list of these accepted contributions is provided in the List of Contributions.

Although approaches to revolutionizing air quality were one of the primary topics of the Special Issue, the number of potential contributions in this field was significantly lower compared to other themes. This indicates that substantial progress must be made in studying air quality for environmental sustainability. Given increasing concerns over climate change, urbanization, and pollution, air quality affects the health of ecosystems and human populations [12]. Poor air quality contributes to environmental and public health issues, including respiratory diseases, cardiovascular conditions, and the deterioration of biodiversity [13].

Consequently, advancing the knowledge of air quality and exploring innovative solutions is important. In this regard, most potential submissions were insufficient to demonstrate the connection between current advanced technologies and their applicability for enhancing environmental sustainability. This gap highlights the need for more focused high-quality research that bridges technological advancements with practical solutions for improving air quality. It also underscores the importance of interdisciplinary collaboration in integrating engineering, environmental science, and policymaking efforts that directly impact sustainability practices.

Among the accepted papers, Contributions 2, 6, and 11 pertain to the 'Clean Water Supplies' theme. Contributions 5, 10, and 14 address topics related to the 'Rethinking Food Systems' theme. The 'Innovating Waste Treatment' section encompassed the largest contri-

butions, including Contributions 1, 3, 4, 7, 8, 9, and 13. The remaining contributions, 12 and 15, were classified under the ‘Water–Energy–Food–Ecosystem (WEFE) Nexus’ approach. Figure 1 illustrates the distribution of contributions across themes.

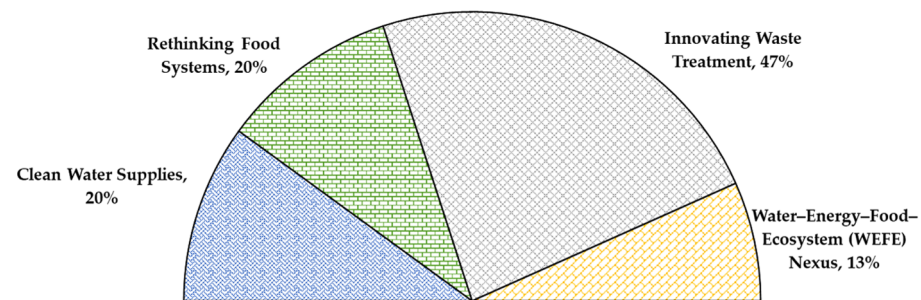


Figure 1. Distribution of contributions across themes in this Special Issue.

Pollution is recognized as one of the most significant environmental and public health threats worldwide. Contribution 2 highlights the growing concern over polluted habitats and the limitations of conventional treatment methods, which are often expensive and energy-intensive. This study proposes a bioremediation method that uses algae and bacteria. Focusing on the hydrocarbon- and heavy-metal-contaminated water of Al Asfar Lake in Saudi Arabia, Contribution 2 demonstrates that certain microalgal species, such as *Chlorella* sp. and *Geitlerianema* sp., exhibit the potential to remove harmful pollutants. This bioremediation method is effective, environmentally sustainable, and cost-efficient, and offers a potential solution for large-scale environmental pollution.

Access to clean and safe drinking water is critical in many rural areas, particularly in developing countries. Contribution 6 examines water quality in rural Kazakhstan, identifying significant chemical content variations depending on the drinking water source. The study reveals that many rural areas experience water contamination, with some villages reporting high cation and anion levels exceeding permissible limits. Notably, residents’ perceptions of water quality were found to correlate with physical water characteristics such as taste, odor, and salinity. This underscores the importance of bridging the gap between scientific water quality assessments and public perception. Establishing robust communication channels between governing bodies and local populations can improve public health outcomes, engender confidence in water management infrastructure, and facilitate the widespread adoption of sustainable water utilization practices.

Discharging bilges and wastewater from ships to the sea is a significant environmental and public health concern. Contribution 11 investigates the carcinogenic and non-carcinogenic risks to human health associated with heavy metals in shipborne wastewater. Using data from Antalya Bay, this study employs the Monte Carlo simulation method to assess the risks from exposure to heavy metals such as copper, iron, chromium, and mercury. The results indicate that certain heavy metals, particularly nickel (Ni), arsenic (As), and chromium (Cr), pose a substantial carcinogenic risk to both swimmers and ship personnel. These findings underscore the urgency of addressing shipborne wastewater and bilge water contamination to protect human health, especially given that the carcinogenic risks in these discharges exceed the standards set by the World Health Organization (WHO). This study emphasizes the need for more stringent regulations and treatment methods to mitigate the health risks associated with maritime pollution.

