eISSN 2583-6986
IDEALISTIC JOURNAL OF ADVANCED RESEARCH IN PROGRESSIVE SPECTRUMS (IJARPS)
A MONTHLY, OPEN ACCESS, PEER REVIEWED, INTERNATIONAL JOURNAL
Volume 05, Issue 03, March 2026

Climate Change and Green Chemistry: The Scientific Foundation of a Developed India 2047

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Received: 21 March 2026 Accepted & Reviewed: 25 March 2026, Published: 31 March 2026

Abstract

India's aspiration to achieve developed-nation status by 2047 the centenary of its independence `depends on the nation's ability to combine economic expansion with ecological balance. Climate change, manifested through temperature rise, irregular monsoons, sea-level increase, and resource scarcity, presents a profound challenge to sustainable development. In parallel, conventional industrial practices relying on toxic chemicals and fossil-based processes have aggravated Environmental degradation. This paper explores how integrating *green chemistry* with *climate science* can create the scientific base for a resilient and developed India. It analyses India's climate vulnerabilities, explains the principles of green chemistry, and illustrates how their intersection can support clean industrialisation. The paper further outlines sector-wise applications and policy recommendations. It concludes that a "green chemistry-driven, climate-resilient economy" provides a credible and scientific pathway toward a developed India by 2047.

Key Words: Climate Change, Green Chemistry, Sustainable Development, Circular Economy, Low-Carbon Industry, Renewable Energy, Environmental Policy, Industrial Decarbonisation, Climate Resilience, Developed India 2047

Introduction

India stands at a critical juncture in its developmental trajectory. Rapid urbanisation, population growth, and industrial expansion have propelled economic progress but also intensified environmental stress. Rising greenhouse-gas emissions, deforestation, and industrial pollution have placed significant pressure on air, water, and soil quality. Simultaneously, climate change is intensifying extreme weather events, threatening livelihoods and infrastructure. To achieve the vision of *Viksit Bharat 2047* (Developed India 2047), the country must adopt a model of industrialisation that is both resource-efficient and environmentally sustainable. Green chemistry the design of chemical products and processes that reduce or eliminate hazardous substances offers a scientific route to achieve this transformation. By merging the knowledge of climate change mitigation and adaptation with green chemistry innovations, India can advance toward an industrial revolution that supports economic prosperity while preserving ecological integrity.

2. Climate Change: Challenges and Implications for India

2.1 Global Perspective: Climate change, primarily driven by human-induced emissions of carbon dioxide, methane, and nitrous oxide, has altered global temperature and precipitation patterns. The consequences include heatwaves, floods, droughts, and changing oceanic cycles. The chemical and manufacturing sectors major contributors to global emissions—are now expected to innovate towards cleaner, low-carbon alternatives. Studies indicate that adopting environmentally benign chemical routes can cut lifecycle emissions by up to ninety percent compared to conventional fossil-based methods (Pandey et al., 2025).

2.2 India's Climate Vulnerability: India is among the world's most climate-vulnerable nations due to its vast population, long coastline, dependence on monsoon-based agriculture, and limited adaptive capacity. Research projects that residential cooling demand could rise by more than one hundred percent by the century's end (Gupta et al., 2024). Meanwhile, Himalayan glaciers are melting rapidly, threatening river systems and water security (Dibrugarh University, 2024). Coastal cities such as Mumbai, Chennai, and Kolkata face inundation risks, while arid regions in Rajasthan and central India are becoming drier.

2.3 Developmental Consequences: Climate change impacts multiple sectors of the Indian economy, posing complex challenges to sustainable growth. In agriculture, increasing variability in rainfall, soil degradation, and rising temperature extremes have significantly reduced crop productivity and threatened food security. Water resources are under strain as glacier retreat and altered river flows disrupt freshwater availability for both agriculture and domestic use. The energy sector faces additional pressure from growing demand for air-conditioning and cooling, which drives higher electricity consumption and burdens existing power grids. Public health is similarly at risk, with more frequent heatwaves, the spread of vector-borne diseases, and worsening air pollution contributing to elevated health hazards. Industrial and trade sectors also face emerging economic risks, as carbon-intensive exports may be subjected to tariffs under international mechanisms such as the EU Carbon Border Adjustment (Financial Times, 2023). Addressing these multifaceted challenges necessitates a comprehensive transformation of industrial practices one in which green chemistry plays a pivotal role by enabling cleaner production, reducing emissions, and fostering sustainable development.

3. Green Chemistry: Concept, Principles, and Importance

3.1 Definition and Core Principles: Green chemistry is defined as the design of chemical products and processes that minimise the use or generation of hazardous substances (Government of India, 2024). The field rests on twelve guiding principles—such as waste prevention, atom economy, energy efficiency, renewable feedstocks, catalysis, and design for degradation—that prioritise safety and sustainability from the molecular level onward. Rather than managing pollution after production, sustainable chemistry promotes prevention at the design stage.

