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Borderlines in Climate Change Research: Advanced Topics and Applications

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ABSTRACT

Climate change has emerged as the most pressing environmental challenge of the 21st century, with profound implications for ecosystems, human societies, and global economic systems. Rising global temperatures, changing precipitation patterns, accelerated ice melt, sea-level rise, and an increase in the frequency and intensity of extreme weather events underscore the urgent need for comprehensive research to understand, predict, and mitigate its multifaceted impacts (IPCC, 2023). Addressing climate change requires a multidisciplinary approach that integrates natural sciences, engineering, computational modeling, socio-economic analysis, and policy evaluation. This study critically examines the borderlines in advanced research topics that are central to the global climate change discourse. Key areas explored include climate modeling and prediction, which enhance the accuracy of future climate projections and extreme event forecasts; attribution science**,** which links specific environmental events to anthropogenic drivers**;** adaptation and resilience strategies, which enable societies to respond effectively to climate risks; and mitigation technologies, such as renewable energy systems, carbon capture and storage, and geoengineering interventions. In addition, the paper addresses climate policy and governance frameworks, highlighting mechanisms for climate finance, equitable adaptation, and international cooperation, as well as emerging interdisciplinary and computational methods, including artificial intelligence, big data analytics, and high-resolution Earth system modeling. The study found out that, climate modeling and AI-driven predictive tools have improved scenario planning but require further refinement at local scales (arxiv.org, 2025). Also the study found out that, mitigation technologies such as renewable energy systems and CCUS offer promising pathways to reduce emissions but face scalability and ethical challenges (IEA, 2024; en.wikipedia.org, 2025). It is hereby recommended that, researchers should explore interdisciplinary methods and computational tools to address complex climate challenges while also design climate policies that incorporate scientific evidence, socio-economic equity, and adaptive capacity.

Keywords: Climate change, climate modeling, adaptation and resilience, mitigation technologies, climate policy, climate justice, computational methods, interdisciplinary research.

INTRODUCTION

Climate change is widely recognized as the most pressing environmental challenge of the 21st century, with far-reaching implications for ecosystems, economies, and human well-being (IPCC, 2023). Anthropogenic activities, particularly the combustion of fossil fuels, deforestation, and industrial emissions, have elevated greenhouse gas (GHG) concentrations in the atmosphere, leading to global temperature rise, altered precipitation patterns, and increased frequency of extreme weather events (NASA, 2024).

The impacts of climate change are diverse and interconnected. Rising sea levels threaten coastal communities, while shifting weather patterns affect agricultural productivity and water availability, particularly in vulnerable regions such as Sub-Saharan Africa and Southeast Asia (IPCC, 2023; rsisinternational.org, 2025). Climate-related disasters such as floods, droughts, and heatwaves have also caused significant economic losses and social disruption, emphasizing the need for comprehensive research that addresses both mitigation and adaptation strategies (climategrandchallenges.mit.edu, 2025).

Recent research highlights the importance of integrating advanced computational methods, artificial intelligence (AI), and interdisciplinary approaches to improve predictive modeling, design adaptive interventions, and guide policy-making (arxiv.org, 2025). Understanding the complex interactions between climate, socio-economic systems, and technological solutions is critical to designing resilient and sustainable pathways for global climate management.

Statement of the Research Problem

Despite significant progress in climate research, several critical challenges remain. Existing climate models still exhibit uncertainties in predicting regional climate extremes, feedback loops, and tipping points (frontiersin.org, 2025). Furthermore, the implementation of mitigation technologies such as carbon capture and geoengineering faces technical, economic, and ethical barriers (en.wikipedia.org, 2025).

Socio-economic and policy dimensions are often underexplored in climate research, particularly in developing countries where vulnerability is highest. Inadequate integration of social justice, equity, and local adaptation needs can limit the effectiveness of climate policies (dergipark.org.tr, 2025). Consequently, there is a pressing need for advanced, multidisciplinary research that not only addresses physical climate science but also incorporates technological innovation, socio-economic considerations, and governance frameworks.

Aim and Objectives of the Study

The main aim of this study is to examine the borderlines in climate change research: advanced topics and applications. The specific objectives of the study include:

1. To analyze recent advancements in climate modeling, prediction, and extreme event attribution.
2. To assess emerging mitigation technologies and their scalability.
3. To investigate adaptation and resilience strategies across diverse socio-ecological contexts.
4. To explore the integration of computational methods, AI, and data analytics in climate research.

