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Incorporation of Green Chemistry and Renewable Energy for sustainable development: A Mini Review

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Abstract
Green chemistry and renewable energy are two of the most important fields in science and technology. Green chemistry, also known as environmentally friendly chemistry or clean chemistry, is dedicated to reducing or eliminating the use of harmful substances and focusing on chemicals and chemical processes that are beneficial for the environment. Renewable energy is a significant direction in the field of green chemistry. With global warming and a constantly increasing demand for energy, the need for conscious and responsible use of existing resources and finding new ways of obtaining energy is becoming more and more urgent. Green chemistry seeks to create environmentally safe chemical processes, and renewable energy is aimed at finding alternative ways of obtaining energy. This literature review summarizes recent research on green chemistry and renewable energy.
Keywords: *Green chemistry; Renewable energy; Global warming.*

Introduction

Green chemistry emphasizes designing chemical processes that reduce or eliminate hazardous substances, while renewable energy focuses on sustainable energy sources like solar, wind, and biofuels. Their integration is crucial for achieving sustainable development goals (SDGs), reducing carbon footprints, and promoting circular economies. The convergence of green chemistry and renewable energy is an extremely promising direction for scientific enterprise. Green chemistry can facilitate renewable energy by designing safer batteries, non-toxic photovoltaic cells, more efficient catalysts for biofuel synthesis, and cleaner methods of production and manufacturing. At the same time, renewable energy can advance green chemistry by enabling zero-emission chemical synthesis, providing alternative ways for industrial production, and allowing for a more sustainable energy footprint.

This literature review will explore this topic by analysing the ways in which green chemistry and renewable energy can intersect and contribute to humanity's sustainable future. The review will assess the available literature on the subject and highlight the primary technological and theoretical approaches that can be used to connect the two fields and further scientific knowledge in these domains. This study will contribute to the field by consolidating the scientific understanding of the relationship between green chemistry and renewable energy.

1. Foundations of Green Chemistry and Sustainable Development

Green Chemistry is a concept that implies the design of chemical products and processes to reduce the hazards they produce through waste minimization, less dangerous solvents and auxiliaries, renewable feedstocks and energy inputs, and efficient energy usage [1]. Out of these principles, the 12 green chemistry principles developed by Anastas and Warner, are the most essential with a strong emphasis on waste prevention, atom economy, safer chemicals, catalysis, and renewable feedstocks [2].

Sustainable development aims to maintain the balance between environmental, economic, and social aspects, and green chemistry principles are aligned with these goals, reducing waste and ensuring sustainable resource use while meeting economic and social needs.

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2. Advances in Green Chemistry Relevant to Renewable Energy

The latest research reports illustrate a connection between green chemistry and renewable energy in several ways:

- The use of **renewable feedstocks** such as biomass and biodegradable polymers to produce energy and materials reduces reliance on fossil fuels [3].
- **Catalysis** offers promising solutions through the use of biocatalysts, heterogeneous catalysts, or photocatalysts which reduce energy requirements and increase selectivity in chemical reactions [4].
- **Green solvents** such as supercritical carbon dioxide, ionic, and deep eutectic solvents can lessen toxicity and waste [5].

- **Nanomaterials** and their green synthesis are also being considered due to photocatalytic and solar energy applications such as the synthesis of silver nanoparticles and zinc oxide nanomaterials [6].

3. The Application of Renewable Energy in Green Chemistry

The application of renewable energy is increasingly employed in green chemistry to develop new chemical processes and products:

- The use of **solar, wind, hydro, and biomass energies** provide clean electricity for chemical production with decreased greenhouse gas emissions [7].
- Production of **green catalysts** by applying renewable energy contributes to the creation of high-efficiency chemical reactions.
- **Inorganic nanostructured** materials can be applied for improved solar cells and energy storage.
- **Green ammonia** production by using renewable energy and novel catalysts allows decreasing carbon emissions [8].

This way, the integration of renewable energy sources into various chemical processes and products contributes to the sustainability of chemical production.

4. Synergies Between Green Chemistry and Renewable Energy

The literature discusses several synergies between green chemistry and renewable energy, including energy-efficient synthesis, circular economy, pollution prevention, and sustainable materials.

- **Energy-efficient synthesis** refers to the use of catalysts and optimized reaction conditions to lower the energy required for chemical reactions, thus supporting the adoption of renewable energy sources in industrial processes [9].
- **Circular economy** is facilitated by using renewable energy sources and developing waste-to-resource processes within the chemical industry.
- Green chemistry helps **prevent pollution** through intensified chemical processes that involve real-time monitoring and avoidance of harmful solvents.
- Finally, because of its emphasis on **sustainability**, green chemistry informs the creation of new materials, including polymers and nanomaterials, which are critical components of emerging renewable energy technologies, such as batteries, solar cells, and fuel cells [10].

5. Challenges and Future Direction

Although significant progress has been made in the field of green chemistry, there are still some challenges ahead, including:

- **High costs and low efficiency** of renewable feedstocks and green catalysts [11].
- **Regulatory and technical barriers** to implementing innovative green chemical processes.
- **The need for standardized sustainability metrics** for assessing the environmental impact of chemical processes.
- **A lack of awareness and education** in the principles of green chemistry in both academic and industrial settings [12].

The future of green chemistry should be dedicated to the development of new methods and technologies, such as:

- scalable green synthesis
- AI-assisted catalyst design
- renewable energy integration into chemical processes
- interdisciplinary collaboration to advance the field

Conclusion

The literature reviewed here provides clear evidence that embracing green chemistry, as well as renewable energy, contributes to sustainability. Green chemistry principles provide safe and smart ways to engage in chemical processes, whereas renewable energy offers sustainable

sources of electricity and other fuels that can make production processes less harmful to the environments.

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