

## Advanced Adsorbent Materials for Sustainable Recovery of Light Rare Earth Elements: A Review and Bibliometric Study

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### Structured Abstract

**Background:** The expected global demand for light rare earth elements (LREEs) such as lanthanum, cerium, neodymium, praseodymium, promethium, samarium, and europium has increased the demand for sustainable, environment-friendly, and efficient recovery technology. LREEs are crucial components of high-tech manufacturing and applications such as electronics, renewable energy, and catalytic systems. However, the traditional methods often pose economic and environmental challenges due to the high energy usage, secondary pollution, and limited resources. This paper reviews the latest trends in adsorption-based recovery methods with a particular interest in developing advanced adsorbent materials and a bibliometric analysis to identify key trends and research gaps.

**Methods:** In this study, two methods were used: a systematic literature review and bibliometric analysis based on the Web of Science (WOS) database, which were performed to derive 373 articles published between years of 2020 and 2025 using keywords such as “adsorption”, “light rare earth elements”, and “advanced adsorbent”. The program VOS viewer was used to visualize research clusters and construct co-occurrence networks. Recovery methods such as adsorption, solvent extraction, biosorption, ion exchange, precipitation, functionalized adsorption, membrane separation, bioleaching, magnetic separation, and electrochemical methods were critically evaluated based on their selectivity, cost, environmental impact, and effectiveness.

**Results:** The created bibliometric map has revealed that the four main research areas were source materials, leaching and pre-treatment, adsorption material and mechanisms, and post-adsorption purification. The most promising of these methods is functionalized adsorption because of its selectivity and high capacity for LREEs, especially when using bio-based or nanostructured materials like graphene oxide, metal-organic frameworks (MOFs), chitosan, and activated carbon. However, there are challenges in scalability, regeneration, and cost.

**Conclusion:** In conclusion, the review provides a deep insight into current trends and possible directions of long-term sustainable LREE recovery. A combination of data-driven bibliometric mapping and advanced adsorbent materials gives valuable insights on improving material design, making the process more efficient, and directing future studies. The findings can be used to create green and circular economy plans to reduce environmental impacts and dependence on primary resources.

**Keywords:** Light Rare Earth Elements, Recovery Methods, Bibliometric Analysis, Advanced Adsorbents, Sustainable Materials

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