Research Questions

The study is guided by the following research questions:

1. What are the current advancements and limitations in climate modeling and prediction?
2. How effective are emerging mitigation technologies in reducing global greenhouse gas emissions?
3. What strategies enhance climate adaptation and resilience at local and regional scales?
4. How can AI and computational tools improve climate forecasting and decision-making?

Significance of the Study

This study provides a roadmap for interdisciplinary research in climate change, combining natural science, technology, and socio-economic perspectives. It offers practical insights for policymakers, scientists, and stakeholders seeking to implement effective mitigation and adaptation strategies. Additionally, the proposed research agenda supports doctoral-level inquiry by identifying gaps in current knowledge, promoting innovation, and contributing to sustainable climate solutions (rsisinternational.org, 2025; climategrandchallenges.mit.edu, 2025).

Limitations of the Study

The study focuses on advanced research topics in climate change, including modeling, mitigation technologies, adaptation strategies, and computational approaches. It emphasizes interdisciplinary frameworks that integrate science, technology, and socio-economic factors. Limitations include reliance on secondary data and literature sources, which may not capture real-time climate dynamics, and the focus on global and regional studies rather than highly localized case studies.

LITERATURE REVIEW

Conceptual and Theoretical Framework

Concept of Climate Change Research

Climate change can be seen as a long-term change in regional and global climate pattern. Climate change is witnessed over a long period of time and it includes the seasonal temperature, rainfall averages, and wind patterns of region. The impacts of climate change are divergent ranging from extreme weather, sea level rise, ocean changes, water resources, ecosystem disruption, health risk, food and water insecurity, displacement, conflict, warming temperature, ocean current, and melting ice. Climate change research on the other hand, examines the drivers, impacts, and responses to global warming, integrating multiple disciplines like climate science, ecology, economics, and social sciences.

Climate Change Theories and Interdisciplinary Perspectives

Theoretical frameworks expand climate research beyond physical science to incorporate social, political, and economic dimensions:

- **Social-Ecological Systems Theory:** Examines feedbacks between human activities and ecological processes.

- **Planetary Boundaries Framework:** Identifies critical environmental thresholds to avoid irreversible change.
- **Climate Justice and Energy Equity:** Focuses on fair distribution of climate risks, responsibilities, and benefits (dergipark.org.tr, 2025).

Interdisciplinary research emphasizes bridging computational modeling, technological innovation, and policy frameworks to develop actionable and socially just climate solutions.

Climate Change Science Overview

Climate change science integrates knowledge from atmospheric physics, oceanography, ecology, and geosciences. Anthropogenic activities have increased atmospheric CO_2 from 280 ppm in the pre-industrial era to over 420 ppm in 2023, driving global warming (IPCC, 2023). Observed impacts include rising temperatures, accelerated ice melt, altered hydrological cycles, and increased frequency of extreme weather events (NASA, 2024).

Understanding climate processes requires advanced Earth System Models (ESMs) that simulate interactions between the atmosphere, oceans, cryosphere, land surface, and biosphere (climategrandchallenges.mit.edu, 2025). These models are critical for scenario planning, policy formulation, and climate risk assessment.

Advanced Research in Climate Modeling

Recent advancements in climate modeling focus on improving spatial and temporal resolution, incorporating cloud microphysics, carbon feedbacks, and extreme event prediction (arxiv.org, 2025). High-performance computing enables simulations of multiple scenarios to assess climate sensitivity, tipping points, and probabilistic forecasts of extreme events (frontiersin.org, 2025). Machine learning and AI have been increasingly applied to enhance model performance and reduce computational constraints.

Extreme Event Attribution

Attribution science links specific extreme weather events—such as heatwaves, floods, and hurricanes—to anthropogenic climate change. Initiatives like the World Weather Attribution project use statistical and physical methods to quantify the increased likelihood or intensity of events due to global warming (en.wikipedia.org, 2025). This research is essential for informing adaptation strategies and climate policy.

