Bibliometric Analysis of The Challenges of Applying Green Technology to Surface Water Quality Management

Fiqi Nurbaya [1,2*] , *Mochamad Arief Budihardjo*[1], *Budi Warsito*[1]

[1] Doctoral Program of Environmental sciences, Postgraduate School, Universitas Diponegoro, Semarang, Indonesia
[2] Public Health Study Program, Veteran Bangun Nusantara University, Central Java, Indonesia

Abstract. Green technology represents a sustainable and environmentally responsible approach to utilizing natural resources to meet human needs. It plays a crucial role in improving water quality through pollution reduction, water conservation, and enhanced access to clean water. This study aims to identify global research trends in the application of environmentally friendly technologies to surface water quality using bibliometric analysis with VOSviewer. Data were retrieved from the Elsevier Scopus database using the keywords green technology and water quality. The visualization results show that green technology is the most frequently occurring keyword. Wang, Feng, is identified as the most collaborative author, while China emerges as the leading country in this research field, with the highest number of publications in 2023. The University of Chinese Academy is recorded as the most productive institution. The study highlights the importance of continued research, interdisciplinary collaboration, and supportive policies to strengthen the development and implementation of green technologies for managing surface water quality.

1 Introduction

Water is needed by living creatures and is part of human life. Water is needed for sustainable development in the socio-economic fields, environmental health and the sustainability of human life. Other compounds cannot replace the function of water for life. The main benefits of water is as drinking water. Water can also be used for irrigation, electrical energy, household needs, agriculture and industry. Responsible water management is very important to ensure the long-term availability of water resources. Humans can obtain water from various sources such as ground water, surface water and rainwater. Surface water includes river water, lakes, reservoirs, swamps and other bodies of water that do not infiltrate underground. Water quality is used as an indicator of water bodies. Water quality is a measure of water conditions seen from physical, chemical and biological characteristics. Water quality is also defined as the term suitability for water use, for example: drinking water, fisheries, irrigation, industry, recreation and so on. Water testing is carried out to

*Corresponding author: fiqinaya@gmail.com

determine water quality. Determination of surface water quality can be determined by comparing parameters with quality standards. The results of comparing water parameters with quality standards indicate the condition of water quality. Water parameter test results exceed quality standards, meaning there is a decrease in water quality [1].

Decreasing water quality is a form of environmental quality degradation due to increasingly high levels of population growth and an increase in the number of industries in Indonesia. Urbanization, agricultural practices, industrial activities, household activities and climate change pose significant threats to surface water quality. The decline in water quality can be overcome by using green technology. Green Technology is defined as a practical science or technology that can be used to develop and create an infrastructure to meet human needs sustainably without destroying or disturbing natural resources. The change towards green technology in water management is not just a trend, but a necessity. Research on green technology for environmental protection has become the main thing in the last few decades because green technology plays an important role in improving environmental sustainability by reducing the ecological impact of human activities. Traditional methods often involve processes that are detrimental to the environment, contributing to pollution and greenhouse gas emissions. Green technology can be applied in various ways to improve surface water quality, such as bio parks. However, important research gaps remain. There has been no multidisciplinary research on the topic of green technology. Green technology research only focuses on the financial and environmental fields, such as in China [2].

Biopark is a technology that can be used to improve the quality of polluted water, such as river water, lakes and canals. Green technology is technology that pays attention to the principles of environmental conservation. Green Technology refers to the sustainable and environmentally friendly use of natural resources to meet human needs. Green Technology plays a role in managing water quality, such as reducing water pollution, conserving water resources and increasing access to clean water. Domestic, industrial and agricultural waste can pollute water sources, reducing the quality of water available for consumption. Green Technology also strives to maintain and optimize the availability of water resources. A sustainable approach to Green Technology helps manage water use wisely, so that it can be maintained for future generations. Green Technology in water management can reduce waste, help create and ensure sustainable and environmentally friendly use of resources. Research objectives: identify trending green technology topics, application of green technology in water quality management, identify research gaps and propose future research directions [3].