Overall, Contributions 2, 6, and 11 highlight the critical role of pollution in environmental and public health issues in different contexts. While Contribution 2 proposes a novel bioremediation approach utilizing algae and bacteria, Contribution 6 draws attention to the complex relationship between water quality indicators and community perceptions,

which is vital for effective water resource management. Contribution 11 addresses the often-overlooked health risks from shipborne wastewater, a source of heavy metal contamination in marine environments. These studies underscore the need for innovative, interdisciplinary approaches to manage environmental pollution, improve water quality, and safeguard public health.

Climate change significantly threatens smallholder farmers' food security and livelihoods in regions such as Ethiopia. Contribution 5 examines how various climate change adaptation practices affect farmers' vulnerability to food insecurity in the Bench Maji Zone of southwest Ethiopia. This study highlights the importance of diverse adaptation strategies including crop management, soil and water conservation, and livelihood diversification. Using a multinomial endogenous treatment effect regression model to address selection bias and endogeneity, this study found that farmers employing multiple adaptation practices were less vulnerable to food insecurity. It recommends supporting farmers in implementing these practices through research, development, and collaboration between farmers, extension services, and researchers. This study emphasizes the crucial role of adaptation strategies in enhancing food security amid climate change.

As climate change intensifies global warming, energy-intensive industries such as cold-storage warehouses must adopt sustainable practices. Contribution 10 examined methods to increase warehouse sustainability by identifying effective practices and technologies through convergent interviews with experts. The resulting practices are organized hierarchically, from essential to best, including optimal refrigeration systems, advanced racking methods, and improved insulation. A key recommendation is to enhance reporting on both successful and unsuccessful implementation to promote wider industry adoption. This study underscores the importance of industry-specific diagnostic tools, such as convergent interviewing, to identify practical strategies for sustainable cold storage in Australia and highlights the need for innovation and communication in the refrigeration industry to mitigate environmental impact.

The global food system faces critical challenges such as increasing food availability, reducing food loss, and addressing food waste. Contribution 14 addressed the complex issues surrounding food consumption, loss, and waste by proposing an ontological framework that combines these three aspects into a cohesive systemic model. This framework offers a comprehensive approach to understanding and managing the intricacies of food systems globally. It accounts for 35,112 potential components related to food consumption, loss, and waste, providing a structured method to analyze and address the problem. The authors argue that the lack of a unified approach to these three factors leads to inefficient management strategies. By utilizing this ontological framework, decision-makers can identify gaps in current systems and develop strategies to bridge them, offering a more holistic solution for managing food systems. This approach provides a novel perspective on food management and can lead to more effective global strategies for addressing food-related challenges.

Overall, Contributions 5, 10, and 14 highlight the multifaceted nature of the environmental and food system challenges in the face of climate change. Contribution 5 demonstrates the importance of combining climate adaptation strategies to enhance smallholder farmers' resilience to food insecurity. Contribution 10 focuses on sustainable practices in the energy-intensive refrigeration industry, highlighting the potential for innovation in cold storage warehouses to reduce environmental impact. Contribution 14 offers a groundbreaking ontological framework for addressing the complex global issues of food consumption, loss, and waste. These studies reflect the growing need for integrated environmental and food management. Addressing climate impacts on agriculture, promoting sustainability in industries such as refrigeration, and holistically managing food systems are all critical for fostering resilience and ensuring long-term sustainability.

Environmental consciousness has prompted a re-evaluation of human waste management, particularly regarding human manure, as a potential resource rather than a liability. Contribution 1 investigates vermicomposting as a sustainable approach for nutrient recovery from human waste. This study examines microbial dynamics by comparing vermicomposting to conventional aerobic composting methods. These findings indicate that vermicomposting is more expeditious owing to the presence of earthworms, although challenges such as ammonia accumulation and earthworm population management persist. The study suggests that while flush toilets remain the most socially acceptable option, integrating vermicomposting into sanitation systems requires overcoming significant obstacles, including public health concerns and user acceptance. This research highlights the potential of vermicomposting to close the loop in human–nature interactions and promote sustainable waste management practices.

Contributions 3, 7, and 8 focus on public knowledge, attitudes, and practices (KAP) regarding sustainability in waste management. Contribution 3 examines public KAP regarding single-use plastic bags in the UAE, emphasizing the importance of understanding local behaviors in promoting sustainable practices. The study revealed that the UAE generally demonstrates a favorable attitude towards sustainability, with a positive correlation between increased knowledge and more sustainable practices. Individuals with higher environmental awareness also tend to engage in more sustainable behaviors. This research suggests that targeted educational interventions and policies, such as those focusing on recycling and reducing plastic bag use, could further enhance public engagement with environmental issues. This study is critical for informing effective policy interventions in plastic waste management.

