

THE CRITICAL ROLE OF RENEWABLE ENERGY IN MITIGATING CLIMATE CHANGE AND PROMOTING SUSTAINABLE DEVELOPMENT

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ABSTRACT

Renewable energy plays a crucial role in mitigating climate change by reducing greenhouse gas emissions, enhancing energy efficiency, and promoting sustainable development. This study examines the contribution of renewable energy sources such as solar, wind, hydro, and geothermal power in reducing dependence on fossil fuels, which are the primary sources of carbon emissions. The transition to renewable energy not only helps limit global temperature rise but also improves energy security, reduces air pollution, and supports economic growth through job creation in the green energy sector. Renewable energy technologies are central to the decarbonization of the power sector, while advancements in energy storage and grid management enhance system reliability and stability. Moreover, increased adoption of renewable energy mitigates adverse health impacts associated with air pollution and supports the achievement of global climate objectives outlined in international frameworks such as the Paris Agreement. Using quantitative data on emission reductions, energy efficiency improvements, and economic outcomes from countries implementing large-scale renewable energy strategies, this paper provides a concise assessment of the role of renewable energy in climate change mitigation.

KEYWORDS: Renewable Energy, Sustainable Energy, Energy Transition, Clean Energy, Lower Emissions, Sustainable Power.

Introduction

The rapid escalation of greenhouse gas (GHG) emissions resulting from anthropogenic activities has accelerated climate change, making it one of the most pressing challenges of the 21st century. The increasing concentration of carbon dioxide (CO₂) and other harmful gases in the Earth's atmosphere is largely driven by continued dependence on fossil fuels, particularly in electricity generation, transportation, and industrial processes. Consequently, the urgency for effective climate change mitigation strategies has intensified. Among the available approaches, the transition to renewable energy emerges as one of the most viable and sustainable solutions. Renewable energy sources-including solar, wind, hydropower, biomass, and geothermal-offer a clear pathway to reducing reliance on fossil fuels and significantly lowering GHG emissions. Unlike fossil fuels, renewable energy sources generate electricity with minimal CO₂ emissions, enabling countries to move closer to their climate targets

under international agreements such as the Paris Agreement. Moreover, the shift toward renewable energy provides multiple co-benefits, including environmental protection, enhanced energy security, long-term cost reductions, and employment generation within the green economy. Recent technological advancements and supportive policy frameworks have improved the cost-effectiveness and scalability of renewable energy systems. However, challenges remain, including the need for substantial infrastructure investments, political and economic constraints, and intermittency issues associated with solar and wind energy.

Renewable Energy

Renewable energy comprises energy derived from continuously replenished natural sources such as solar, wind, hydropower, biomass, and geothermal resources. In the context of India, renewable energy plays a critical role in reducing greenhouse gas emissions, enhancing energy security, and supporting sustainable development

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objectives. India has emerged as one of the world's leading renewable energy producers, driven by large-scale deployment of solar and wind power and policy initiatives aligned with international climate commitments such as the Paris Agreement. At the sub-national level, Karnataka stands out as a frontrunner in renewable energy adoption, particularly in solar and wind power generation. The state has achieved significant capacity additions through utility-scale solar parks, rooftop solar programs, and extensive wind farms, contributing substantially to its electricity mix. Hydropower continues to play a supportive role, while biomass-based energy systems utilize agricultural residues to promote decentralized and rural energy access.

Sustainable Energy

Sustainable energy refers to energy systems that are capable of meeting present energy demands while minimizing environmental impacts and ensuring long-term resource availability for future generations. It emphasizes the use of renewable energy sources such as solar, wind, hydropower, biomass, and geothermal energy, which produce low greenhouse gas emissions and reduce dependence on finite fossil fuels. In the context of climate change mitigation and sustainable development, sustainable energy integrates environmental protection, economic viability, and social equity. It supports decarbonization of the energy sector, enhances energy security, reduces air pollution and associated health risks, and promotes inclusive economic growth through green employment and technological innovation. Sustainable energy also involves advancements in energy efficiency, energy storage, and smart grid systems to ensure reliability and resilience. By aligning national and regional energy strategies with global climate frameworks such as the Paris Agreement, sustainable energy provides a pathway toward low-carbon development and a resilient energy future.

Role of Renewable Energy in Climate Change Mitigation

At the operational stage, major renewable energy systems—solar, wind, hydropower, biomass, and geothermal—produce negligible or no direct greenhouse gas emissions, making them effective tools for climate change mitigation.

