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Role of Green Chemistry Achieving Climate Justice

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ABSTRACT

Climate change is one of the most pressing challenges of the 21st century and has negatively impacted the lives of vulnerable groups, which causes social, economic, and environmental inequalities. Accordingly, climate justice implies the fair distribution of environmental benefits and burdens and equitable access to sustainable resources. Global warming has been targeted by scientists using green chemistry principles, which have been acknowledged and valued for their contribution to sustainable industrial development. Since green chemistry promotes the use of environmentally friendly chemical processes, it helps achieve a lower level of hazardous waste, greenhouse gas emissions, and energy consumption. The current research analyzes the role of green chemistry in climate justice from the standpoint of relevant literature, current technologies, and actual practices. The paper provides an overview of the 12 principles of green chemistry and analyzes their contribution to the reduction of greenhouse gas emissions, production of renewable energy, development of green catalysts, creation of biodegradable materials, and development of environmental-friendly agricultural and pharmaceutical technologies. The results indicate that attention to the process of green chemistry helps to minimize the level of environmental degradation and eliminate inequality in access to clean technologies.

Introduction

The issue of climate change is one of the greatest environmental challenges faced by people in the XXI century. Global warming, natural disasters, loss of biodiversity, melting of glaciers, rise of sea levels, water crisis and increasing pollution have severe environmental and socio-economic effects all over the world. The latest scientific research showed that the impact of climate change is being intensified by an increase of greenhouse gas emissions because of industrial development, fossil fuel consumption, unsustainable agricultural practices and excessive use of natural resources. These changes have a serious effect on vulnerable groups of people, especially in developing countries. Thus, climate change is not only an environmental issue, but also a matter of social justice and human rights. (IPCC, 2023; UNEP, 2023; Anastas & Warner, 1998). To solve these inequalities, the idea of climate justice emerged with a focus on fairness in addressing the problem of climate change, which would guarantee equality in the matter of governance and access to natural resources. Climate justice recognizes that those countries and communities which least contribute to global greenhouse gas emissions face the greatest damage. Thus, sustainable development will require the implementation of technologies and policies aimed at minimizing environmental impact of human activity while making sure that the access to green energy, clean water, healthy environments and economic opportunities is equal for everybody. Chemistry has always played a crucialThe traditional methods of producing chemicals require the use of hazardous substances, solvents and a lot of energy, and lead to solid waste generation. Such a situation results in air, water, soil pollution, greenhouse gas emissions, and health problems. Associated with the growth of industries, it is obvious even today that innovative technologies in the field of chemistry are needed to promote economic development without causing harm to the environment.

Green Chemistry is a recent solution to this problem. Having appeared in the 1990s, it elaborates on the chemical design that minimizes or eliminates the need to use hazardous materials. Green Chemistry is based on the principle of pollution prevention rather than pollution elimination. As this approach is implemented, the environment-friendly and resource-efficient manufacturing process will be obtained. The emergence of green chemistry will ensure the transformation of various industries thanks to the availability of various effective solutions, such as green catalysts, bio-materials, biopolymers, solvent-free synthesis, etc.These new scientific practices provide evidence of the possibility of combining environmental care with economic development. An important achievement of green chemistry is its contribution to the reduction of greenhouse gas emissions during the life cycle of chemical substances. The use of renewable raw materials and energy-efficient production technologies can significantly reduce the pollution of the atmosphere by industries. Apart from that, green chemistry aids in moving towards the circular economy, promoting recycling, recovery of raw materials, and sustainable consumption. This approach allows the preservation of natural resources while reducing the adverse effects on the environment and is conducive to the fight against climate change.

Green chemistry is also vital for environmental justice as it lowers the possibility of exposure of vulnerable communities to dangerous chemicals and other pollutants. Usage of cleaner production leads to the improvement of the quality of water and air and the minimization of occupational health risks and environmental dangers. These benefits are especially significant for developing countries with poor environmental legislation and waste management systems. On top of industrial applications, green chemistry is also important for the achievements of several UN Sustainable Development Goals (SDGs) such as SDG 3 (Good Health and Well-being), SDG 6 (Clean Water and Sanitation), SDG 7 (Affordable and Clean Energy), SDG 9 (Industry, Innovation, and Infrastructure), SDG 12 (Responsible Consumption and Production), SDG 13 (Climate Action), and SDG 15 (Life on Land). The implementation of green chemistry in the national policies and strategies of industrial development can accelerate the achievement of global sustainability goals.

