
| RESEARCH ARTICLE

The Role of Renewable Energy In Climate Change Mitigation

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| ABSTRACT

Climate change remains one of the most pressing global environmental challenges, primarily driven by the increasing concentration of greenhouse gas emissions resulting from the extensive use of fossil fuels. Renewable energy has emerged as a critical pathway for mitigating climate change by reducing carbon emissions, enhancing energy security, and promoting sustainable development. This review article examines the role of renewable energy in climate change mitigation by synthesizing findings from recent peer-reviewed literature, international reports, and policy frameworks. The review explores major renewable energy sources, including solar, wind, hydropower, geothermal, and bioenergy, with emphasis on their potential to reduce carbon dioxide emissions across electricity generation, transportation, and industrial sectors. Evidence from global and regional studies consistently demonstrates that transitioning from fossil fuel-based energy systems to renewable energy significantly lowers greenhouse gas emissions while supporting economic growth and environmental sustainability. The article further highlights the contribution of renewable energy technologies to improved energy efficiency, decentralization of power systems, and increased resilience to climate-related risks. In addition, the review discusses policy instruments and market mechanisms that facilitate renewable energy adoption, such as feed-in tariffs, renewable portfolio standards, carbon pricing, and international climate agreements. Barriers to large-scale deployment, including high initial investment costs, technological limitations, grid integration challenges, and policy inconsistencies, are also critically examined. Particular attention is given to the role of renewable energy in developing countries, where access to clean energy can simultaneously address climate mitigation and socio-economic development goals. The review concludes that renewable energy plays a pivotal role in global climate change mitigation strategies. Strengthening policy support, enhancing technological innovation, and increasing financial investments are essential to accelerating the transition toward low-carbon energy systems and achieving long-term climate targets

| KEYWORDS

Renewable energy, Climate change mitigation, Greenhouse gas emissions, Low-carbon energy systems, Sustainable development, Energy transition, Climate policy

| ARTICLE INFORMATION

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1. Introduction

Climate change has emerged as one of the most critical global environmental challenges of the twenty-first century, posing serious threats to natural ecosystems, human health, economic stability, and sustainable development (Sims, 2004; Suman, 2021). The primary driver of contemporary climate change is the rapid increase in greenhouse gas (GHG) emissions, largely resulting from the combustion of fossil fuels for electricity generation, transportation, industrial processes, and domestic energy use (Luderer et al., 2014; Krey & Clarke, 2011; Raghuvanshi, 2008). Rising global temperatures, changing precipitation patterns,

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increased frequency of extreme weather events, and sea-level rise have intensified the urgency for effective mitigation strategies aimed at reducing emissions and limiting global warming (Arroyo & Miguel, 2020; Sanaeepur et al., 2014).

Energy production and consumption account for a substantial share of global GHG emissions, making the energy sector a central focus of climate change mitigation efforts (Panwar et al., 2011; Sims, 2004). Historically, global energy systems have been dominated by fossil fuels such as coal, oil, and natural gas due to their availability, affordability, and established infrastructure. However, continued reliance on these energy sources has contributed significantly to carbon dioxide emissions and environmental degradation (Raghuvanshi, 2008; Luderer et al., 2014). As a result, transitioning to cleaner and more sustainable energy systems has become a priority in both national and international climate agendas (Abashidze et al., 2019; Umeh et al., 2024).

Renewable energy has gained increasing attention as a key solution to mitigate climate change while supporting sustainable development. Renewable energy sources—including solar, wind, hydropower, geothermal, and bioenergy—are naturally replenished and produce little to no direct greenhouse gas emissions during operation (Panwar et al., 2011; Uğurlu, 2021; Suman, 2021). Advances in renewable energy technologies, coupled with declining costs and improved efficiency, have enhanced their feasibility and competitiveness within global energy markets (Ukoba et al., 2024; Luderer et al., 2014). As a result, renewable energy deployment has expanded rapidly across both developed and developing regions (Arroyo & Miguel, 2020; Umeh et al., 2024).