2 Method

The research method uses bibliometric analysis. Bibliometrics is a quantitative approach that combines ideas and methods from applied mathematics, information science, computer science, and graphics.The stages in this research began with data collection, data filtering and data visualization. The first stage is the data collection process. Data collection was carried out in September 2024. Data was taken in 2020 – 2024. The data in this research article was collected from Elsevier Scopus. The keywords used are green technology and water quality. The second stage in this research is data filtration. After data filtering, 1,461 documents were collected from 1972-2024. The first article published in 1972 was 1 article. All journals found using the keywords green technology and water quality amounted to 2,588 documents. The final stage in this research is data visualization using VOSViewer. VOSviewer is used to perform visualizations related to co-authorship and co-occurrence [4]. Visualization is needed to obtain an overview of research trends regarding green technology and new topics.

3 Results and Discussion

Bibliometric data analysis using VOS Viewer. VOS Viewer is a software used to visualize bibliometric maps, map current research topics, search for the most used references in a particular field and others VOS Viewer software has three different visualization categories, namely network visualization, overlay visualization, and density visualization. Network visualization aims to show an overview of the relationship between topics based on article titles and keywords from journals. Overlay visualization aims to see the relationship between topics and year information. Density visualization functions to see which discussion topics are discussed the most or least and is displayed with a heat map. The more discussions on a topic, the color will be yellow and if there are fewer discussions on a topic, the color will be bluer. This study presents the results of bibliometric analysis with the keywords green technology and water quality, which focuses on network visualization, overlay visualization, and density visualization from the aspects of co-occurrence and co-authorship [5].

3.1 Co Occurance Analysis (author keywords)

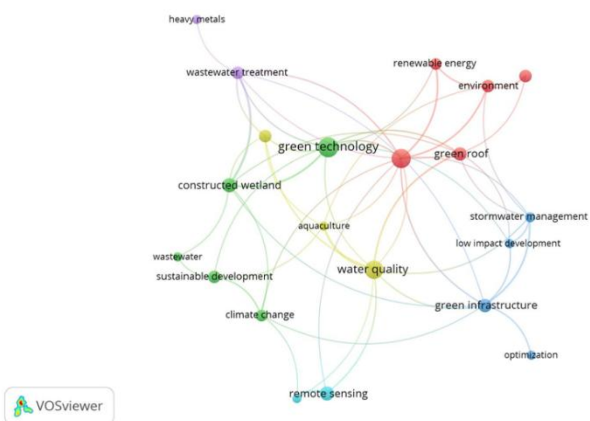

Figure 1 Keywords for Network Visualization

The bibliometric analysis identified three primary clusters reflecting global research directions in sustainable and environmentally friendly technologies. Cluster 1 (Renewable Energy Sustainability) focuses on the strong linkage between sustainability and green technology, emphasizing the adoption of renewable and eco-friendly production systems to support sustainable development. Sustainability encompasses environmental, social, and economic dimensions, while green technology contributes to environmental protection and resource efficiency. Cluster 2 (Sustainable Green Technology) highlights the role of clean and environmentally friendly innovations in reducing pollution, mitigating climate change, and enhancing access to clean water through efficient water management systems. It also underscores the relationship between green technology and green infrastructure as integral components of environmental preservation. Cluster 3 (Green Infrastructure Optimization) centers on sustainable water management strategies, including Low Impact Development (LID), to improve stormwater systems and water quality. The growing prominence of green infrastructure research indicates its essential role in environmental engineering and urban sustainability through ecosystem enhancement and healthier living environments [6].