While great success has been attained, there are still a number of issues hindering the development of green chemistry. The initial costs of investment, technological infrastructure, and the level of awareness about, as well as political support of, green chemistry are still challenges that should be overcome, especially in low- and middle-income countries.

Literature Review

Green chemistry is swiftly emerging as one of the most vital scientific techniques for sustainable development and combating climate change. Researchers over the last three decades have presented abundant evidence that green chemical techniques can significantly decrease pollution, greenhouse gas emissions, hazardous waste generation, and depletion of resources. Recent studies point to the fact that green chemistry is not just an eco-friendly approach but also an effective means of promoting climate justice. The concepts of green chemistry were invented by Paul T. Anastas and John C. Warner with the help of the twelve principles of green chemistry directed towards the pollution prevention, atom economy, safety in chemical synthesis, renewable materials, energy efficiency, catalysis, and designing of biodegradable products. Studies have shown that applying these principles reduces pollution of the environment and encourages the establishment of higher productivity and economic sustainability. The authors point out that traditional chemical industries are the key sources of greenhouse gas emissions since they rely on fossil fuels, toxic solvents, and energy-consuming production methods. The research shows that the emergence of green chemicals in contrast with traditional practices such as solvent-free reactions, microwave-assisted synthesis, photocatalysis, biocatalysis, and use of biomass-derived chemicals has improved the efficiency of processes and has led to a considerable decrease in carbon emissions. There are increasing connections in the literature between green chemistry and environmental justice.The authors Wang and colleagues (2023) discuss the background of how environmental injustices are closely linked to the use of toxic chemicals that cause adverse effects primarily to economically weaker regions. According to their research, green chemistry creates a favorable solution to this problem through modification of chemical manufacturing processes that reduce pollution from hazardous chemicals in the first place.

Climate justice literature emphasizes the idea that developing countries are responsible for significantly lower amount of greenhouse gases; however, they suffer more from climate change's effects (including floods, droughts, hunger, health dangers, and extinction of species compared to developed nations). Therefore, researchers recommend using green chemistry to promote sustainable industrial development and use of renewable energy technologies for cleaning production in these countries.

In particular, the pharmaceutical industry has benefitted from the concepts of green chemistry as well. Scientists have created environmentally friendly synthetic methods for manufacturing chemical products that minimize consumption of solvents, increase reaction yield, create fewer toxic by-products, and decrease manufacturing costs. The use of green catalytic reactions, flow chemistry, enzyme-based synthesis, and bio-based solvents improves the environmental efficiency of chemical production while making production more competitive.

Green chemistry technologies are also used in agriculture since many eco-friendly pesticides, bio-fertilizers, controlled-release fertilizers, and plant-based chemicals have been developed. These technologies allow decreasing soil pollution and ecological toxicity while increasing the effectiveness of agriculture.

Scientists are also analyzing how green chemistry helps develop renewable energy technologies. For example, hydrogen production, production of batteries, biomass technologies, materials for carbon capture, and economical photovoltaic devices will demonstrate how green chemistry helps create low-carbon energy systems. Therefore, these technologies are expected to reduce the reliance on fossil fuels and facilitate the establishment of climate mitigation goals.

Green chemistry is also used in water treatment, where it has already proven to be effective. The development of biodegradable absorbents, eco-friendly membranes, photocatalytic nanomaterials, etc. will enhance the capacity for removing pollutants from wastewater. Nevertheless, despite these numerous achievements of green chemistry, many studies still identify challenges in its application. The main barriers are high initial investment costs, lack of technological infrastructure, lack of awareness among industries, lack of incentives from governments, and lack of sufficiently trained specialists. The authors of the articles suggest that stronger environmental regulations, higher research budgets, transfer of technology, and education can help overcome these hurdles.

Overall, the existing studies demonstrate that green chemistry is an effective scientific approach to solving the problems of pollution.

