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*Editorial*

# Low-Carbon Water Treatment and Energy Recovery

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## 1. Introduction

Climate change led by excessive carbon dioxide ($CO_2$) emissions poses a global challenge. Developing innovative wastewater treatments that minimize or eliminate $CO_2$ emissions is crucial to achieve carbon neutrality. To reduce carbon emissions from the water treatment processes, technological and scientific advances are required, such as biomass production to lower $CO_2$ emissions, the use of bubble-less gas mass transfer bioreactors, reduced aeration with enhanced microbial processes, high-efficiency pumps and blowers, low-pressure self-cleaning free membranes, and the integration of solar power systems and bioelectrical systems. The present technology for water and wastewater treatment offers significant room for improvement. By exploring low-carbon sewage treatment technologies, a theoretical basis for practical engineering applications is expected to be established, contribute toward the goal of carbon neutrality, which is of great significance for promoting sustainable socio-economic development [1]. This rationale underpins the Special Issue focusing on low-carbon water treatment and energy recovery.

## 2. Application of Energy Saving and Low-Carbon Technologies in Water Treatment

In light of the above, this Special Issue aims to gather cutting-edge research on pertinent subjects, specifically focusing on advancements in water treatment technologies based on conventional water treatment technologies, to achieve the best possible utilization of resources and energy consumption, as well as low-carbon treatment technologies to minimize greenhouse gases emissions. Challenging issues relating wastewater treatment in the process of sustainable and resource-based utilization were addressed. A total of 14 papers were submitted, of which 11 (79% acceptance rate) were selected for publication. The Special Issue encompasses a wide range of topics, primarily centered on energy recovery, pollutant removal, and the assessment of removal efficacy.

Fuel cells have been attracting increasing attention owing to their ability to directly convert chemical energy in fuel into electrical energy. The paper authored by Han et al. demonstrated that compared with other types of fuel cells, aluminum–air fuel cells have the characteristics of high-power density, high current density, high fuel utilization rate (up to approximately 95% energy utilization), stable structure, and strong adaptability to fuel [2]. In addition, aluminum–air fuel cells offer a promising solution for achieving carbon neutrality in wastewater treatment, presenting an alternative to traditional energy-consuming electrocoagulation systems [2]. Hydrogen ($H_2$), known for its cleanliness, cost-effectiveness, and renewability, was considered an attractive alternative to traditional fossil fuels, and could greatly alleviate the global greenhouse effect and energy crisis at present. Amongst various $H_2$ production methods, an electrocatalytic $H_2$ evolution reaction (HER) via electrochemical water splitting, an important energy recovery technique, has attracted considerable attention in the field. In their forthcoming paper, Jiang et al.

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found that HER activity is inherently correlated with the density of the GBs in Au NPs, where active sites bind $H_2$ more strongly [3]. Their finding holds promise for enhancing the catalyst's HER performance. Advances in nanotechnology have paved the way for antimicrobial technology in nanomaterials. The increased bacterial and viral resistance has hindered traditional methods of water purification and disinfection. The review by Xin et al. was an exhaustive summary of recent research advances on antimicrobial ZnO-based nanomaterials [4]. By summarizing previous studies, ZnO-based nanomaterials with excellent antibacterial effects were obtained. In detail, various strategies to enhance the antimicrobial ability of ZnO-based nanomaterials were proposed. Finally, current limitations of the improvement strategies outline future directions for development and potential applications in the field. Here, two papers focus on the degradation of pollutants in water, specifically addressing typical organic pollutants and metal ions. In the first paper authored by Liu et al., the persistence, toxicity, mobility, and widespread pollution of short-chain PFASs in the water cycle are discussed. The study compares how various treatment techniques, such as the adsorption, electrochemical oxidation, and photocatalytic degradation have certain removal effects on short-chain PFASs [5]. Among these techniques, adsorption proves to be the most widely applied technique for the effective removal of short-chain PFASs, suitable for a wide concentration range of pollution and aligning with low-carbon policies. The findings provide a scientific basis for the effective treatment and regulation of short-chain PFAS contaminations in diverse water sources. For metal ions, the coexistence of iron and manganese was common in groundwater. Ways in which to remove iron and manganese efficiently and stably have become the focus of research. Kang et al., [6] developed a three-dimensional response surface to investigate the interaction of three variables (pH, manganese sand dosage, and the initial Fe/Mn concentration ratio) on the removal of iron and manganese ions. The study revealed that pH exerts the most significant influence on the adsorption process, and the optimal conditions for Fe and Mn ion adsorption by modified Mn sand were pH 7.2, 3.54 g/L of sand, and an initial Fe/Mn ratio of 3.8. In addition, the authors confirmed that the relative error between the model predictions and experimental values was close to 1%.

