



Sustainable Pollution-Control Technologies for Marine Environmental Protection

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Abstract: Marine pollution is one of the major environmental challenges that threatens marine ecosystems, biodiversity, and human activities in coastal areas. Increasing pollution from plastic waste, oil spills, domestic wastewater, and maritime activities highlights the need for effective and environmentally sustainable pollution-control technologies. This article aims to examine the application and potential of sustainable pollution-control technologies for protecting marine environments. The study uses a literature review approach by analyzing scientific publications and relevant studies concerning marine pollution sources, pollution-control methods, and environmentally friendly technologies. The results indicate that several technologies, including advanced wastewater treatment, oil-spill response technologies, plastic waste recovery and recycling, bioremediation, and environmentally friendly filtration systems, can contribute to reducing pollutant loads in marine environments. The integration of renewable energy, resource recovery, and circular-economy principles can further improve the sustainability and efficiency of pollution-control systems. However, the implementation of these technologies remains challenged by high investment costs, technological limitations, maintenance requirements, and differences in environmental conditions. Therefore, the development and integration of sustainable pollution-control technologies, supported by effective environmental management and continuous technological innovation, are essential for reducing marine pollution and maintaining the long-term health of marine ecosystems.

Keywords: Sustainable Technology; Marine Pollution; Pollution Control; Marine Environment; Environmental Protection

1. Introduction

Marine ecosystems play an important role in maintaining ecological balance, supporting biodiversity, providing food resources, and contributing to economic activities such as fisheries, transportation, and tourism. However, the increasing intensity of human activities in coastal and marine areas has contributed to the growing problem of marine pollution. Various pollutants, including plastic waste, oil, domestic wastewater, industrial effluents, and other hazardous substances, can enter marine environments through rivers, coastal settlements, maritime transportation, industrial activities, and accidental spills. The accumulation of these pollutants can alter water quality, damage marine habitats, and negatively affect marine organisms and human activities that depend on marine resources [1].

Marine pollution is particularly difficult to control because pollutants can be transported over considerable distances by ocean currents, waves, tides, and wind. Conventional pollution control methods may reduce pollutant concentrations effectively, but some approaches require substantial energy, generate secondary waste, or involve high operational and maintenance costs. These limitations highlight the importance of developing pollution control technologies that not only remove pollutants efficiently but also minimize environmental impacts throughout their life cycle [2].

Sustainable pollution control technologies offer an approach that combines pollution reduction with resource efficiency and long term environmental protection. Technologies such as advanced wastewater treatment, oil spill containment and recovery systems, plastic waste recovery and recycling, bioremediation, membrane filtration, and environmentally friendly adsorption materials have potential applications in marine and coastal environments. The integration of renewable energy and circular economy principles can further

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improve the sustainability of these technologies by reducing energy consumption, minimizing waste generation, and enabling the recovery and reuse of valuable materials [3].

Despite the development of various pollution control technologies, their application in marine environments still faces several challenges. Differences in water characteristics, pollutant types, hydrodynamic conditions, technological costs, maintenance requirements, and the availability of supporting infrastructure can influence the effectiveness of pollution control systems. Therefore, selecting and implementing appropriate technologies requires consideration of both pollution removal performance and long-term environmental, economic, and operational sustainability [4].

Based on these considerations, this article discusses sustainable pollution control technologies for marine environmental protection, with emphasis on their applications, mechanisms, advantages, and limitations. The discussion also considers the potential integration of sustainable practices and innovative technologies to improve pollution management in marine and coastal environments. Through the development and appropriate application of sustainable pollution control technologies, marine pollution can be addressed more effectively while supporting the long term conservation and sustainable use of marine ecosystems [5].