Methodology

Research Design-The current investigation adopts a research design that is descriptive and qualitative and encompasses a thorough review and critical analysis of literature related to the field of science. The rationale behind selecting the literature approach is the aim of the present study, which is to analyze the influence of green chemistry on climate justice. The current work makes use of theories, scientific facts, case studies, and technological achievements to determine how green chemistry is able to help reduce environmental pollution.

Data Sources-The present research is completely based on secondary data obtained from well-known and reputable academic sources. In this connection, scientific data has been gathered from journal articles, review articles, books, conference and seminar proceedings, as well as reports prepared by international companies and organizations, which are mentioned below:

Springer Nature, Elsevier (Science Direct), Wiley Online Library, American Chemical Society (ACS), Royal Society of Chemistry (RSC), Journals of MDPI, Google Scholar, United Nations Environment Programme (UNEP), Intergovernmental Panel on Climate Change (IPCC), World Health Organization (WHO)

All of the above-mentioned sources were chosen because they give reliable up-to-date scientific data about green chemistry.

Literature Selection Criteria- Relevant literature was searched through the use of the following keywords: green chemistry, climate justice, sustainable developments, reduction of emissions, renewable resources, green catalysis, circular economy, environmentally friendly production, and obtaining of climate justice. The priority was given to research papers that were published in the last ten years (2015-2025) along with significant writings relevant to the research topic, to form theoretical and historical background for the research.

The criteria by which the selected literature was analyzed were the following:

•Peer-reviewed papers published in scientific journals.
•Relevant to the field of green chemistry and climate justice,
•Substantiated by evidence-based results for sustainable technologies.
•Discussed industrial, environmental, or policy applications.
•Written in English and available in approved scientific databases.

Publications that do not provide scientific significance and relevance to the research questions were eliminated.

Data Collection Methodology- An organized literature search was made using electronic databases and scientific libraries. The identified publications were screened properly by reviewing title, abstract, and body text in order to find out their relevance for research purposes. The information collected regarding the concepts of green chemistry, sustainable industrial processes, renewable energy technologies, pollution prevention methods, carbon mitigation, and environmental justice was properly organized depending on the research objectives.

The identified data are classified into major themes such as:

•Green Chemistry Principles,
•Sustainable Industrial Processes,
•Renewable Feedstocks,
•Green Catalysis,
•Energy-Efficient Chemical Synthesis,
•Waste Minimization,
•Carbon Emission Reduction,
•Circular Economy,
•Climate Justice.

Data Processing-The analyzed information was organized in a thematic way. Similar ideas, studies, and technological advancements were clustered together in order to discover connections between green chemistry and climate justice. Additionally, a comparative study was conducted to determine environmental, economic, and social advantages of green chemistry as compared to traditional chemical methods.

The research also focused on establishing the ways in which green chemistry can help to:

•Minimize greenhouse gas emissions.
•Prevent hazardous chemical contamination.

•Preserve natural resources.
•Enhance public health.
•Encourage renewable energy technologies.
•Sustainable industrial growth.
•Fair environmental protection for vulnerable people.

The results obtained from various studies were compared and summarized in order to come up with a clear conception of the role of green chemistry in the achievement of climate justice.

Conceptual Framework-This study is based on the assumption that green chemistry principles enable the creation of eco-friendly industrial processes that reduce pollution, improve resource efficiency, decrease greenhouse gas emissions, and contribute to climate justice. The framework highlights the link between sustainable innovations in the field of chemistry and equitable environmental protection and development.

Green chemistry principles → Sustainable industrial practices → Reduced pollution and emissions → Protection of the environment → Climate justice → Sustainable development

Research Scope-The present research mainly tackles the role of green chemistry in combating climate change via eco-friendly chemical processes and technologies. The study involves the use of green chemistry in pharmaceuticals, agriculture, renewable energy sources, water purification, industrial production, biodegradables, and waste management. Furthermore, it touches upon policy implications and the role of green chemistry in reaching the United Nations Sustainable Development Goals (SDGs).