3.2 Relevance to Indian Industry: India's industrial growth depends heavily on energy, water, and raw materials. Implementing environmentally sustainable chemistry offers numerous advantages: **(i)** India's industrial growth relies heavily on the continuous availability of energy, water, and raw materials, making sustainability a critical factor in its long-term development strategy. The adoption of green chemistry principles provides a transformative opportunity to enhance industrial efficiency while reducing environmental impact. **(ii) Resource Efficiency:** By optimizing chemical reactions and industrial processes, sustainable chemistry minimizes the consumption of feedstocks, water, and energy, leading to higher productivity and lower operational costs. **(iii) Pollution Reduction:** Cleaner synthetic routes and environmentally benign processes significantly reduce effluent discharge and air pollution in industries such as pharmaceuticals, textiles, and fertilizers *(Kapoor & Mehendale, 2021)*. These approaches contribute to achieving India's environmental compliance goals and improving public health outcomes. **(iv) Global Competitiveness:** Eco-friendly and sustainable production methods enable Indian industries to meet international environmental standards, thereby improving export potential and competitiveness in global markets. The shift toward sustainability also strengthens India's reputation as a responsible manufacturing and innovation hub. **(v) Circular Economy Integration:** Environmentally benign and sustainable chemistry supports the principles of a circular economy by encouraging recyclability, reuse, and biodegradability *(Khare & Srivastava, 2025)*. This integration not only reduces waste and resource depletion but also fosters new business models cantered on material recovery and sustainable product design. **(vi) Innovation and Research:** Continued advancements in catalysis, nanotechnology, and bio-based chemistry reinforce India's scientific and technological capabilities. Strengthening research and innovation ecosystems in these areas can drive the creation of sustainable industrial materials, cleaner technologies, and renewable chemical processes, ensuring that India's industrial growth aligns with both climate goals and global sustainability benchmarks.

3.3 Global Developments in Green Chemistry: Globally, the chemical industry is undergoing a shift toward bio-based and carbon-neutral processes. Studies suggest that such routes can cut emissions by up to ninety percent by 2050 (RSC Sustainability, 2024). Moreover, photosynthetic microorganisms such as cyanobacteria are being harnessed to capture carbon dioxide and produce renewable chemicals (Pandey et al., 2025). These global trends position India to become a leader in sustainable chemistry research and application.

4. Climate Science and Green Chemistry: Building Synergy

I. **Decarbonising Industrial Production:** The chemical sector contributes significantly to industrial emissions. Green chemistry can decarbonise this sector by adopting renewable feedstocks, efficient catalysts, and low-energy synthetic routes. Transitioning to environmentally benign and sustainable chemistry, bio-methanol, and biodegradable polymers would drastically reduce India's carbon footprint (Green Chemistry Journal, 2024).

II. **Supporting Climate Adaptation:** As temperatures and weather extremes rise, industries require materials that are both sustainable and resilient. Environmentally benign and sustainable chemistry enables the development of heat-resistant composites, safer refrigerants, and biodegradable packaging. These innovations aid adaptation by reducing vulnerability to climate stress.

III. **Advancing the Circular Economy: Waste** reduction lies at the heart of both climate resilience and sustainable chemistry. Chemical recycling, biodegradable plastics, and closed-loop production systems transform waste into valuable inputs, conserving natural resources while reducing emissions.

IV. **Environmental and Social Co-Benefits: Cleaner** industrial processes lower air and water pollution, leading to improved health outcomes. Reduced chemical exposure also prevents accidents, benefiting workers and communities. Thus, Environmentally benign chemistry not only mitigates climate change but also enhances social welfare.

V. **Strengthening Human Capital:** Developing expertise in green chemistry and climate science nurtures skilled scientists and engineers capable of driving innovation. This investment in human capital strengthens India's knowledge economy—an essential feature of a developed nation.

5. Sectoral Pathways for Sustainable Development

5.1 Energy and Chemical Feedstocks: Decarbonising India's energy sector is central to achieving climate goals. Green chemistry supports this transition through renewable hydrogen, biofuels, and carbon capture technologies. The conversion of carbon dioxide into value-added chemicals and fuels offers a dual advantage of emission reduction and economic gain (Sobha, 2022).

5.2 Construction and Manufacturing: The construction industry accounts for substantial carbon emissions. Green chemistry can replace traditional Portland cement with geopolymer alternatives derived from industrial waste. For instance, IIT Indore developed an eco-friendly concrete using fly ash and slag (Times of India, 2024). Likewise, solvent-free and low-energy manufacturing processes reduce waste and enhance competitiveness.

5.3 Agriculture and Agro-Industries: Agriculture remains the backbone of the Indian economy but faces severe climate stress. Environmentally benign chemistry can help by creating biodegradable pesticides, slow-release fertilisers, and bio-based soil conditioners. Using agricultural residues as biomass for biofuel or bioplastic production strengthens the rural economy and mitigates emissions.

5.4 Waste Management and Recycling: India's growing urban population generates massive amounts of waste. Green chemistry facilitates the chemical recycling of plastics and the conversion of waste biomass into valuable chemicals. Non-toxic solvent systems and safer catalysts further enhance the environmental performance of recycling operations.