Reliable evaluation and accurate prediction of water pollution indicators are crucial for effective water resource management and pollution control. In studies on water quality evaluation and prediction, water quality evaluation and prediction models were established, combining the autoregressive integrated moving average (ARIMA) model and the wavelet neural network (WNN) mode with the bat algorithm to determine the optimal weight of each individual model [7]. The trained T–S fuzzy neural network was applied to the water quality evaluation, achieving total positive water quality grade evaluation rates of 90.38% and 88.46%, respectively. For the prediction of water quality, the combined model (ARIMA–WNN) produced a higher prediction accuracy, with an improvement of up to 68.06%. In the following article authored by Zhang et al., the focus was on nitrogen removal through partial nitrification coupled with ANAMMOX technology treating livestock wastewater. The study aimed to evaluate the influences of non-biodegradable organic matter and microbial communities on the performance [8]. Nitrite accumulation efficiencies of 78.4% and 64.7% were obtained in an intermittent aeration sequencing batch reactor and a continuous aeration sequencing batch reactor, respectively, at a loading rate of 0.93 kg ammonium/$m^3$/d. With ANAMMOX activity at low loading rates (118 $\pm$ 13 mg COD/L and 168 $\pm$ 9 mg COD/L) and an average nitrite removal rate of 87.4%, partial nitrification treating the livestock wastewater was successfully achieved.

To address the gap in computer-aided multi-class environmental microorganism (EM) detection, Li et al., proposed a novel squeeze-and-excitation-based mask region convolutional neural network (SEM–RCNN) [9]. Mask RCNN, one of the most applied object detection models, uses ResNet for feature extraction. Specifically, in terms of technology, an improved method combining Mask RCNN with SENet was proposed in this paper. In terms of applications, model training and testing were conducted in a small dataset of EMs and a large dataset of blood cells, respectively. Currently, the field of transparent image analysis has emerged as a prominent research topic due to advancements in computer vision, enabling image analysis through computer use. To address the low contrast between the foreground and background of transparent images making their segmentation difficult for computers, Li and Yang [10] aimed to address these problems in transparent images by cropping the image into patches and classifying their foreground and background. They used CNNs and ViT deep learning methods to compare the patch- and pixel-level performances of the transparent image segmentation. The study highlighted the advantages of CNN and ViT models in image classification. CNN excels at extracting the local features of images, whereas ViT effectively captures the global features of images combined with contextual information. To address the limitation of contour conglutination of dense objects while counting, the next paper [11] proposed a novel pixel interval down-sampling network (PID-Net), which was an end-to-end convolutional neural network (CNN) model with an encoder–decoder architecture for dense, tiny object (yeast cells) counting tasks with higher accuracy. By comparing with the proposed PID-Net and classical U-Net-based yeast counting results, the evaluation indexes of accuracy, dice, Jaccard, precision, counting accuracy, and Hausdorff distance of PID-Net improved by 0.04%, 0.15%, 0.26%, 0.4%, and 5.7%, respectively, and the Hausdorff distance decreased by 0.0394. These results highlighted the enhanced segmentation performance of PID-Net for the accurate counting of dense, tiny objects in a small dataset.

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