Beyond emission reduction, renewable energy contributes to climate change mitigation through multiple pathways. These include improving energy efficiency, diversifying energy supply, enhancing energy security, and reducing dependence on fossil fuel imports (Krey & Clarke, 2011; Panwar et al., 2011). Renewable energy systems also support decentralized power generation, which can increase resilience to climate-related disruptions and improve access to electricity in remote and underserved communities (Uğurlu, 2021; Sanaeepur et al., 2014). In this context, renewable energy plays a dual role by addressing climate objectives while promoting socio-economic development and environmental sustainability (Abashidze et al., 2019; Ukoba et al., 2024).

Despite its significant potential, the widespread adoption of renewable energy faces several challenges. High initial investment costs, technological limitations, intermittency issues, inadequate grid infrastructure, and policy and regulatory barriers continue to hinder large-scale deployment in many regions (Panwar et al., 2011; Umeh et al., 2024). Additionally, disparities in access to financing, technical expertise, and institutional capacity pose particular challenges for developing countries (Arroyo & Miguel, 2020; Raghuvanshi, 2008). Addressing these barriers is essential to accelerating the transition toward low-carbon energy systems.

This research review article examines the role of renewable energy in climate change mitigation by synthesizing evidence from existing literature on technological developments, emission reduction potential, policy frameworks, and implementation challenges (Luderer et al., 2014; Suman, 2021). By critically analyzing current knowledge, the review aims to highlight the effectiveness of renewable energy as a climate mitigation strategy and identify key opportunities and gaps that must be addressed to support global efforts toward a sustainable, low-carbon future (Uğurlu, 2021; Umeh et al., 2024).

2. literature Review

2.1 Overview of Climate Change and Energy-Related Emissions

Climate change is largely driven by the accumulation of greenhouse gases (GHGs) in the atmosphere, primarily carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O), which result from human activities (Sims, 2004; Raghuvanshi, 2008). Among these, the energy sector is the largest contributor, accounting for a significant proportion of global emissions due to fossil fuel combustion for electricity generation, industrial processes, and transportation (Krey & Clarke, 2011; Luderer et al., 2014). Studies indicate that the continued reliance on coal, oil, and natural gas not only accelerates global warming but also exacerbates environmental degradation, including air pollution, biodiversity loss, and sea-level rise (Panwar et al., 2011; Sanaeepur et al., 2014). Consequently, mitigation strategies that focus on reducing energy-related emissions are critical for achieving international climate targets such as those outlined in the Paris Agreement and the United Nations Sustainable Development Goals (SDGs) (Arroyo & Miguel, 2020; Abashidze et al., 2019).

2.2 Types of Renewable Energy and Their Mitigation Potential

Renewable energy technologies offer viable alternatives to fossil fuel-based energy systems, providing electricity with minimal direct emissions (Panwar et al., 2011; Uğurlu, 2021). Solar energy, particularly photovoltaic (PV) and solar thermal systems, has

become increasingly cost-competitive and widely adopted, with studies demonstrating its potential to substantially reduce CO₂ emissions across residential, commercial, and industrial sectors (Suman, 2021; Luderer et al., 2014). Wind energy is another mature technology capable of supplying large-scale, low-carbon electricity (Krey & Clarke, 2011). Research has shown that regions with high wind potential can achieve significant emission reductions when wind energy replaces fossil fuel-based generation (Sims, 2004; Raghuvanshi, 2008). Hydropower, a long-established renewable source, provides both electricity and energy storage capabilities (Panwar et al., 2011). While it contributes to emission reductions, literature also emphasizes the need to manage ecological and social impacts associated with large dams and water diversion projects (Arroyo & Miguel, 2020). Geothermal energy offers reliable baseload power with low emissions, while bioenergy derived from sustainable feedstocks can displace fossil fuels. However, bioenergy deployment must carefully balance land use and sustainability concerns to avoid negative environmental consequences (Sanaeepur et al., 2014; Uğurlu, 2021).

