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Editorial

Pathways to Net-Zero—Innovations and Challenges in Achieving Carbon Neutrality

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The global pursuit of net-zero carbon emissions has become one of the most critical challenges of the 21st century, as extreme climate events, rising temperatures, and environmental degradation force a reckoning with the carbon-intensive practices that define many of our industrial, agricultural, and energy systems. The transition to a sustainable future, free from anthropogenic greenhouse gas (GHG) emissions, requires not only technological advancements but also a reimagining of our management, governance, and economic models. This Special Issue entitled "Net-Zero Principles and Practices" contains a comprehensive collection of original research and review papers focused on principles and practices that are essential for achieving a net-zero carbon system, with a diverse range of topics covering agriculture, energy, industry, transportation, and ecosystem management.

The journey to net-zero demands a multidisciplinary approach, as illustrated by the research contributions in this issue. Hernandez et al. [1] on methanol fuel cells in Finland highlight the role of alternative energy technologies in mitigating GHG emissions and enhancing grid resilience, especially in regions vulnerable to weather-induced power outages. The study provides a promising case for high-temperature proton-exchange membrane fuel cells as a low-carbon alternative to traditional diesel generators, although its wider applicability needs further exploration.

The importance of natural ecosystems in the net-zero equation is emphasized in Cowan et al. [2], which explores the potential of Nordic saltmarshes as carbon sinks. Saltmarshes, often overlooked in climate mitigation discussions, are shown to play a crucial role in promoting biodiversity while sequestering carbon. The participatory workshop detailed in the study stresses the importance of involving stakeholders in creating governance strategies to protect and expand these vital ecosystems. Saltmarshes offer a nature-based solution that, with the right policy frameworks, could become central to achieving the European Union's Green New Deal target of 2050 net-zero. In the context of forestry and soil carbon dynamics, Fekete et al. [3] investigate how climate-induced changes in precipitation affect soil organic matter in oak forests. The findings show that while drier forest soils may enhance the stability of certain carbon compounds, thus potentially increasing soil organic carbon, the broader implications for carbon sequestration are complex and demand more research. This study underscores the intricate balance between climate change, soil chemistry, and forest management in maintaining the carbon storage capacity of ecosystems.

Corporate governance is another key factor influencing GHG emissions, as demonstrated by Kim et al. [4], which examines the effects of board independence on GHG emissions and financial performance in South Korean firms. The study reveals that higher board independence is associated with lower GHG emissions, as independent boards tend to prioritize environmental considerations alongside financial performance. Interestingly, firms with higher emissions tend to have better financial outcomes, but board independence

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mitigates this relationship, indicating a balanced approach to sustainability and profitability. These findings provide important insights for corporate managers and policymakers on the role of governance structures in reducing GHG emissions.

Moving beyond specific ecosystems, the review articles in this issue address broader strategies for climate neutrality. Reijnders [5] on climate-neutral agriculture delves into the formidable challenges of achieving net-zero emissions in farming, where GHG emissions from livestock, fertilizers, and rice paddies contribute significantly to global emissions. While practices such as soil carbon sequestration, afforestation, and changes in livestock feed composition are promising, the uncertainties surrounding their large-scale impact remain a significant barrier to full agricultural decarbonization. The review calls for a concerted global effort to shift dietary patterns, improve nitrogen-use efficiency, and innovate in carbon-neutral agricultural practices.

The ambition to decarbonize the energy sector is also critically examined in the study by Yap and McLellan [6], which provides a historical analysis of hydrogen economy research. Despite its promise as a long-term solution for deep decarbonization, the progress towards a functional hydrogen economy has been slower than anticipated. This study uses bibliometric and content analysis to trace the evolving landscape of hydrogen research, revealing how hype cycles and mismatches between expectations and reality have hampered development. Nevertheless, with renewed international focus on hydrogen as a clean energy vector, the review points to the importance of setting realistic milestones and addressing the underlying challenges in infrastructure and policy.

Finally, the Technical Note by Robinson and Benke [7] on the uncertainty of soil organic carbon depth profiling presents a methodological advance that could have far-reaching applications for carbon farming and land management. By refining models that estimate soil organic carbon, the study enhances our ability to monitor carbon sequestration efforts, which are key to the success of nature-based solutions like reforestation and carbon farming. Understanding and reducing uncertainty in these models is critical for scaling up such practices and ensuring their reliability as part of the net-zero strategy.

Across all these contributions, certain themes emerge. The first is the critical role of interdisciplinary collaboration in tackling the multifaceted challenge of net-zero. From energy systems and agriculture to natural ecosystems and industrial processes, achieving carbon neutrality requires a synthesis of scientific innovation, policy reform, and societal engagement. The second theme is the persistent uncertainty in how various technologies and practices will perform at scale. Whether it is the feasibility of hydrogen as a primary energy carrier or the effectiveness of soil carbon sequestration in mitigating emissions, ongoing research must focus on closing these knowledge gaps.

As we look ahead, the path to net-zero will demand not only technical solutions but also behavioral and structural changes. Governments, industries, and individuals must align their efforts to decarbonize, adopt responsible consumption patterns, and embrace sustainable practices. The papers in this Special Issue entitled "Net-Zero Principles and Practices" offer valuable insights into the principles and practices that can guide this transition, but they also highlight the complexities and uncertainties that must be addressed to fully realize a carbon-neutral future. This editorial concludes the Special Issue, drawing together the key findings and offering a broader perspective on the global challenge of achieving net-zero emissions. We hope that these contributions inspire further research, policy development, and practical action toward a sustainable and climate-resilient world.

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