Limitations-The current research is based solely on secondary data gathered from published scientific literature. No laboratory work, field surveys, or primary data collection were conducted. Hence, the findings rely on the quality and availability of the previous research. In addition, green chemistry is a field that undergoes serious changes with the advent of new technologies and policies thus leading to the obsolescence of some findings in the future. Still, the authors believed that utilizing recent peer-reviewed sources allows them to get a competent and thorough evaluation of green chemistry activation in climate justice achievement.

Results and Discussion

Overview of the Research Results-The published scholarly literature indicates that green chemistry is essential in tackling climate change and advancing climate justice. Investigation results show the application of green chemistry principles leads to reduction in pollution of the environment, decrease in greenhouse gas emissions, conservation of natural resources, and improvement of industrial sustainability. In addition, green chemistry processes bring social and economic fans by boosting the quality of public health, creating jobs in the area of environmentally friendly jobs, and providing equal opportunitiesaccess to cleaner production processes. Overall, these results contribute to gaining climate justice, by decreasing the level of unfair environmental problems faced by marginally poor people (Chen et al., 2020; UNEP, 2023; WHO, 2021).

Green Chemistry and Decrease of Greenhouse Gas Emissions-The most significant outcome of the research is the fact that green chemistry plays a crucial role in combating greenhouse gas emissions. Traditional chemical industry utilizes fossil fuels, energy-intensive production methods, and toxic agent leading to the increase of CO_2, CH_4, and N_2O emissions. According to the literature, the implementation of energy-efficient technology, the use of renewable feedstock, catalytic chemical reactions, and solventless reaction lead to the reduction of carbon emissions in the manufacturing sector mean.The philosophy of green chemistry is not to let hazardous waste get produced in the first place, unlike the conventional way of dealing with waste through treatment methods.

Green chemistry innovators reported considerable reductions in:
•Hazardous waste
•Toxic emissions
•Contamination of water
•Air pollution

The introduction of such tools as atom economy, a safer reaction pathway, recyclable catalysts, and biodegradable chemicals enhances the efficiency of production processes at the expense of lowering the environmental impact. The use of cleaner production technologies lowers waste disposal costs and enhances the sustainability of industrial enterprises.

Contribution to Climate Justice-The goal of climate justice is to guarantee equality of every community in being protected from environmental hazards and access to sustainable resources.

The data prove that green chemistry is playing an important role in achieving this goal by cutting down the pollution in areas occupied by industries. Developing countries are exposed to a higher level of environmental hazards despite producing fewer greenhouse gases. Application of green technologies will help them improve air quality, safe drinking water and reduce people's exposure to toxic substances.

Industrial Applications Supporting Sustainability-The reresearched sources show that green chemistry has brought improvement in various industries.

Pharmaceuticals -Green chemistry practices are responsible for the reduction of hazardous waste in this industry. New technologies allow for continuous flow synthesis, enzyme catalysis, and recycling the solvent without any effect on the quality of the produced drugs.Agricultural Industry. The field of green chemistry has enabled the production of bio-fertilizers and plant-based growth regulators among others. The introduction of such technologies has contributed to improving soil fertility, minimizing pollution from chemicals, and advancing sustainable agricultural practices.

Water Purification-The use of bio-based adsorbents and catalytic materials as well as advanced oxidation and membrane techniques have positively transformed the process of water treatment. This technology guarantees the removal of undesirable substances such as heavy metals, colors, drugs, and organic pollutants with the minimum level of secondary pollution.

Plastic Manufacturing-Biodegradable plastic is made out of natural compounds like starch, cellulose, and polylactic acid.

Its application helps to combat against plastic pollution and make a positive contribution toward the development of a circular economy.

Renewable Energy-Green chemistry has considerably boosted research in hydrogen manufacturing, bio fuels, fuel cells and battery materials technologies.

The inventions help reduce dependency on fossil fuels in turn facilitating the establishment of environmentally-friendly energy systems.

Economic Aspect of Green Chemistry-The results suggest that green chemistry provides significant economic benefits in addition to ecological ones.

The main economic benefits are as follows:
-Reduced consumption of raw materials,
-Reducing energy consumption,
-Lower costs of waste management,
-Improved efficiency of production,
-Higher efficiency of resource consumption,
-Better industrial competitiveness,
-New job opportunities.