The next three clusters emphasize the environmental applications of sustainability and technology. Cluster 4 (Water Quality Treatment) focuses on effective water management and treatment processes to address declining water quality caused by pollution and eutrophication. Common methods such as coagulation, flocculation, sedimentation, and filtration aim to ensure safe and sustainable water use. Cluster 5 (Wastewater Treatment) discusses efforts to mitigate environmental and health risks from wastewater contamination. Biological treatment methods both aerobic and anaerobic remain widely used, while new approaches involving nanocomposite photocatalysts are being developed to enhance pollutant removal efficiency. Cluster 6 (Remote Sensing) explores advanced monitoring technologies for detecting harmful algal blooms (HABs) and assessing environmental parameters such as productivity, temperature, and vegetation. Satellite-based remote sensing also provides critical data for monitoring environmental hazards like landslides, demonstrating its importance in supporting sustainable water and land resource management [7].

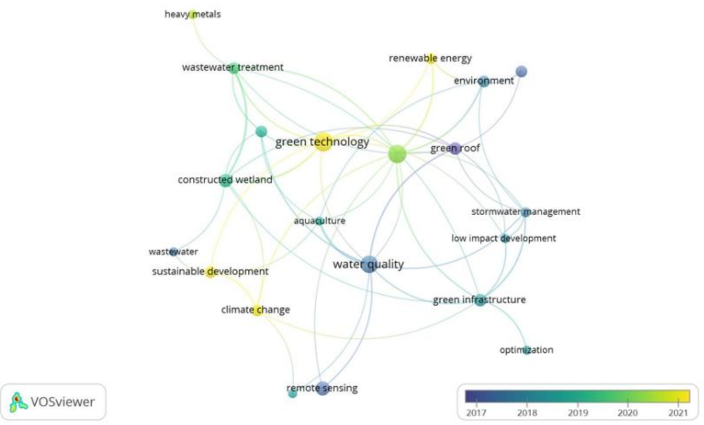

Figure 2 Keywords for Overlay Visualization

The bibliometric overlay visualization depicts the temporal evolution of research themes through keyword occurrences, with color gradations from purple to yellow representing publication years. The thickness of connecting lines indicates the strength of relationships between keywords, showing increasing interconnection over time. The keyword green roof appeared in 2017 and is closely linked to green building (2018). As integral components of environmentally friendly construction, green roofs offer environmental, economic, and social benefits by improving insulation, reducing energy use, and retaining rainwater for urban water management. Earlier studies are represented by purple tones, while recent research appears in yellow. The dominant keyword in 2018 was water quality, strongly related to aquaculture (2019), emphasizing the importance of monitoring physical, chemical, and biological parameters to maintain aquatic ecosystem health [8]. In 2019, environmentally friendly infrastructure emerged and showed linkages with wastewater treatment. Green infrastructure, particularly biofiltration systems, has been recognized as a sustainable and efficient approach for urban wastewater management. By 2020, sustainability became the central theme, followed by the emergence of green technology, renewable energy, climate change, and sustainable development in 2021, reflecting the global shift toward environmentally responsible innovations.