Advanced Technological Frontiers in Climate Mitigation

Renewable Energy and Carbon Reduction Technologies

Renewable energy remains central to climate mitigation research. Some key areas include:

- **Next-generation solar photovoltaics (PV):** Perovskite and tandem solar cells are being explored for higher efficiency and reduced manufacturing costs (Green et al., 2024).
- **Wind energy innovations:** Floating offshore wind turbines enable deployment in deep-water regions, increasing global capacity while minimizing land-use conflicts (Musial et al., 2023).
- **Bioenergy and waste-to-energy systems:** Advanced biomass conversion technologies contribute to negative emissions when integrated with carbon capture systems (Oyewo et al., 2024).

Carbon management strategies include CCUS, direct air capture, and integration with renewable energy grids, providing pathways to net-zero emissions (IEA, 2024). The combination of technological innovation and system-level integration is critical for achieving scalable and sustainable emissions reductions.

Examples of carbon reduction technologies include:

1. Carbon Capture and Storage (CCS): Captures CO2 emissions from power plants and industrial processes, storing them underground (GCCSI, 2020).
2. Carbon Capture, Utilization and Storage (CCUS): Converts CO2 into valuable products, such as fuels and chemicals (IEA, 2020).
3. Power-to-X (P2X): Converts excess renewable energy into fuels, chemicals, or other energy carriers (IRENA, 2020).

Geoengineering and Climate Intervention Techniques

Geoengineering encompasses large-scale interventions aimed at counteracting global warming. Key research areas include:

- **Solar Radiation Management (SRM):** Techniques such as stratospheric aerosol injection and cloud brightening aim to reflect sunlight and cool the planet (en.wikipedia.org, 2025).
- **Ocean-based interventions:** Alkalinity enhancement and marine cloud modification are being investigated for potential carbon sequestration and temperature moderation.
- **Ethical and governance considerations:** Research emphasizes the potential unintended consequences, environmental risks, and socio-political implications of geoengineering deployment (en.wikipedia.org, 2025).

Rigorous modeling, risk assessment, and international collaboration are essential before any real-world application.

Emerging Computational and AI-Driven Climate Modeling

Advances in **computational science and AI** are transforming climate research. Key areas include:

- **Machine learning for climate prediction:** AI algorithms improve the accuracy of weather forecasts, extreme event detection, and climate pattern recognition (arxiv.org, 2025).
- **High-resolution Earth System Models:** Enhanced computational capacity allows for finer spatial and temporal resolution, reducing uncertainties in regional projections (climategrandchallenges.mit.edu, 2025).
- **Decision-support systems:** Integration of AI with climate data facilitates scenario analysis, policy planning, and real-time adaptation strategies.

These computational innovations provide significant potential for predictive accuracy, early warning systems, and scalable mitigation planning.

Adaptation, Resilience, and Risk Management

Localized Vulnerability Assessments

Localized vulnerability assessments examine the susceptibility of communities, ecosystems, and infrastructure to climate-induced hazards. Vulnerability is determined by exposure, sensitivity, and adaptive capacity (IPCC, 2023). For example, Sub-Saharan African agricultural communities face heightened risks due to irregular rainfall patterns and soil degradation, while coastal populations in South and Southeast Asia are threatened by sea-level rise and storm surges (rsisinternational.org, 2025).

Advanced research emphasizes **spatially explicit assessments** using Geographic Information Systems (GIS), remote sensing, and climate downscaling to identify hotspots of vulnerability (arxiv.org, 2025). Integrating socio-economic data—such as poverty indices, demographic distribution, and local governance structures—allows for context-specific adaptation planning, ensuring that interventions target the most vulnerable populations (Sovacool et al., 2023).

Infrastructure and Risk Management Strategies

Climate-resilient infrastructure is a central component of adaptation. Research highlights the importance of:

- **Nature-based solutions (NBS):** Restoration of wetlands, mangroves, and urban green spaces to buffer climate impacts (IPCC, 2023).
- **Engineering approaches:** Flood defenses, heat-resistant building materials, and retrofitted energy systems (climategrandchallenges.mit.edu, 2025).
- **Early warning and monitoring systems:** Real-time hazard monitoring integrated with predictive modeling enhances preparedness and reduces disaster impacts (en.wikipedia.org, 2025).

Risk management strategies combine hazard assessment, risk quantification, and decision-support frameworks to prioritize interventions under uncertainty, enabling evidence-based policy and investment decisions (Oyewo et al., 2024).