2. Materials and Methods

This study employed a literature review method to examine sustainable pollution control technologies for marine environmental protection. The research focused on identifying, analyzing, and synthesizing information from scientific literature related to marine pollution sources, pollution control technologies, their mechanisms, applications, effectiveness, advantages, limitations, and sustainability aspects. Relevant literature was collected from academic databases and scientific search platforms, including Google Scholar, ScienceDirect, SpringerLink, and other scholarly sources. The literature search used several keywords, including "sustainable pollution control technologies," "marine pollution," "marine environmental protection," "oil spill control," "plastic pollution," "wastewater treatment," "bioremediation," and "green technology." [6].

The literature selection was conducted based on its relevance to sustainable pollution control in marine and coastal environments. Scientific publications were selected when they discussed technologies designed to reduce, remove, or manage pollutants in marine environments and provided information regarding their environmental performance, technological applications, or sustainability. Publications that were not directly related to marine pollution control or did not provide sufficient information about the technology and its environmental application were excluded. The selected literature was subsequently classified according to the main technological approaches, including wastewater treatment, oil spill control and recovery, plastic waste management, bioremediation, filtration, adsorption, and other environmentally friendly pollution control technologies [7].

Data were collected by reviewing the selected publications and extracting information related to pollutant types, pollution sources, technological principles, treatment processes, environmental applications, pollution reduction potential, energy and resource requirements, advantages, limitations, and sustainability considerations. The collected information was analyzed using descriptive and comparative approaches to identify the characteristics, effectiveness, and potential applications of each technology. The analysis also considered environmental impacts, operational requirements, resource efficiency, and the potential integration of renewable energy and circular economy principles. The findings from the reviewed literature were then synthesized to provide an overall assessment of how sustainable pollution control technologies can contribute to reducing marine pollution and supporting long term protection and sustainable management of marine ecosystems [8].

3. Results

The literature review indicates that sustainable pollution control technologies have significant potential to reduce pollution and support the protection of marine and coastal environments. The reviewed studies identified several major technological approaches, including advanced wastewater treatment, oil spill control and recovery, plastic waste management, bioremediation, and filtration and adsorption technologies. These technologies differ in their mechanisms and applications, but they share the objective of reducing the concentration, distribution, and environmental impacts of pollutants entering marine ecosystems [9].

Advanced wastewater treatment was identified as an important approach for controlling pollutants originating from domestic, industrial, and coastal activities. Treatment processes such as biological treatment, membrane filtration, adsorption, and advanced oxidation can reduce suspended solids, organic pollutants, nutrients, and other contaminants before wastewater is discharged into marine environments. The reviewed literature shows that

combining several treatment processes can improve pollutant removal performance while enabling treated water to be reused in suitable applications. However, energy consumption, operational complexity, and maintenance requirements remain important considerations in implementing these systems [10].

Oil spill control and recovery technologies were also found to play an important role in reducing the impacts of petroleum pollution in marine environments. Physical containment and recovery systems, including floating barriers and mechanical recovery equipment, can limit the spread of oil and facilitate its removal from the water surface. In addition, sorbent materials and biological treatment approaches can be used as complementary methods for recovering or degrading residual hydrocarbons. The reviewed studies indicate that the effectiveness of oil spill response technologies depends on factors such as the characteristics of the oil, wave and current conditions, response time, and the scale of the spill [11].

Plastic pollution management represents another major area of sustainable pollution control. The literature shows that technologies for collecting, sorting, recycling, and recovering plastic waste can reduce the amount of plastic entering marine ecosystems. Mechanical recycling and material recovery can support resource conservation by returning recovered plastics to productive use, while innovative collection systems can help intercept waste before it reaches coastal and marine waters. Nevertheless, the effectiveness of these approaches is influenced by waste composition, contamination levels, collection infrastructure, and the availability of appropriate recycling facilities [12].

Bioremediation was identified as an environmentally oriented technology with potential for treating certain marine pollutants, particularly petroleum hydrocarbons and organic contaminants. This approach utilizes microorganisms or other biological agents to transform pollutants into less harmful substances under suitable environmental conditions. Compared with some conventional treatment methods, bioremediation can provide a lower impact alternative because it relies on natural biological processes. However, its performance may vary depending on temperature, salinity, nutrient availability, pollutant concentration, and the characteristics of the microorganisms involved [13].