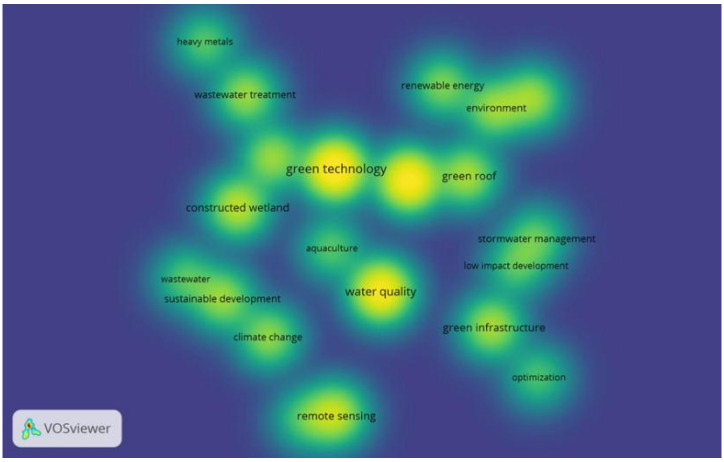

Figure 3 Density Visualization Keywords

Density visualization is used in bibliometric analysis to illustrate the concentration of research topics [9]. In this visualization, colored dots represent topic density, with color intensity reflecting the level of research attention. Yellow areas indicate topics that have been extensively studied and show strong interconnections between themes, while greenish-yellow represents moderately explored areas. In contrast, blue regions signify emerging or less-studied topics, suggesting opportunities for novelty and future exploration. The most frequently researched themes include green technology, water quality, and sustainability, highlighting their central role in environmental studies. Conversely, topics displayed in smaller text and lighter colors such as green extraction, green hydrogen, recycling, hydroponics, and nutrition represent related but underexplored research areas that offer potential for further investigation.

3.2 Co-Authorship Analysis (Author)

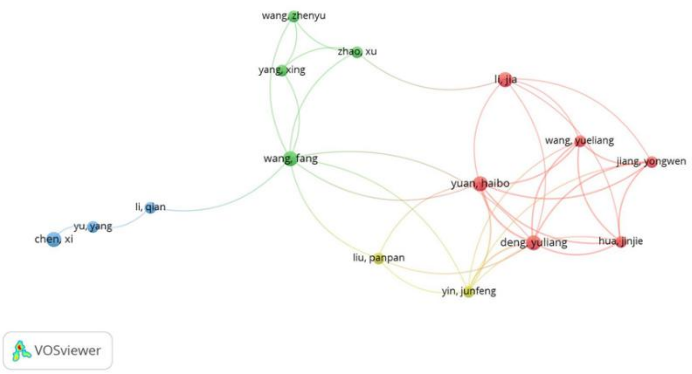

Figure 4 Network Visualization Co-Author

Co-authorship analysis illustrates the network of research collaborations between authors. Cluster 1 (red) includes researchers such as Yuan Haibo and Deng Yuliang, who co-authored two studies on green tea processing. Both are highly cited, with one paper receiving 23 citations and the other 15. Cluster 2 (green) features Wang Fang, the only author connected to researchers in all four clusters. Her highly cited article, “Assessing the in vitro toxicity of degradation products from photocatalytic deoxynivalenol degradation using upconversion nanoparticles@TiO_2 composite," has received 50 citations. Cluster 3 (blue) consists of Li Qian and Yu, who co-authored the highly cited paper, "Comprehensive performance evaluation of LID practices for sponge city construction: A case study in Guangxi, China," with 212 citations. However, their collaborations are limited beyond Wang Fang. Cluster 4 (yellow) includes Liu Panpan and Yin Junfeng, who collaborated with researchers from other clusters on several green tea-related studies, including joint work with Yuan Haibo and Wang Fang. Overall, the co-authorship analysis indicates strong intra-cluster collaboration with limited inter-cluster connections, indicating the need for broader interdisciplinary collaboration [10].

