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Editorial

Topic: Water and Energy Monitoring and Their Nexus

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1. Introduction

The global community faces unprecedented pressures on its vital water and energy infrastructures, exacerbated by challenges such as drought, escalating population growth, evolving energy and land use patterns, profound socioeconomic shifts, and a rapidly changing climate. In light of these critical circumstances, it has become imperative to re-evaluate how water and electricity are managed, with a particular focus on their intricate interactions, commonly referred to as the water–energy nexus. This nexus is exemplified by the significant energy required for water treatment and distribution, as well as the considerable water utilized in energy generation.

Our collective endeavor, initiated through this Special Issue,aimed to precisely identify and explore sustainable strategies and innovative technologies capable of alleviating these mounting pressures on our most essential resources. While recognizing the paramount importance of understanding the deep interdependencies within the water–energy nexus, we also acknowledge the necessity of examining water and energy individually to grasp their unique complexities and challenges comprehensively. This topic was designed to foster a rich exchange among researchers and participants from both academic and industrial sectors, inviting them to share recent findings that contribute to a more comprehensive understanding, effective planning, and robust management of water and energy systems. Through a meticulous selection of five journals (*Water*, *Energies*, *Sensors*, *Sustainability*, and *Data*), we sought to encompass a broad spectrum of research addressing critical aspects of water and energy monitoring, their nexus, and related areas such as disaggregation, modeling, data standards, decision-making tools, and forecasting. The contributions herein highlight the innovative approaches and diverse perspectives essential for securing a sustainable future for these foundational resources.

2. Contributions to the Topic

The research papers submitted to this topic collectively highlight a broad and diverse range of work, encompassing varied practical applications and advanced methodological tools.

2.1. Practical Applications of Water and Energy Monitoring and Their Nexus

The applications of the research brought together here often emphasize the water-energy nexus while, at the same time, showcase a wide array of contexts and applications for advancements in water and energy management.

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One significant area of application is within residential and industrial buildings. The research here focuses on smarter energy management and efficiency initiatives. This includes the estimation of energy consumption at an appliance level from aggregate data in residential settings [1], which supports energy efficiency, demand-side management, and user awareness. In contrast, industrial kitchens are recognized as energy-intensive environments but are often overlooked; research in this area is dedicated to developing taxonomies to help identify and understand electricity consumption patterns with the aim of developing, through benchmarking, a standard or best practice for energy auditing as a pathway to facilitate sustainable energy systems in that environment [2].

Another critical domain is water treatment and resource recovery. Studies in this area address improving the efficiency and environmental impact of various water treatment processes, along with recovering valuable resources from wastewater. This includes the accurate prediction of ammonia nitrogen concentration in sequencing batch reactors (SBR) to reduce consumption through automatic control and ensure emission compliance [3]. Research has also evaluated the potential for local energy production from treatment wetlands by assessing biomethane yield from biomass, contributing to circular economy principles, and potentially reducing maintenance costs [4]. Furthermore, efforts are directed at enhancing nutrient removal efficiency from mariculture wastewater using microalgae, promoting more sustainable aquaculture practices [5].

The research also extensively covers water infrastructure operations and management. This involves enhancing the reliability, safety, and efficiency of large-scale water supply and distribution systems. Applications include contaminant source identification in water distribution networks, which is crucial for ensuring public health [6]. For water conservancy hubs, research focuses on precise gate-front water level forecasting to improve scheduling and reduce flood risks [7]. In water pumping stations, advancements include trend prediction and fault alarm systems for operating parameters to optimize operation and maintenance management [8], as well as virtual inspection systems with multimodal feedback to enhance inspection safety, efficiency, and effectiveness [9].