Contribution 7 evaluates KAP regarding plastic pollution among Malaysians. The study found that overall public knowledge and practices were suboptimal, with younger individuals (18–30 years) demonstrating lower levels of awareness and action than older age groups. This study highlights the need for education and intervention strategies to promote better waste management practices. These interventions may include raising awareness of plastic pollution through formal education, increasing recycling facilities, and encouraging responsible consumer behaviors. These findings suggest that targeted age-specific strategies can effectively reduce plastic pollution in Malaysia.

Contribution 8 investigates KAP regarding waste segregation in the UAE. Their study found that while residents exhibit positive attitudes towards sustainability, waste segregation practices are still lacking, with education and gender showing significant correlations with better practices. This study recommends tailored educational campaigns that address specific sociodemographic factors to improve waste segregation behavior. This research contributes to the growing body of knowledge on how cultural, social, and academic factors influence sustainable waste management practices and suggests a path forward through improved public engagement and policy reforms.

With the increasing demand for indium in electronic devices, there is growing pressure to identify sustainable solutions for recycling this valuable material. Contribution 4 presents a patented technology (circular strategies for indium recovery from ground panels, SCRIPT) for recovering indium from end-of-life LCD panels, demonstrating a recovery efficiency of over 90%. This study focuses on optimizing this process at the bench scale and assessing its environmental and economic sustainability. The findings indicate that the process effectively recovers indium and converts the residual materials into concrete, providing a useful byproduct. This research demonstrates the potential for indium recycling to contribute to a circular economy, reduce mining dependence, and support the sustainability of high-tech industries. This study emphasizes the viability of this recycling technology,

particularly at high indium concentrations, and suggests that such methods can be scaled up for global applications.

The cement industry contributes significantly to global greenhouse gas emissions and has considerable potential for improvement through alternative resources and fuel use [14]. Contribution 9 examines the environmental impact of utilizing alternative resources and waste-based fuels in Korea's cement industry. The study reveals that co-processing with alternative fuels, such as waste-derived energy sources, can reduce emissions by approximately 106.9 kg of CO₂ per ton of cement. Additionally, utilizing alternative materials such as silica stone and limestone helps reduce the overall carbon footprint. This research demonstrates that the cement industry can significantly contribute to climate change mitigation by adopting more sustainable practices, thus offering both environmental and economic benefits such as cost savings and extended landfill lifespans.

Plastic pollution, particularly from polyethylene terephthalate (PET), is a pressing global issue [15]. Contribution 13 explores the challenges and opportunities in recycling PET waste, focusing on global efforts to reduce the environmental impacts of plastic pollution. This investigation examines initiatives such as extended producer responsibility (EPR) systems, plastic prohibitions, and deposit-return schemes to promote PET recycling. Researchers have highlighted India's efforts to implement recycling strategies and advocate for global collaboration among governments, industries, and consumers to increase recycling rates. This study emphasizes that effective PET management and recycling reduces plastic waste and generates economic opportunities through recycled products, thereby contributing to a more circular economy.

Contributions 1, 3, 4, 7, 8, 9, and 13 provide diverse insights into sustainable practices across various sectors, from waste management to resource recovery. Contributions 1 and 4 provide innovative solutions for resource recovery through composting and metal recycling, respectively, emphasizing the significance of circular economy principles in waste management. Contributions 3 and 7 elucidate the critical role of public awareness and education in promoting sustainable behaviors, particularly concerning plastic pollution. Contribution 8 elucidates the intricacies of waste sorting techniques, which are crucial for optimizing recycling mechanisms in metropolitan areas. Contribution 9 indicates the potential for industries such as cement to contribute substantially to emission reductions, while Contribution 13 focuses on the global importance of PET recycling in mitigating plastic waste. Collectively, these studies reinforce the necessity for integrated strategies that combine technological innovation, public engagement, and policy reforms to address the complex environmental challenges faced by contemporary society.