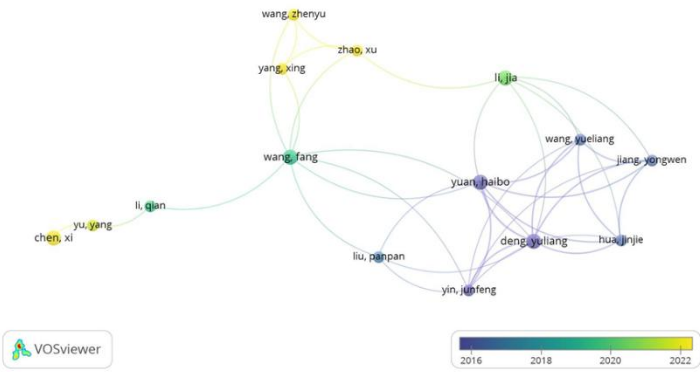

Figure 5 Overlay Visualization Co-author

Overlay visualization is useful for mapping the author's historical track record in environmental research using VOSviewer. Nodes have varied colors and edges that connect one researcher to another researcher. The dark color on the node indicates research that has been carried out in the past over a specified time period. In 2016 research was carried out by Yuan, haibo; Deng, yuliang and Yin, junfeng. In 2018, research was carried out by Wang, Yuelliang; Jiang, yongwen; Hua, jinjie. Research in 2020 was conducted by Wang, Fang; Li, qian and Li, jia. Research in 2022 was conducted by Yang, xing; Wang, zhenyu; and Zhao, xu. The density or emphasis of the research topic "green technology and water quality" based on the author network is presented in. The brighter and bigger the color on the cluster means the bigger or stronger the writer's network in that cluster, the dimmer the color on the map means the lower the strength of the writer's network in that cluster. Wang, Fang is a writer who has the strongest network ties among other researchers.

3.3 Co Authorship Analysis (Country)

The bibliometric analysis identified six country clusters contributing to green technology research, with China emerging as the most dominant contributor. Rapid industrial growth following four decades of economic reform has led China to face severe environmental challenges, particularly water pollution, which accounts for 52% of global environmental emergencies. In response, the government has adopted various innovative strategies to balance economic development and environmental protection, positioning China as a global leader in implementing green technologies for water management [11].

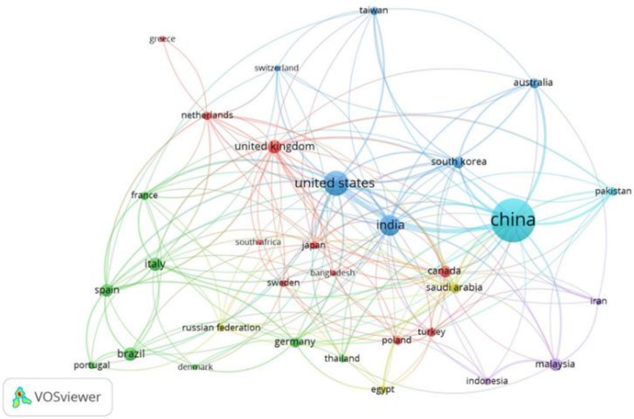

Figure 6 Network Visualization Country

Bioremediation has become a key environmentally friendly approach to improve water quality, while industrial water efficiency initiatives promote sustainable resource allocation and pollution control. In 2014, industrial activities accounted for 24% of China's total water use, prompting the government to advance water-saving measures and rational waste management technologies under the Environmentally Friendly Industry Development Plan to achieve the SDGs. In contrast, the United States remains the world's largest energy consumer, relying heavily on fossil fuels that supply 80% of global demand. Rising energy needs and depletion risks have accelerated renewable innovations such as biofuel production, which provides a sustainable, low-carbon alternative due to its photosynthesis-based carbon-neutral cycle [12].

Globally, research on green technology has evolved rapidly, reflecting each country's priorities in addressing environmental challenges. Developed nations such as the United States, Germany, and the United Kingdom initially dominated this field through early innovations in sustainable energy, wastewater treatment, and environmental infrastructure. However, in recent years, emerging economies particularly. China have demonstrated significant growth in green technology research, driven by government policies, industrial transformation, and sustainability targets aligned with the Sustainable Development Goals (SDGs). This global shift indicates a transition from traditional energy dependence to environmentally responsible technologies, emphasizing collaboration and innovation across regions [13].