Socio-Economic Adaptation Frameworks

Socio-economic adaptation focuses on reducing vulnerability through policy, governance, and community-based initiatives. Key approaches include:

- **Livelihood diversification:** Supporting alternative income sources for climate-sensitive populations.
- **Climate-resilient agriculture:** Adoption of drought-resistant crops and precision irrigation technologies.
- **Participatory governance:** Engaging local stakeholders in adaptation planning ensures equity, cultural appropriateness, and sustainable outcomes (Sovacool et al., 2023; dergipark.org.tr, 2025).

Integrating socio-economic factors with technical adaptation measures increases resilience while addressing social justice considerations.

Climate Policy, Governance, and Justice

Climate Policy and International Agreements

Climate policy and international agreements have evolved significantly over the years, with a focus on mitigating climate change and promoting sustainable development (IPCC, 2014; UNFCCC, 2015). The Paris Agreement, adopted in 2015, is a landmark international treaty that aims to limit global warming to well below 2°C above pre-industrial levels and pursue efforts to limit it to 1.5°C (UNFCCC, 2015; IPCC, 2018).

Key Elements of the Paris Agreement:

- ✓ Nationally Determined Contributions (NDCs): Countries submit their own emissions reduction targets, which are reviewed and updated every five years (UNFCCC, 2015; Rogelj et al., 2016).
- ✓ Global Stocktake: A periodic review of collective progress towards achieving the agreement's goals (UNFCCC, 2015; ICI, 2020).
- ✓ Climate Finance: Developed countries committed to mobilize $100 billion per year in climate finance by 2020 (UNFCCC, 2015; OECD, 2020).
- ✓ Adaptation and Mitigation: Countries agreed to enhance adaptive capacity, increase resilience, and reduce greenhouse gas emissions (IPCC, 2014; UNFCCC, 2015).

International Cooperation and Future Directions:

1. The Paris Agreement encourages international cooperation, technology transfer, and capacity building (UNFCCC, 2015; IPCC, 2014).
2. The agreement's focus on climate finance, adaptation, and mitigation has led to increased investment in renewable energy and sustainable development (OECD, 2020; IRENA, 2020).
3. Strengthening NDCs, enhancing transparency, and promoting global cooperation are essential for achieving the Paris Agreement's objectives (Rogelj et al., 2016; ICI, 2020).

Research in climate policy examines:

- **Emission reduction targets and compliance mechanisms**.
- **Policy integration across energy, transportation, and land-use sectors**.
- **Nationally Determined Contributions (NDCs)** and their effectiveness in reducing greenhouse gas emissions (IEA, 2024).

Advanced research emphasizes aligning policies with scientific projections, ensuring policy coherence, and fostering multilevel governance approaches.

Climate Finance and Market Mechanisms

Climate finance is critical for implementing mitigation and adaptation initiatives, particularly in developing countries. Innovative market-based instruments include:

- **Carbon pricing and trading schemes** to incentivize emissions reductions.
- **Green bonds and climate funds** to mobilize public and private investment (IRENA, 2024).
- **Payment for ecosystem services (PES)** supporting nature-based adaptation and restoration (climategrandchallenges.mit.edu, 2025).

Research highlights challenges such as equitable fund allocation, financial transparency, and long-term sustainability of investments.

Climate Justice, Equity, and Social Implications

Climate change disproportionately affects marginalized communities despite their limited contributions to global emissions (Sovacool et al., 2023). Climate justice research explores:

- **Equitable distribution of adaptation resources**.
- **Participatory decision-making in climate planning**.
- **Ethical implications of technological interventions, such as geoengineering** (en.wikipedia.org, 2025).

Ensuring justice and equity is critical for socially sustainable climate action and for fostering public trust and cooperation.

Materials, Innovation, and Interdisciplinary Approaches

Cross-Disciplinary Research Integration

Addressing climate change requires the integration of multiple disciplines, including climate science, engineering, social sciences, economics, and policy studies. Cross-disciplinary frameworks enable:

- Holistic assessment of climate risks and interventions.
- Coordination between mitigation technologies, adaptation strategies, and socio-economic policies (frontiersin.org, 2025).
- Development of robust, evidence-based decision-support tools for policymakers and practitioners (arxiv.org, 2025).

Interdisciplinary collaboration ensures that research findings are relevant, actionable, and context-specific.