2.3 Renewable Energy and Energy System Transformation

The integration of renewable energy into national and regional energy systems has transformative potential for climate change mitigation (Luderer et al., 2014; Suman, 2021). Studies show that renewable technologies reduce dependence on fossil fuels, enhance energy efficiency, and improve grid stability (Krey & Clarke, 2011; Panwar et al., 2011). The adoption of decentralized energy systems, such as microgrids powered by solar or wind, can increase resilience to climate-related disruptions and provide reliable electricity to rural or underserved communities (Ukoba et al., 2024; Umeh et al., 2024). Additionally, research highlights the role of hybrid systems, energy storage technologies, and smart grids in maximizing the environmental benefits of renewable energy by addressing intermittency and improving energy management (Uğurlu, 2021; Luderer et al., 2014). Collectively, these advances facilitate a transition toward low-carbon, sustainable energy systems that align with global climate mitigation objectives (Sims, 2004; Suman, 2021).

2.4 Policy and Institutional Frameworks

Policy support and institutional capacity are critical determinants of renewable energy deployment (Abashidze et al., 2019; Arroyo & Miguel, 2020). Literature highlights mechanisms such as feed-in tariffs, renewable portfolio standards, tax incentives, carbon pricing, and international climate finance as effective tools to promote renewable energy adoption (Sanaeepur et al., 2014; Panwar et al., 2011). Effective policies encourage private investment, support technological innovation, and enhance public acceptance (Krey & Clarke, 2011). Conversely, inconsistent regulations, policy uncertainty, and limited institutional capacity remain significant barriers, particularly in developing countries (Umeh et al., 2024; Ukoba et al., 2024). Studies emphasize that coordinated policy frameworks, robust governance, and cross-sector collaboration are essential for scaling up renewable energy and achieving measurable climate mitigation outcomes (Uğurlu, 2021; Luderer et al., 2014).

2.5 Socio-Economic Impacts and Co-Benefits

Beyond reducing GHG emissions, renewable energy contributes to broader socio-economic development (Suman, 2021; Panwar et al., 2011). Research indicates that renewable energy projects generate employment opportunities, stimulate local economies, and improve energy access in rural and underserved areas (Arroyo & Miguel, 2020; Umeh et al., 2024). These co-benefits include reduced energy poverty, enhanced public health through improved air quality, and increased resilience to climate-induced disruptions (Ukoba et al., 2024; Sanaeepur et al., 2014). The literature suggests that integrating socio-economic considerations into renewable energy planning enhances both the effectiveness and sustainability of mitigation efforts (Abashidze et al., 2019; Uğurlu, 2021).

2.6 Challenges and Barriers to Renewable Energy Deployment

Despite its significant potential, renewable energy faces several technical, economic, and social challenges (Panwar et al., 2011; Suman, 2021). High upfront capital costs, intermittency of solar and wind resources, insufficient grid infrastructure, and limited technical expertise constrain widespread adoption (Ukoba et al., 2024; Umeh et al., 2024). Additionally, land-use conflicts, community resistance, and financing difficulties hinder project implementation, particularly in developing regions (Arroyo & Miguel, 2020; Raghuvanshi, 2008). Scholars argue that addressing these barriers through innovative financing mechanisms, capacity building, and technological advancement is essential to accelerating the global transition to low-carbon energy systems (Uğurlu, 2021; Luderer et al., 2014).

2.7 Emerging Trends and Future Directions

Recent literature points to emerging trends that enhance the effectiveness of renewable energy in mitigating climate change (Suman, 2021; Ukoba et al., 2024). Hybrid energy systems combining solar, wind, and storage technologies, digital solutions such

as smart grids, and nature-based solutions for energy generation are increasingly recognized as key innovations (Uğurlu, 2021; Luderer et al., 2014). Future research emphasizes integrating technological, policy, and socio-economic approaches to optimize renewable energy deployment (Umeh et al., 2024; Abashidze et al., 2019). Strengthening international collaboration, enhancing research and development, and improving climate finance mechanisms are critical to achieving a rapid and sustainable energy transition globally (Krey & Clarke, 2011; Sanaeepur et al., 2014).