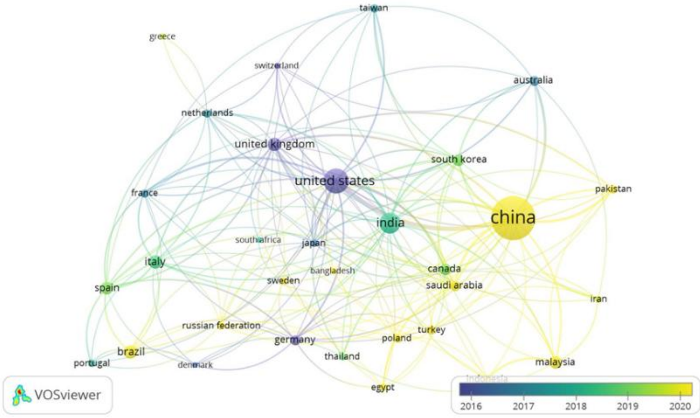

Figure 7 Overlay Visualization Country

Figure 7 illustrates the global country network on green technology research, showing that the United States was the earliest and one of the most influential contributors, producing 51 documents since 2016. Its studies, such as High-efficiency ramie fiber degumming and self-powered degumming wastewater treatment using triboelectric nanogenerator (cited 131 times) and Urban Stormwater Governance: The Need for a Paradigm Shift (cited 122 times), highlight the application of innovative green technologies in textile wastewater treatment and sustainable stormwater management. Germany and the United Kingdom also began publishing in 2016, contributing research on sustainable water treatment systems in tourist resorts and geothermal-based energy systems in ocher-rich coal mine water environments, respectively. Although China entered this research area later, around 2020, it now leads with 561 publications and over 500 citations. The rapid rise of green technology innovation in China since 2017 is evident through increasing patent grants, international collaborations, expansion of environmentally related technologies, and substantial government investment in research and development [14].

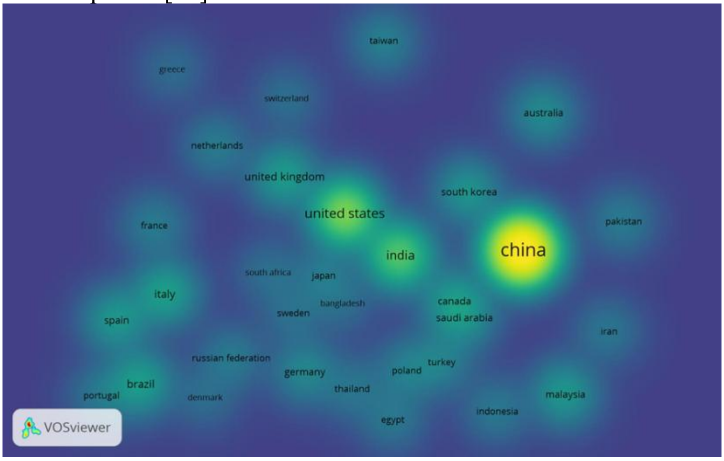

Figure 8 Density Visualization Country

Density visualization is used to identify the presence of density or emphasis on nodes which means that there is a connection between countries researching green technology topics. The level of node saturation in density visualization is indicated by the number of countries involved in environmental research. China has the lightest node density color. China is the country that plays the most role in research on green technology topics. China consistently conducts research on green technology topics because China is the country with the highest energy consumption in the world. China relies on fossil fuels and has experienced enormous industrial growth. China is taking steps to improve energy efficiency, expand the use of renewable energy, diversify its energy sources, and participate in international energy governance. China is the largest producer of electronic waste, accounting for about one-fifth of global electronic waste production [15].

4 Conclusion

Green technology emerged as the most dominant and frequently discussed keyword, reflecting its central role in environmental sustainability research. It contributes significantly to improving access to clean water and enhancing surface water quality through applications such as bioremediation, biofiltration, and biopark systems. The bibliometric analysis shows that research trends have evolved from early studies on green roofs and water treatment to the integration of green infrastructure and environmentally friendly technologies in wastewater management. China and the United States were identified as leading contributors to green technology research, supported by government initiatives and technological innovation. However, a noticeable research gap remains, as most studies focus primarily on environmental and economic aspects, with limited multidisciplinary collaboration. Therefore, future research should emphasize continuous development through cross-sectoral partnerships, integration of diverse scientific fields, and the implementation of supportive policies to accelerate the adoption of sustainable and eco-friendly technologies in managing surface water quality.