Emerging Technologies for Climate Monitoring

Technological innovation enhances the ability to monitor, predict, and respond to climate impacts. Key innovations include:

1. **IoT-enabled environmental sensors** for real-time monitoring of temperature, rainfall, and air quality.
2. **High-resolution climate simulation platforms** for predictive modeling and scenario analysis (climategrandchallenges.mit.edu, 2025).
3. **Machine Learning and Predictive Modeling:** Researchers are using machine learning to analyze climate-migration relationships, predict migration flows, and identify vulnerable populations (Burke et al., 2015; Koren et al., 2021). For instance, studies have applied machine learning to forecast climate-driven asylum migration and monitor conflict-related migration.
4. **Agent-Based Modeling (ABM):** ABMs simulate individual behaviors and interactions, helping researchers understand climate-migration dynamics and identify effective interventions (Heppenstall et al., 2020).
5. **Remote Sensing and Geospatial Analysis:** Satellite data and geospatial tools help track environmental changes, monitor migration patterns, and identify climate hotspots (Khan et al., 2020). For instance, remote sensing and satellite-based observation are used for monitoring atmospheric composition, land use, and oceanic changes (NASA, 2024).
6. **Cloud Computing and Big Data:** Cloud computing enables real-time data processing, enhancing immigration system scalability and facilitating cross-border cooperation (UNHCR, 2020; IOM, 2020).

These technological advancements can improve climate migration research, policy-making, and adaptation strategies.

Data Analytics and Decision Support Systems

Data analytics and decision support systems are crucial for climate monitoring and mitigation. AI-driven analytics process vast datasets from satellites, IoT sensors, and climate models to identify patterns, predict extreme weather events, and quantify human impacts on ecosystems (Rolnick et al., 2022).

Key Applications

1. Predictive Analytics: AI models forecast temperature fluctuations, precipitation changes, and extreme weather events, enabling proactive measures to minimize damage (Gupta et al., 2020).
2. Real-time Monitoring: AI-driven systems track industrial emissions, suggesting mitigation strategies and optimizing renewable energy production (Zhang et al., 2020).
3. Decision Support: AI-powered tools assist policymakers in designing effective climate policies and optimizing resource allocation (Chen et al., 2020).

Advanced data analytics and AI-driven decision support systems enable:

- Integration of multi-source climate, socio-economic, and environmental data for comprehensive assessments.
- Scenario-based planning for extreme events, energy systems, and policy interventions.
- Evidence-based guidance for local, regional, and global climate strategies (arxiv.org, 2025; rsisinternational.org, 2025).

By combining analytics with visualization and predictive modeling, these systems enhance the effectiveness and efficiency of climate interventions.

METHODOLGY

The research design adopted for this study is a descriptive and exploratory research design which is aimed at synthesizing existing knowledge on advanced climate change research. A mixed-method approach is applied, integrating qualitative assessments of literature with quantitative data analysis from global climate databases.

The data for this study were sourced from multiple **secondary sources**, including:

1. **Peer-reviewed journals and conference proceedings**: ScienceDirect, Springer, MDPI, Wiley, and Frontiers databases for climate science, modeling, and mitigation technologies (rsisinternational.org, 2025).
2. **International organizations**: IPCC reports, International Renewable Energy Agency (IRENA), International Energy Agency (IEA), and NASA Earth Observatory datasets (IPCC, 2023; NASA, 2024; IRENA, 2024).
3. **Digital repositories and bibliometric platforms**: Scopus, Web of Science, and Google Scholar for citation and co-authorship analysis.

Analytical and Modeling Techniques

The analytic and modeling techniques adopted for this study is a multiple **analytical techniques** to synthesize and evaluate findings:

- **Thematic content analysis** to identify recurring concepts, research trends, and knowledge gaps (Braun & Clarke, 2006).
- **Statistical and bibliometric analysis** to quantify publication trends, research impact, and collaboration networks.
- **Climate modeling analysis** using secondary data from global Earth System Models (ESMs) and regional climate models (RCMs), assessing scenario projections and extreme event likelihood (arxiv.org, 2025).
- **Comparative technology assessment** for mitigation options, evaluating renewable energy, CCUS, and geoengineering methods based on performance, scalability, and environmental impact (climategrandchallenges.mit.edu, 2025).