The initial costs of implementing green technologies might be high, nevertheless, the reduction of costs associated with these technologies in the long run compensates for this initial investment.Contribution towards Sustainable Development Goals (SDGs). The evaluation shows that green chemistry directly impacts a number of Sustainable Development Goals (SDGs) formulated by the United Nations. The green chemistry facilitates:
•SDG number three (Good Health and Well-being) which is achieving by decreasing poisonous chemicals usage.
•SDG number six (Clean Water and Sanitation) through diminishing water pollution.
•SDG number seven (Affordable and Clean Energy) by means of using renewable energy technologies.
•SDG number nine (Industry, Innovation and Infrastructure) as sustainable industrial practices are implemented.
•SDG number twelve (Responsible Consumption and Production) because of waste reduction and resource efficiency.
•SDG number thirteen (Climate Action) by means of greenhouse gas emissions decline.
•SDG number fifteen (Life on Land) because of biodiversity and environmental decay reduction.

Challenges-Despite the overwhelming benefits, in the paper, a number of obstacles on the way to implementation of green chemistry has been identified. These impediments are:
•High costs of modern technologies usage.
•Lack of awareness in industries.
•Inadequate funding for the research.
•Lack of specialists.
•Some developing countries have weak environment standards.

•Limited accessibility of renewable resources.
•Slow process of environmental technology transfer from developed countries to developing countries.

Future Development-The outlook of the green chemistry is quite bright as a progress in the field of artificial intelligence, machine learning, nanotechnology, biotechnology, production of green nanomaterials, carbon capture technologies, and bio-based production is anticipated. The future scientific research needs to be aimed at creating affordable ways of producing green technology for low- and middle-income countries. The cooperation should be established between states, governmental organizations, and research institutions, as well as private sectors to make innovations and achieve a more equal climate solution. Thus, the results of the research proves that green chemistry can be regarded as a complex strategy of solving issues related to the deterioration of nature and inequality. Green chemistry offers real solutions for the challenges arising in connection with climate changes due to its capability of preventing pollution and minimizing exhaust fumes.

Conclusion

Among the biggest global challenges the world is currently facing is climate change. The findings of this study indicate that green chemistry serves as a useful and effective scientific approach to addressing climate change while promoting climate justice. Through the redesign of chemical products and processes to minimize or even eliminate waste and toxic products, green chemistry plays a big role in minimizing pollution, protecting natural resources, and increasing energy efficiency. The literature analyzed in this study shows that the use of the twelve principles of green chemistry has contributed to an increase in sustainability in various sectors, including pharmaceuticals, agriculture, water treatment, renewable energy and chemicals production. Green technologies such as green catalysis, renewable resources, biodegradable materials, solvent-free synthesis, bio-based chemicals, and waste reduction methods have proven their effectiveness in reducing the negative environmental impact of industries while ensuring high profitability. Another important conclusion that can be drawn from the research done is that green chemistry helps achieve climate justice. Climate justice is an idea that all people should equally benefit from the environmental advantages of development and should not bear the negative consequences of pollution and climate change.The utilization of green chemistry minimizes the risk of chemical exposure, enhances air and water quality, improves ecological systems, and promotes the health of the population. This is especially important for developing nations and underprivileged communities where environmental deterioration leads to severe socio-economic inequalities. The application of green chemistry has proven its value in aiding the fulfillment of the UN Sustainable Development Goals, especially in facilitating health improvement, provision of clean water and energy, responsible consumption, sustainable industry, climate-related actions, and nature preservation. Green chemistry, despite all its advantages, still confronts numerous obstacles for its global implementation, such as high initial costs, low awareness, and technical skills available, little support from the policymakers, and restricted access to high technologies across many developing countries. Constituting the factors necessary to eliminate the above-mentioned barriers requires the support of the governments, increased funding for research and development, the initiating of environmental legislation, and cooperation of industries. Innovation development in green chemistry is expected to go ahead thanks to the use of artificial intelligence, biotechnology, and nanotechnology, renewable energy solutions, carbon capturing technologies, and circular systems. All in all, green chemistry is much more than an environmentally friendly method of chemical production.

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