Reference

1. Liu, X. *et al.* Estimation of the Key Water Quality Parameters in the Surface Water, Middle of Northeast China, Based on Gaussian Process Regression. *Remote Sens.* **14**, 6323 (2022). https://doi.org/10.3390/rs14246323
2. Zhang, H., Shao, Y., Han, X. Chang, H.-L. A road towards ecological development in China: The nexus between green investment, natural resources, green technology innovation, and economic growth. *Resour. Policy* **77**, 102746 (2022). https://doi.org/10.1016/j.resourpol.2022.102746
3. Bose, S., Mazumdar, A. Basu, S. Evolution of groundwater quality assessment on urban area- a bibliometric analysis. *Groundw. Sustain. Dev.* **20**, 100894 (2023). https://doi.org/10.1016/j.gsd.2022.100894
4. Liu, C. *et al.* Energy reserves and gut microbiota of marine mussels under combined exposure to pathogens and predation risk. *Aquaculture* **595**, 741483 (2025). https://doi.org/10.1016/j.aquaculture.2024.741483.
5. Sid, A. N. E. H. *et al.* Investigating the Efficacy of Oily Water Treatment at a De-Oiling Facility in the Northern Industrial Center of CINA, Hassi Messaoud: A Statistical Physics Assessment. *Water* **15**, 3360 (2023). https://doi.org/10.3390/w15193360
6. Zhao, Y. *et al.* Toward environmental sustainability: data-driven analysis of energy use patterns and load profiles for urban electric vehicle fleets. *Energy* **285**, 129465 (2023). https://doi.org/10.1016/j.energy.2023.129465
7. Saini, G. K., Kaur, I. Sharma, H. A Comprehensive Review and Analysis of Landslide Detection Through Advanced Image Analysis Techniques. in *2024 5th International Conference for Emerging Technology (INCET)* 1–6 (IEEE, 2024). https://doi.org/10.1109/INCET61516.2024.10593354.
8. Bryukhov, M. Ulrikh, D. Wastewater treatment: methods and prospects. *IOP Conf. Ser. Earth Environ. Sci.* **1061**, 012049 (2022). https://doi.org/10.1088/1755-1315/1061/1/012049
9. Riaman, Sukono, Supian, S. Ismail, N. Mapping in the Topic of Mathematical Model in Paddy Agricultural Insurance Based on Bibliometric Analysis: A Systematic Review Approach. *Computation* **10**, 50 (2022). https://doi.org/10.3390/computation10040050
10. Alagumalai, A. Song, H. Exploring the landscape of machine learning-aided research in biofuels and biodiesel: A bibliometric analysis. *Green Energy Resour.* **2**, 100089 (2024). https://doi.org/10.1016/j.gerr.2024.100089
11. Sridhar, C. *et al.* Green Technology and Sustainable Renewable Energy Analysis. in 617–625 (2022). https://doi.org/10.1007/978-981-16-8987-1_66.
12. Mahmood, S. *et al.* Integrating machine and deep learning technologies in green

buildings for enhanced energy efficiency and environmental sustainability. *Sci. Rep.* **14**, 20331 (2024). https://doi.org/10.1038/s41598-024-70519-y

13. Mohammed, S. I. Advantages of Green Technology to Mitigate the Environment Problems. *IOP Conf. Ser. Earth Environ. Sci.* **779**, 012133 (2021). https://doi.org/10.1088/1755-1315/779/1/012133
14. Liang, L., Jin, L., Selopal, G. S. Rosei, F. Peace Engineering in Practice: China's Energy Diplomacy Strategy and Its Global Implications. *Sustainability* **15**, 1442 (2023). https://doi.org/10.3390/su15021442
15. Dathe, T., Müller, V. Helmold, M. Energy Supply. in 53–66 (2023). https://doi.org/10.1007/978-3-031-31933-4_5.