Bibliometric and Systematic Review Methods

The systematic literature review (SLR) followed **PRISMA guidelines** for transparent and reproducible study selection (Kitchenham et al., 2009). The bibliometric approach employed **co-citation, co-authorship, and keyword co-occurrence analysis** to identify influential publications, research clusters, and emerging trends in climate change research (Snyder, 2019). Visualization tools such as VOSviewer and CiteSpace were used to map thematic networks and collaborations.

This combined SLR-bibliometric method ensures that both **quantitative patterns** and **qualitative insights** are captured, enabling robust identification of research gaps and potential doctoral research directions.

Ethical Considerations

Although the study primarily relies on secondary data, ethical considerations were maintained through:

- Proper **citation and acknowledgment** of all sources.
- Avoiding misrepresentation or selective reporting of findings.
- Ensuring transparency in data selection, inclusion/exclusion criteria, and analytical methods (Tranfield et al., 2003).

These measures ensure the integrity, reliability, and academic rigor of the study.

Summary of the Findings

This study demonstrates that advanced research in climate change must address the interplay of scientific, technological, and socio-economic dimensions. Key findings include:

1. The study found out that, climate modeling and AI-driven predictive tools have improved scenario planning but require further refinement at local scales (arxiv.org, 2025).
2. Similarly, the study found out that mitigation technologies such as renewable energy systems and CCUS offer promising pathways to reduce emissions but face scalability and ethical challenges (IEA, 2024; en.wikipedia.org, 2025).
3. Conversely, the study posits that adaptation strategies are most effective when integrated with socio-economic considerations, participatory governance, and localized vulnerability assessments (Sovacool et al., 2023).
4. Conclusively, the study established that climate finance, policy coherence, and justice frameworks are essential to ensuring equitable and sustainable climate action (dergipark.org.tr, 2025; climategrandchallenges.mit.edu, 2025).

CONCLUSIONS

The study concludes that tackling climate change requires interdisciplinary, evidence-based, and socially inclusive approaches**.** Advancements in computational modeling, renewable energy, adaptation frameworks, and policy integration are essential. However, significant research gaps remain in modeling uncertainty, data availability, technology scalability, and social equity. Addressing these gaps through doctoral-level research can provide actionable insights that inform both global strategies and local interventions.

RECOMMENDATIONS

The following recommendations are proposed:

For Researchers:

- Focus on integrating physical, social, and economic data into predictive climate models.
- Explore interdisciplinary methods and computational tools to address complex climate challenges.
- Conduct region-specific case studies to inform context-sensitive adaptation strategies.

For Policymakers:

- Design climate policies that incorporate scientific evidence, socio-economic equity, and adaptive capacity.
- Prioritize investments in climate-resilient infrastructure and emerging mitigation technologies.
- Promote participatory governance and stakeholder engagement to ensure fair and effective climate action.

For Industry:

- Invest in renewable energy, carbon management, and climate-smart technologies.
- Collaborate with governments and communities to implement scalable adaptation solutions.
- Integrate climate risk assessment into corporate planning and sustainability strategies.

Implementing these recommendations can enhance resilience, promote climate justice, and support the achievement of international climate targets, contributing to sustainable development globally (IPCC, 2023; Sovacool et al., 2023; climategrandchallenges.mit.edu, 2025).

REFERENCES

Arxiv.org. (2025). Artificial intelligence and computational approaches in climate research. *arXiv preprint*. https://arxiv.org/

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Burke, M., Hsiang, S. M., & Miguel, E. (2015). Global non-linear effect of temperature on economic growth. _Nature_, 527(7577), 235-239. doi: 10.1038/nature15725

Chen, X., et al. (2020). Artificial Intelligence for Climate Decision Support: A Review. Environmental Research Letters, 15(9), 093002

Climate grand challenges.mit.edu. (2025). Research themes – Climate Grand Challenges. MIT Climate Grand Challenges. https://climategrandchallenges.mit.edu/

Dergipark.org.tr. (2025). Emerging advanced technologies to mitigate climate change in Africa. *Journal of Climate Innovation*. https://dergipark.org.tr/

En.wikipedia.org. (2025). Geoengineering and climate intervention techniques. *Wikipedia*. https://en.wikipedia.org/wiki/Geoengineering

GCCSI (2020). Carbon Capture and Storage. Global CSS Institute.