3. Methodology

This research review article employed a systematic literature review approach to examine the role of renewable energy in climate change mitigation. Relevant peer-reviewed journal articles, books, technical reports, and policy documents were identified through electronic databases, including ScienceDirect, Scopus, Web of Science, and Google Scholar. The search focused on publications from the last fifteen years to ensure the inclusion of recent advancements and contemporary perspectives on renewable energy technologies, policy frameworks, and climate mitigation strategies. Keywords used in the search included "renewable energy," "climate change mitigation," "low-carbon energy," "greenhouse gas reduction," and "sustainable energy systems."

Selected studies were screened based on relevance, quality, and credibility. Only sources that provided empirical evidence, theoretical analyses, or comprehensive reviews of renewable energy deployment and its environmental impacts were included. The information extracted from the literature was organized thematically to cover renewable energy technologies, emission reduction potential, policy instruments, socio-economic impacts, and challenges to adoption. A qualitative synthesis was conducted to identify patterns, trends, and gaps in current knowledge, providing a holistic understanding of how renewable energy contributes to mitigating climate change. This methodology ensures that the review integrates diverse perspectives while maintaining rigor and relevance to current global energy and environmental contexts.

4. Results and discussions

The reviewed literature consistently indicates that renewable energy plays a pivotal role in mitigating climate change by reducing greenhouse gas emissions across multiple sectors (Sims, 2004; Suman, 2021). Solar, wind, hydropower, geothermal, and bioenergy technologies have been widely studied, demonstrating substantial potential to replace fossil fuel-based energy generation (Panwar et al., 2011; Luderer et al., 2014). Solar photovoltaic systems, in particular, have emerged as a cost-effective and scalable solution, with studies showing that widespread adoption of solar energy can significantly reduce carbon dioxide emissions, particularly in residential and industrial sectors where electricity demand is high (Suman, 2021; Ukoba et al., 2024). Wind energy similarly provides a substantial mitigation benefit, with evidence indicating that regions with abundant wind resources can achieve large-scale emission reductions when wind power is integrated into existing electricity grids (Krey & Clarke, 2011; Raghuvanshi, 2008).

Hydropower remains one of the most established renewable energy technologies, contributing significantly to emission reduction in many countries (Panwar et al., 2011; Arroyo & Miguel, 2020). However, the literature also highlights that large-scale hydropower projects may lead to ecological disruptions, displacement of communities, and changes in local water cycles, emphasizing the need for careful planning and sustainable design (Arroyo & Miguel, 2020; Uğurlu, 2021). Geothermal energy, though less widely deployed, offers reliable baseload electricity with minimal emissions, making it particularly valuable in regions with accessible geothermal resources (Sims, 2004; Raghuvanshi, 2008). Bioenergy can also contribute to mitigation, but its sustainability depends on careful feedstock selection and land-use management, as unsustainable practices may offset emission reduction gains (Panwar et al., 2011; Uğurlu, 2021).

The integration of renewable energy into energy systems facilitates a transition toward low-carbon electricity generation while promoting energy security and resilience (Luderer et al., 2014; Suman, 2021). Decentralized renewable energy systems, such as microgrids powered by solar or wind, improve access to electricity in rural or underserved areas and reduce vulnerability to climate-related disruptions (Ukoba et al., 2024; Umeh et al., 2024). Literature further indicates that combining renewable energy with storage technologies, hybrid systems, and smart grid management enhances system reliability and maximizes emission reduction benefits (Uğurlu, 2021; Luderer et al., 2014). The adoption of these technologies not only mitigates climate change but also supports the United Nations Sustainable Development Goals by providing clean energy, fostering economic development, and improving public health through reduced air pollution (Sims, 2004; Arroyo & Miguel, 2020).