Filtration and adsorption technologies were also found to have considerable potential for removing pollutants from contaminated water. Various filtration systems and adsorbent materials can capture suspended particles, organic compounds, hydrocarbons, and other contaminants. The development of low impact and renewable or waste derived adsorbent materials provides opportunities to improve the sustainability of these systems. However, the treatment capacity, regeneration of adsorbent materials, generation of secondary waste, and disposal of used materials must be considered to ensure that pollution is not transferred from one medium to another [14].

Overall, the reviewed literature demonstrates that no single technology is universally applicable to all types of marine pollution. The effectiveness and sustainability of pollution control systems depend on pollutant characteristics, environmental conditions, treatment objectives, energy requirements, operational costs, and available infrastructure. The integration of complementary technologies, together with resource recovery, renewable energy utilization, and circular economy principles, provides a potential pathway for developing more sustainable marine pollution control systems. These findings indicate that technological integration and adaptation to local environmental conditions are important factors in achieving effective and long term marine environmental protection [15].

4. Discussion

The results indicate that sustainable pollution control technologies can effectively support marine pollution reduction and long term environmental protection. Technologies such as advanced wastewater treatment, oil spill control, plastic waste management, bioremediation, and filtration can be adapted to different types of pollutants. However, their effectiveness depends on environmental conditions, pollutant characteristics, energy requirements, operational costs, and available infrastructure [16].

Advanced wastewater treatment can reduce contaminants from domestic and industrial sources, although some systems require high energy and maintenance. Oil spill containment and recovery can limit pollution, while bioremediation can help degrade residual hydrocarbons under suitable environmental conditions. Plastic collection and recycling can reduce marine waste, but require adequate collection, sorting, and recycling infrastructure. Filtration and adsorption can remove pollutants from water, but their waste materials must be properly managed to prevent secondary pollution [17].

Overall, sustainable marine pollution control requires an integrated approach rather than reliance on a single technology. Combining appropriate technologies with renewable energy, resource recovery, waste reduction, and circular economy principles can improve environmental sustainability. Technology selection should consider local marine conditions, economic feasibility, and long term maintenance to ensure effective

protection of marine ecosystems [18].

5. Conclusion

Sustainable pollution control technologies play an important role in reducing marine pollution and protecting coastal and marine ecosystems. The literature review shows that wastewater treatment, oil spill control and recovery, plastic waste management, bioremediation, and filtration or adsorption technologies can be applied to address different types of marine pollutants. However, the effectiveness and sustainability of these technologies depend on environmental conditions, pollutant characteristics, energy requirements, operational costs, and available infrastructure. Therefore, an integrated approach that combines appropriate pollution control technologies with renewable energy, resource recovery, waste reduction, and circular economy principles is needed. Continuous technological development and effective environmental management are also essential to improve the long term protection and sustainable management of marine ecosystems.