Finally, regional water and resource management constitutes a vital application area, addressing broad resource challenges in specific geographical regions. In the Nine Provinces of the Yellow River Basin, China, studies assess and optimize the coupled coordination of water–food–energy systems, identifying key driving mechanisms for enhanced system coordination in this economic region [10]. Similarly, in the Brazilian Tropical Savanna (Cerrado Biome), the analysis of the spatio-temporal dynamics of center pivot irrigation systems provides an important foundation for public policies directed toward the sustainable use of water resources [11].

2.2. Enabling Methodological Tools

The topic contributions highlight a diverse range of tools and methodologies employed across various applications to enhance water and energy management, including the water–energy nexus.

A significant number of methodologies revolve around advanced modeling and prediction techniques to understand complex system dynamics and forecast critical parameters. In particular, cutting-edge development of machine learning or AI tools is demonstrated to enable significant progress in waste and water treatment. For instance, in water treatment, an innovative Transformer-long short-term memory (Transformer-LSTM) network model is proposed for accurately predicting ammonia nitrogen concentration in sequencing batch reactor (SBR) systems, integrating inputs like dissolved oxygen, electrical conductivity, and oxidation–reduction potential, along with their rates of change and cumulative values [3]. This model, when combined with automatic control technology, led to significant

reductions in energy or time consumption [3]. Similarly, for water conservancy hubs, a GRU–TCN–Transformer-coupled model is utilized for gate-front water level forecasting, which also incorporates Singular Spectrum Analysis (SSA) and Complete Ensemble Empirical Mode Decomposition with Adaptive Noise (CEEMDAN) to separate data into frequency components, and the Permutation Entropy (PE) algorithm for sequence division [7]. In the context of water pumping stations, a trend prediction model leverages PCA-based multi-task learning (MTL) and an attention mechanism (AM) to predict operating parameter changes and facilitate fault diagnosis and alarming [8]. For regional resource management, a panel data model is employed to analyze driving mechanisms for enhancing the coupled coordination of water–food–energy systems in the Yellow River Basin, supported by a theoretical framework of coupled coordination and visualized using ArcGIS [10].

Beyond prediction, several methodologies focus on data analysis, characterization, and system optimization. In residential buildings, load disaggregation is a key technique for providing appliance-level energy consumption estimates from aggregate data [1]. This process is enhanced by investigating the influence of data characteristics, such as noise, on hyperparameter selection, using an appliance-to-noise ratio metric to guide the tuning of hyperparameters like input sequence length [1]. For industrial kitchens, a methodological framework is proposed to develop taxonomies for understanding electricity consumption patterns, involving steps like knowledge domain identification, term extraction, data collection, and information analysis, to standardize energy demand assessment [2]. In water distribution networks, fitness landscape analysis is conducted using the Nearest-Better Network (NBN), a method specifically applicable to mixed-encoding problems, to understand landscape features and inform algorithm design for contaminant source identification [6].

Furthermore, the research incorporates specific system implementations and experimental methodologies. For water pumping stations, a novel virtual inspection system is presented, integrating virtual reality interaction and haptic force feedback technology for enhanced immersion and realism [9]. This system uses 3Ds Max for 3D model crafting and Unity3D for integrating with external databases. In the realm of water treatment and resource recovery, Biochemical Methane Potential (BMP) determination is used to evaluate the potential of common reed biomass from treatment wetlands for local energy production, while falling-head tests assess hydraulic conductivity variations and their influence on biomethane yield [4]. For nutrient removal from mariculture wastewater, the methodology involves phytohormone supplementation (e.g., 3-indoleacetic acid, gibberellic acid, zeatin) with Oocystis borgei in a sequential batch operation to enhance efficiency [5].

3. Conclusions

The increasing pressures on global water and energy resources necessitate a critical re-evaluation of their management and intertwined dynamics. Ultimately, this topic serves as a vital platform to disseminate cutting-edge findings that advance our understanding and facilitate the effective planning and management of resilient water and energy systems, with a particular focus on the water–energy nexus. Collectively, the diverse research presented aims to promote sustainable strategies and technologies essential for ensuring the long-term sustainability and resilience of these invaluable resources.

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