5.5 Water and Ecosystem Protection: Water scarcity and pollution are worsening under climate pressure. Ecofriendly chemistry provides advanced purification technologies, including catalytic oxidation, membrane separation, and biodegradable coagulants. These innovations ensure clean water access while conserving energy and reducing chemical hazards.

6. Policy and Research Recommendations:

6.1 Policy Framework: To integrate green chemistry into India's development pathway, a coordinated set of policy measures is essential. Establishing a **National Mission on Green Chemistry and Climate-Resilient Industry 2047** would provide national direction for sustainable industrial transformation. The government should introduce **tax incentives and green financing** to support industries adopting eco-friendly technologies, while **lifecycle-based environmental assessments** must be made mandatory to ensure accountability and resource efficiency. Integrating **ecofriendly chemistry education** into science and engineering curricula will help build a skilled workforce capable of driving innovation in sustainable production. Additionally, promoting **international collaboration** through platforms like the **G20 and UNFCCC** will facilitate the exchange of technology and expertise, strengthening India's position as a global leader in environmentally benign climate-resilient industrial development. Encourage international collaboration under G20 and UNFCCC frameworks to exchange technology and expertise.

6.2 Research and Innovation Priorities: India must make strategic investments in **research and technological innovation** to advance the goals of green chemistry and climate resilience. Priority areas include the **development of advanced catalysts and eco-friendly solvents** that improve process efficiency while reducing environmental harm. Significant potential also lies in the **utilisation of carbon dioxide as an industrial feedstock**, converting emissions into valuable products such as fuels, chemicals, and polymers. Further, India should focus on the **creation of biodegradable materials and sustainable polymers** to address plastic pollution and promote a circular economy. In parallel, **regional studies on climate–chemistry interactions,** particularly in ecologically sensitive areas like the Himalayas, are essential for understanding how changing climatic patterns affect hydrology and ecosystem stability. Finally, establishing **pilot projects for circular chemical plants and waste-to-resource systems** will demonstrate scalable models of sustainable industrial practice. Collectively, these investments will strengthen India's scientific capacity, foster environmentally benign and sustainable innovation, and support the nation's transition toward a climate-resilient, low-carbon economy by 2047.

6.3 Implementation Strategy: The transformation requires coordinated participation of stakeholders: (i) **Industry:** Conduct ecofriendly audits and set emission-reduction targets. (ii) **Government:** Offer policy consistency, fiscal incentives, and clear regulations. (iii) **Academia:** Strengthen interdisciplinary research and create innovation clusters. (iv) **Civil Society:** Promote consumer awareness and community-level sustainability initiatives. (v) Regular monitoring using indicators such as carbon intensity, waste reduction, and pollution levels should guide policy adjustments.

7. Vision for a Developed India 2047

A truly developed India must reflect not only economic progress but also environmental responsibility. The integration of climate science and green chemistry can redefine development in the following ways: **(i) Low-Carbon Economy**: India's future industrial landscape must be rooted in a low-carbon economy, where industries operate using renewable energy sources. This transition will significantly reduce dependence on fossil fuels and cut greenhouse gas emissions, aligning national progress with global climate goals. **(ii) Sustainable Infrastructure**: To achieve true development, India must invest in sustainable infrastructure urban spaces, transport systems, and buildings designed for efficiency, durability, and climate resilience. Smart city planning and environmental construction practices will minimize resource use while improving the quality of urban life. **(iii) Circular Resource Flow**: Adopting a circular economy model ensures that materials are reused, recycled, or biodegraded rather than discarded. By converting waste into valuable inputs, India can reduce imports, minimize landfill waste, and conserve natural resources, promoting both economic efficiency and environmental protection. **(iv) Scientific Leadership**: India has the potential to become a global leader in sustainable chemistry and climate innovation. Strengthening research institutions, promoting technology transfer, and fostering innovation ecosystems can position the nation as a hub for environmentally sustainable technologies, benefiting both domestic industries and the global market. **(v) Enhanced Quality of Life**: Ultimately, the goal of development is to ensure an enhanced quality of life for all citizens. Cleaner air, safe drinking water, and healthy ecosystems are vital for public health and social well-being. Through the adoption of sustainable chemistry practices, India can build a future where prosperity and environmental integrity coexist.

By integrating climate science and green chemistry into its national development strategy, India can demonstrate that economic growth and ecological sustainability are mutually reinforcing. The nation's journey toward 2047—its centenary of independence—offers an opportunity to showcase how innovation, responsibility, and resilience can together define a truly developed India that leads the world toward a sustainable future.

8. Conclusion

The path to a developed India by 2047 must be built on scientific innovation and environmental stewardship. Climate change poses both risks and opportunities it demands rethinking industrial systems, while green chemistry offers the solutions for cleaner, safer, and more efficient production. Together, these disciplines can transform India into a nation that leads in sustainable technology and inclusive growth. By embracing sustainable chemistry across sectors and aligning it with national climate goals, India can ensure prosperity that does not compromise planetary health. The scientific foundation of a developed India must, therefore, be *green, circular, and climate-resilient* a model for sustainable progress in the twenty-first century.

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