References

- [1] E. M. Tuuri and S. C. Leterme, "How plastic debris and associated chemicals impact the marine food web: A review," *Environ. Pollut.*, vol. 321, no. July 2022, 2023, doi: 10.1016/j.envpol.2023.121156.
- [2] C. Cai, L. Zhu, and B. Hong, "A review of methods for modeling microplastic transport in the marine environments," *Mar. Pollut. Bull.*, vol. 193, p. 115136, 2023, doi: 10.1016/j.marpolbul.2023.115136.
- [3] V. Aliko, C. R. Multisanti, B. Turani, and C. Faggio, "Get Rid of Marine Pollution: Bioremediation an Innovative, Attractive, and Successful Cleaning Strategy," *Sustain.*, vol. 14, no. 18, 2022, doi: 10.3390/su141811784.
- [4] J. Nikiema and Z. Asiedu, "A review of the cost and effectiveness of solutions to address plastic pollution," *Environ. Sci. Pollut. Res. Int.*, vol. 29, pp. 24547–24573, 2022, doi: 10.1007/s11356-021-18038-5.
- [5] L. Tian, Y. Yin, W. Bing, and E. Jin, "Antifouling Technology Trends in Marine Environmental Protection," *J. Bionic Eng.*, vol. 18, no. 2, pp. 239–263, 2021, doi: 10.1007/s42235-021-0017-z.
- [6] M. M. El-Sheekh, H. Y. El-Kassas, and S. S. Ali, "Microalgae-based bioremediation of refractory pollutants: an approach towards environmental sustainability," *Microb. Cell Fact.*, vol. 24, no. 1, 2025, doi: 10.1186/s12934-024-02638-0.
- [7] J. Shamshad and R. Ur Rehman, "Innovative approaches to sustainable wastewater treatment: a comprehensive exploration of conventional and emerging technologies," *Environ. Sci. Adv.*, vol. 4, no. 2, pp. 189–222, 2024, doi: 10.1039/d4va00136b.
- [8] X. Wang and M. Shafieezadeh, "A decision framework for sustainable industrial water pollution control to protect marine environments," *Mar. Pollut. Bull.*, vol. 214, p. 117726, 2025, doi: 10.1016/j.marpolbul.2025.117726.
- [9] R. Krishnan, S. Manikandan, R. Subbaiya, N. Karmegam, W. Kim, and M. Govarthanan, "Recent approaches and advanced wastewater treatment technologies for mitigating emerging microplastics contamination - A critical review," *Sci. Total Environ.*, p. 159681, 2022, doi: 10.1016/j.scitotenv.2022.159681.
- [10] S. Kato and Y. Kansha, *Comprehensive review of industrial wastewater treatment techniques*, vol. 31, no. 39, 2024. doi: 10.1007/s11356-024-34584-0.
- [11] A. Dhaka and P. Chattopadhyay, "A review on physical remediation techniques for treatment of marine oil spills," *J. Environ. Manage.*, vol. 288, p. 112428, 2021, doi: 10.1016/j.jenvman.2021.112428.
- [12] K. Bernat, "Energies 2023, 16, 3504. <https://doi.org/10.3390/en16083504>," *Energies*, vol. 16, no. 8, p. 3504, 2023, [Online]. Available: <https://www.mdpi.com/1996-1073/16/8/3504>
- [13] F. Dell' Anno, E. Rastelli, C. Sansone, A. Dell' Anno, C. Brunet, and A. Ianora, "Bacteria, fungi and microalgae for the bioremediation of marine sediments contaminated by petroleum hydrocarbons in the omics era," *Microorganisms*, vol. 9, no. 8, 2021, doi: 10.3390/microorganisms9081695.
- [14] A. Saravanan, S. Jeevanantham, S. Karishma, B. Tajsabreen, P. Yaashikaa, and B. Reshma, "Effective water/wastewater treatment methodologies for toxic pollutants removal: Processes and applications towards sustainable development," *Chemosphere*, vol. 280, p. 130595, 2021, doi: 10.1016/j.chemosphere.2021.130595.
- [15] J. Winther et al., "Integrated ocean management for a sustainable ocean economy," *Nat. Ecol. Evol.*, vol. 4, pp. 1451–1458, 2020, doi: 10.1038/s41559-020-1259-6.
- [16] M. N. Hutagaol and F. Hidayah, "Sustainable bioremediation techniques for mitigating marine pollution in maritime operations," *JPBI (Jurnal Pendidik. Biol. Indones.)*, 2025, doi: 10.22219/jpbi.v11i1.39484.
- [17] D. Laishram, S.-B. Kim, S. Lee, and S. Park, "Advancements in Biochar as a Sustainable Adsorbent for Water

- Pollution Mitigation," *Adv. Sci.*, vol. 12, 2025, doi: 10.1002/advs.202410383.
- [18] R. N. Mankaa and M. Traverso, "Regional management options for floating marine litter in coastal waters from a life cycle assessment perspective," *Int. J. Life Cycle Assess.*, vol. 28, no. 12, pp. 1705–1722, 2023, doi: 10.1007/s11367-023-02236-z.