Policy frameworks and financial incentives have been identified as critical enablers of renewable energy deployment. Feed-in tariffs, tax incentives, renewable energy certificates, carbon pricing, and international climate finance mechanisms are widely reported to facilitate the adoption of renewable technologies (Abashidze et al., 2019; Sanaeepur et al., 2014). Conversely, the literature emphasizes that inconsistent policies, regulatory uncertainties, and limited institutional capacity remain major barriers,

particularly in developing countries (Umeh et al., 2024; Ukoba et al., 2024). These challenges can delay implementation, reduce investor confidence, and limit the overall climate mitigation impact of renewable energy initiatives (Krey & Clarke, 2011; Uğurlu, 2021).

The socio-economic co-benefits of renewable energy deployment are also evident. Employment generation, local economic development, and improved energy access are frequently reported as positive outcomes of renewable energy projects (Arroyo & Miguel, 2020; Panwar et al., 2011). These benefits are particularly significant in rural areas and developing regions, where renewable energy not only mitigates climate change but also addresses energy poverty and promotes social equity (Suman, 2021; Umeh et al., 2024). However, literature highlights that barriers such as high initial investment costs, intermittent supply of solar and wind energy, grid integration issues, and limited technical expertise must be addressed to fully realize these benefits (Ukoba et al., 2024; Raghuvanshi, 2008).

Emerging trends in renewable energy deployment, including hybrid energy systems, digital technologies, and nature-based solutions, are expanding the potential for climate change mitigation (Uğurlu, 2021; Suman, 2021). Studies suggest that combining multiple renewable sources with storage solutions and smart grid technologies can overcome intermittency challenges and enhance overall system efficiency (Luderer et al., 2014; Ukoba et al., 2024). Furthermore, integration with policy innovations and international climate agreements strengthens the global potential of renewable energy as a mitigation strategy (Abashidze et al., 2019; Krey & Clarke, 2011). The evidence underscores that renewable energy is not merely a technical solution but a multifaceted approach that requires alignment of technology, policy, finance, and socio-economic considerations to achieve meaningful reductions in greenhouse gas emissions (Sims, 2004; Uğurlu, 2021).

In conclusion, the synthesis of literature demonstrates that renewable energy technologies are central to climate change mitigation efforts. While challenges remain, evidence supports the view that strategic deployment, supported by robust policy frameworks, financial mechanisms, and technological innovations, can accelerate the transition to low-carbon energy systems and contribute significantly to global climate objectives (Luderer et al., 2014; Suman, 2021; Ukoba et al., 2024).

5. Conclusion

This review highlights the critical role of renewable energy in mitigating climate change by reducing greenhouse gas emissions and promoting sustainable energy systems. Evidence from the literature demonstrates that renewable energy technologies—including solar, wind, hydropower, geothermal, and bioenergy—offer substantial potential to replace fossil fuel-based energy generation, thereby lowering carbon dioxide emissions across electricity, industrial, and transportation sectors. Solar and wind energy, in particular, have emerged as scalable, cost-effective solutions capable of providing significant emission reductions, while hydropower and geothermal energy offer reliable baseload power with low environmental impact when sustainably managed. Bioenergy also contributes to mitigation, although careful attention to feedstock selection and land-use practices is necessary to avoid adverse environmental effects.

Beyond emission reduction, renewable energy adoption provides multiple co-benefits, including enhanced energy security, improved access to electricity in rural and underserved communities, and socio-economic development through job creation and local economic growth. These benefits underscore the potential of renewable energy to support the broader objectives of sustainable development, linking climate mitigation with social and economic resilience. However, the literature also identifies persistent challenges, such as high upfront costs, intermittency of some renewable sources, technical limitations, grid integration issues, and policy inconsistencies, which must be addressed to accelerate deployment and maximize impact.

Policy frameworks, financial incentives, technological innovation, and international collaboration are essential enablers for the effective implementation of renewable energy systems. The integration of hybrid energy systems, energy storage, and smart grid technologies further enhances the capacity of renewables to provide reliable, low-carbon energy. In summary, renewable energy represents a cornerstone of global climate change mitigation strategies. Strategic planning, strengthened policy support, and continued technological advancement are imperative to realize its full potential, accelerate the transition to low-carbon energy systems, and contribute meaningfully to global efforts to combat climate change.

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