Sustainable agricultural practices require a comprehensive understanding of the complex interactions among energy, water, land, and waste. Contribution 12 presents a detailed analysis of these nexus elements in Cameroon, utilizing input–output modeling and location quotient (LQ) analysis for ten regions from 2009 to 2018. The findings indicate that water usage and waste production are the most significant components of the nexus, with water accounting for 67.88% of agricultural water withdrawal and waste, contributing to 97.81% of the total waste produced. This study identifies the central, littoral, and western regions as key areas for agricultural production and emphasizes the importance of considering regional variations when developing strategies for agricultural sustainability. This study provides valuable insights into how water, waste, and land management can contribute to more sustainable agricultural systems, suggesting that these elements should be integrated into national strategies for food security and sustainable resource utilization.

Nature-based solutions (NBSs) present a promising approach for addressing challenges within the Water–Ecosystem–Food (WEF) nexus, offering environmental, economic, and social benefits. Contribution 15 describes a comprehensive methodology developed

in the European Union-funded 'LEarning and action alliances for NexuS EnvironmentS (LENSES)' project to assess the implementation of NBSs in six pilot areas across five Mediterranean countries. The results demonstrate that NBSs contribute to improved water distribution, enhanced food security, and ecosystem preservation while supporting adaptation to climate change. This study emphasizes the significance of participatory approaches, engaging multiple stakeholders to gain insights into local challenges, and facilitating the operationalization of the WEF nexus. By identifying context-specific vulnerabilities and solutions, this study highlights the potential of NBSs to enhance the resilience and sustainability of agri-food systems in the Mediterranean region. This study provides a valuable framework for future policy development and NBS implementation in similar contexts.

Contributions 12 and 15 underscore the importance of a systems approach to sustainability, emphasizing the need to balance resource use across sectors and to adopt nature-based solutions to enhance environmental resilience. Both studies highlight the value of the local context in identifying effective solutions in terms of agricultural practices or environmental interventions and emphasize integrating these approaches into broader policy frameworks to ensure long-term sustainability and food security. These studies also demonstrate the growing recognition of the Water–Ecosystem–Food nexus as a critical area of focus, particularly in regions facing climate change and resource scarcity. Integrating technological innovation, nature-based solutions, and participatory policymaking is crucial to address the complex challenges of sustainability. Furthermore, the findings suggest that understanding local environmental dynamics and engaging stakeholders in decision-making processes can improve the effectiveness of interventions and foster more sustainable behaviors across different sectors.

It is imperative to develop and implement innovative solutions to address the challenges of air, water, food, and waste management. The intersection of technology, policy, and public awareness presents a unique opportunity to recover from a crisis and create a more sustainable and healthier world for future generations. It is no longer adequate to consider environmental sustainability a peripheral concern. Air, water, food, and waste management must be integrated into the fundamental structures of the economy, society, and governance systems. The urgency of these issues, the interconnectedness of these resources, and the need for global cooperation should be acknowledged. The imperative for innovation and action is immediate, as humankind's health, planet, and future depend on it.

While the diverse novel approaches introduced in this Special Issue demonstrate significant potential, their success is contingent on collaboration between governments, businesses, and communities. Policymakers should establish regulatory frameworks that provide incentives for sustainability and attract investments in green technologies. Implementing a wide-ranging public education initiative is crucial for fostering deeper comprehension among all members of society regarding sustainable practices and facilitating their active participation in environmental conservation efforts. Therefore, solutions cannot rely solely on innovation to ensure a sustainable future. This necessitates a paradigm shift in society's interactions with the planet. Cross-sectoral collaboration can ensure the development of sustainable ecosystems by incorporating innovative approaches, essential for sustenance and improved quality of life in the coming years.

The imperative to create a better world has transcended idealistic aspirations and rhetorical discourse, thus becoming an urgent necessity. By implementing innovative strategies for air purification, water management, food production, and waste processing, substantial advancements can be realized towards establishing a more sustainable and ecologically balanced environment that honors planetary and human welfare. It is crucial

to undertake resolute measures to safeguard the future in natural ecosystems that thrive harmoniously with human progress, ensuring a viable legacy for subsequent generations.

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Abbreviations

The following abbreviations are used in this manuscript:

AI	Artificial Intelligence
COVID-19	COronaVirus Disease of 2019
EPR	Extended Producer Responsibility
IoT	Internet of Things
KAP	Knowledge, Attitudes, and Practices
LD	Linear Dichroism
LENSES	LEarning and action alliances for NexuS Environments
MDPI	Multidisciplinary Digital Publishing Institute
NBS	Nature-Based Solution
PET	PolyEthylene Terephthalate
SCRIPT	Circular Strategies for Indium Recovery from Ground Panels
WEF	Water–Ecosystem–Food
WEFE	Water–Energy–Food–Ecosystem
WHO	World Health Organization

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