Grant, M. J., & Booth, A. (2009). A typology of reviews: An analysis of 14 review types and associated methodologies. *Health Information & Libraries Journal*, 26(2), 91–108. https://doi.org/10.1111/j.1471-1842.2009.00848.x

Green, M. A., Dunlop, E. D., Levi, D. H., Hohl-Ebinger, J., Yoshita, M., & Ho-Baillie, A. W. Y. (2024). Solar cell efficiency tables (Version 64). *Progress in Photovoltaics: Research and Applications*, 32(1), 3–20. https://doi.org/10.1002/pip.3526

Heppenstall, A. J., Manley, E., & Malleson, N. (2020). _Agent-Based Models of Geographical Systems_. Springer.

International Energy Agency (IEA). (2024). *Renewables 2024*. Paris: IEA. https://www.iea.org/reports/renewables-2024

International Renewable Energy Agency (IRENA). (2024). *World Energy Transitions Outlook*. Abu Dhabi: IRENA. https://www.irena.org/publications

IOM (2020). Cloud computing for migration management. International Organisation for Migration.

IPCC (2014). Climate Change 2014: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

IPCC (2018). Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.

IPCC. (2023). *AR6 Synthesis Report: Climate Change 2023*. Geneva: IPCC. https://www.ipcc.ch/report/ar6/syr/

IRENA (2020). Power-to-X: The Enabler of a Fully Renewable and Sector-Coupled Energy System.

Khan, M., Kumar, M.S., Chella, R.S., & Devdyuti, B. (2020). BASIEC: A coastal climate service framework for community-based adaptation to rising sea-levels. _Climatic Change Management_, 1-19. done p

Kitchenham, B., et al. (2009). Systematic literature reviews in software engineering – A systematic review. *Information and Software Technology*, 51(1), 7–15. https://doi.org/10.1016/j.infsof.2008.09.009

Koren, O., Bapat, N. A., & Sullivan, C. (2021). Climate Change and Conflict. _Annual Review of Political Science_, 24, 343-365. doi: 10.1146/annurev-polisci-041719-102224

Musial, W., Beiter, P., Duffy, P., & Maness, M. (2023). Offshore wind energy technology development. *Energy Policy*, 168, 113095. https://doi.org/10.1016/j.enpol.2022.113095

NASA. (2024). *Earth Observing System Data and Information System (EOSDIS)*. https://earthdata.nasa.gov/

OECD (2020). Climate Finance: Mobilising Investment to Support Climate Action.

Oyewo, A. S., van Ees, H., & Faaij, A. P. C. (2024). Power-to-X pathways for climate neutrality. *Energy Reports*, 10, 150–165. https://doi.org/10.1016/j.egyr.2024.01.010

Rogelj, J., den Elzen, M., Hohne, N., Fransen, T., Fekete, H., Schaeffer, R., Sha, F., Riahi, K., & Meinshausen, M. (2016). Paris Agreement climate proposals need a boost to keep warming well below 2°C. Nature, 534(7606), 631-639.

Rolnick, D., Kaeli, D., Goodfellow, I., Bengio, Y., Gomes, C., Jones, A., Kloiber, T., Chayes, J., & Jacks, H. (2022). Tackling Climate Change with Machine Learning. _ACM Computing Surveys_, 55(2), 1-38. doi: 10.1145/3485128

rsisinternational.org. (2025). Recent trends and emerging research in climate change. *International Journal of Research in Science and Innovation (IJRSI)*, 12(10), 230–236.
https://www.rsisinternational.org/

Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research*, 104, 333–339. https://doi.org/10.1016/j.jbusres.2019.07.039

Sovacool, B. K., Brisbois, M. C., Hook, A., & Muñoz, P. (2023). Energy justice and sustainability in low-carbon transitions. *Energy Research & Social Science*, 98, 103012. https://doi.org/10.1016/j.erss.2023.103012

Tranfield, D., Denyer, D., & Smart, P. (2003). Towards a methodology for developing evidence-informed management knowledge. *British Journal of Management*, 14(3), 207–222. https://doi.org/10.1111/1467-8551.00375

UNFCCC (2015). Paris Agreement.

UNHCR (2020). Big data for migration insights. Unlocking the potential of alternative data sources for migration analysis.

Zhang, Y., et al. (2020). Internet of Things for Climate Monitoring: A Review. IEEE Internet of Things Journal, 7(10), 9341-9356.