Emission Reduction Potential of Renewable Energy Technologies: Renewable energy possesses substantial potential to reduce greenhouse gas emissions, particularly within the energy sector, which is responsible for a significant share of global emissions. The substitution of coal,

oil, and natural gas with low-carbon renewable energy technologies can significantly lower the carbon intensity of electricity generation. Solar and wind power exhibit near-zero operational emissions and are highly scalable, enabling their deployment at utility scale to meet growing energy demands. Hydropower is also a low-emission energy source, although its overall environmental impact varies according to project size, location, and ecosystem considerations. Biomass energy, when sustainably sourced and managed, can be considered largely carbon-neutral, as the carbon dioxide absorbed during biomass growth offsets emissions released during energy conversion. Geothermal energy further contributes to emissions mitigation by providing stable, reliable, and low-emission base load power. According to the International Renewable Energy Agency, large-scale deployment of renewable energy could reduce carbon emissions in the energy sector by up to 70% by 2050. Empirical studies further suggest that an accelerated transition to renewable energy could lower global carbon dioxide emissions by several gigatons annually.

Renewable Energy in Comparison with Fossil Fuel-Based Energy Systems

In contrast to fossil fuels, renewable energy sources are virtually inexhaustible and produce substantially lower environmental impacts. Solar and wind energy generate electricity without emitting air pollutants during operation, while geothermal and hydropower technologies produce only minimal emissions, primarily associated with construction and infrastructure development. Fossil fuel extraction and processing activities, including mining and drilling, result in significant environmental degradation, such as habitat loss, water contamination, and methane leakage, all of which intensify global warming. By harnessing naturally occurring energy flows, renewable energy technologies provide a sustainable long-term energy solution with a considerably reduced environmental footprint. From an economic perspective, the competitiveness of renewable energy has increased rapidly. Technological advancements, economies of scale, and expanded manufacturing capacity have driven substantial cost reductions, making solar and wind power cost-competitive or cheaper than fossil fuel-based electricity in many regions. Furthermore, advances in energy storage technologies and grid modernization initiatives have enhanced the reliability and system integration of renewable energy, effectively addressing intermittency challenges associated with variable resources such

as solar and wind.

Economic Effects of Renewable Energy Development

Renewable energy is a critical driver of structural transformation in the global economy and a key instrument for addressing environmental externalities. The transition toward low-carbon energy systems has demonstrated measurable economic benefits, including declining technology costs, job creation across renewable value chains, and strengthened macroeconomic growth prospects, thereby improving the economic viability and scalability of renewable energy deployment.

Technological Advancements in Solar and Wind Energy

In recent years, solar and wind energy have undergone significant technological breakthroughs, transforming them from experimental technologies into mainstream sources of electricity generation. Advances in photovoltaic (PV) cell technology have substantially increased efficiency while reducing production costs. Innovations such as perovskite solar cells, bifacial PV modules capable of capturing sunlight on both sides, and tandem cells that integrate multiple material layers have markedly improved solar energy conversion efficiency. These rapidly evolving technologies enable higher electricity output using smaller surface areas and allow operation under a broader range of environmental conditions. Similarly, wind energy has experienced major technological advancements aimed at enhancing energy capture at lower wind speeds. The development of taller wind turbines with longer blades and improved aerodynamic designs has significantly increased power generation efficiency. Additionally, floating offshore wind turbine technologies have expanded wind energy deployment into deeper waters, where wind resources are stronger and more consistent, while reducing exposure to coastal constraints and sea-level rise risks. Collectively, these breakthroughs in solar and wind energy have not only driven substantial cost reductions but have also expanded the geographical viability of renewable energy deployment, enabling effective utilization across diverse climatic and regional settings.

Integration of Energy Storage Technologies into Power Grids

Energy storage is a critical component of renewable energy systems, particularly for variable generation sources such as solar and wind. Storage technologies enable the reliable integration of renewable energy into power grids

by balancing supply and demand and ensuring energy availability independent of real-time generation conditions. At present, lithium-ion batteries dominate the energy storage market, driven by substantial improvements in energy density, efficiency, cycle life, and cost reductions. However, emerging storage technologies are increasingly complementing and in some applications potentially replacing lithium-ion systems. These include solid-state batteries, flow batteries, and advanced hydrogen-based storage solutions, which offer enhanced safety, longer storage durations, higher energy density, and improved scalability for large-scale and long-duration energy storage applications.

Conclusions

Renewable energy plays a fundamental role in mitigating climate change by substantially reducing greenhouse gas emissions, enhancing energy security, and supporting sustainable economic development. Achieving global climate objectives requires a strong and sustained emphasis on renewable energy sources, including solar, wind, hydropower, biogas, and geothermal energy. Continuous technological advancements, coupled with significant cost reductions, have improved the accessibility, scalability, and competitiveness of renewable energy solutions. Although challenges remain—such as grid integration, energy storage requirements, and land-use constraints—the benefits of renewable energy deployment far outweigh these limitations. Accelerated adoption of renewable energy not only contributes to climate change mitigation but also delivers wide-ranging social and environmental co-benefits, including improved public health outcomes and biodiversity conservation. Consequently, the implementation of robust policy frameworks and sustained investment in renewable energy infrastructure is imperative for countries seeking to meet urgent climate action goals under international commitments such as the Paris Agreement and to advance toward a sustainable, resilient, and low-carbon global energy future.

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