



Original Article

Generative AI for Climate Change Prediction and Environmental Resource Management

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Abstract

Climate change has emerged as one of the most significant global challenges of the twenty-first century, affecting ecosystems, biodiversity, water resources, agriculture, and human health. Traditional climate models have substantially improved our understanding of climate systems; however, they often face challenges related to computational complexity, uncertainty quantification, and real-time decision support. The recent emergence of Generative Artificial Intelligence (Gen AI), including Large Language Models (LLMs), Generative Adversarial Networks (GANs), Diffusion Models, and Transformer-based architectures, presents transformative opportunities for climate forecasting and environmental resource management. Generative AI enables the synthesis of high-resolution climate data, prediction of extreme weather events, simulation of future climate scenarios, and optimization of natural resource allocation. This paper critically reviews recent advances in Generative AI applications for climate change prediction and environmental resource management. The study examines AI-driven climate forecasting frameworks, environmental monitoring systems, digital twins, disaster risk assessment, water resource optimization, forest conservation, and sustainable agriculture. Challenges related to explainability, data bias, computational energy consumption, ethical concerns, and governance are also discussed. The paper proposes an integrated framework for sustainable deployment of Generative AI in climate resilience and environmental sustainability. The findings suggest that Generative AI can significantly enhance climate adaptation and mitigation strategies while supporting evidence-based environmental policymaking.

Keyword: Generative AI, Climate Change Prediction, Environmental Resource Management, Large Language Models, Digital Twin, Sustainability, Climate Resilience, Environmental Monitoring.

Introduction

Climate change has become an existential challenge affecting every component of the Earth system. Rising global temperatures, increasing frequency of extreme weather events, biodiversity loss, water scarcity, and ecosystem degradation require innovative technological interventions for effective adaptation and mitigation strategies. Traditional climate prediction models based on physical equations and Earth System Models (ESMs) have contributed significantly to understanding climate dynamics; however, increasing climate complexity demands more adaptive and data-driven approaches.

Artificial Intelligence (AI) has emerged as a transformative technology capable of processing large-scale environmental datasets and extracting complex patterns beyond conventional statistical approaches. Recent developments in Generative Artificial Intelligence (GenAI), including Large Language Models (LLMs), Generative Adversarial Networks (GANs), Variational Autoencoders (VAEs), and Diffusion Models, have further expanded the scope of AI applications in climate science. These technologies can generate synthetic climate datasets, reconstruct missing environmental observations, improve spatial and temporal climate projections, and support decision-making processes.

Recent studies demonstrate that AI-enhanced climate models significantly improve the prediction of floods, droughts, wildfires, heatwaves, and other extreme climate events. Moreover, Generative AI supports environmental resource management through intelligent monitoring of forests, water resources, agricultural systems, and biodiversity conservation programs. Despite these advances, significant concerns remain regarding model transparency, ethical governance, computational resource consumption, and environmental impacts associated with training large AI models. Sustainable deployment frameworks are therefore essential to maximize societal benefits while minimizing ecological costs.

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This paper aims to:

- Review the role of Generative AI in climate change prediction.
- Examine AI applications in environmental resource management.
- Identify opportunities and limitations.
- Propose a sustainable implementation framework.

Research Methodology

1. Systematic Literature Review (SLR)

This review follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) framework to identify, screen, and analyze studies related to Generative Artificial Intelligence (GenAI) applications in climate change prediction and environmental resource management.

Data Sources

Literature was collected from:

- Scopus
- Web of Science
- ScienceDirect
- SpringerLink
- IEEE Xplore
- Wiley Online Library
- Google Scholar

Search Keywords

The following search string was employed:

("Generative AI" OR "Large Language Models" OR "GANs" OR "Diffusion Models") AND ("Climate Change" OR "Climate Prediction" OR "Environmental Sustainability") AND ("Resource Management" OR "Water Management" OR "Biodiversity Conservation")

Inclusion Criteria

- Peer-reviewed journal articles.
- Conference papers indexed in Scopus.
- Publications between 2022–2026.
- English language.
- Environmental and climate-related applications.

Exclusion Criteria

- Non-peer-reviewed articles.
- Duplicate studies.
- Editorials and opinion papers.
- Studies unrelated to environmental applications.

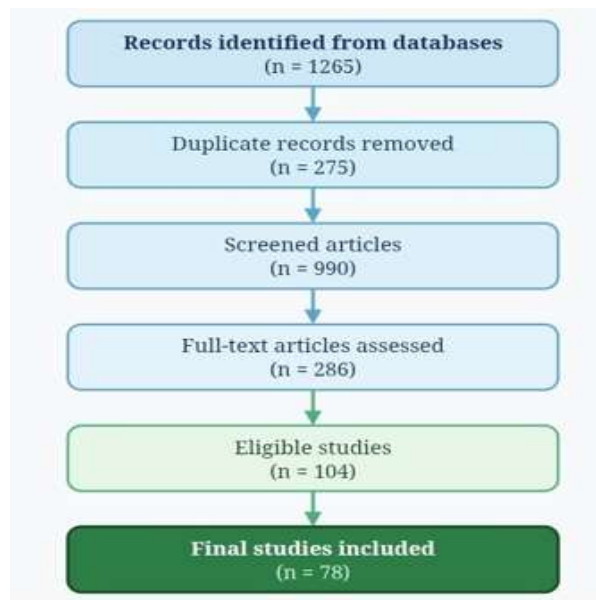


Figure 1. PRISMA Workflow

The search process identified 1,265 records. After removal of 275 duplicate records, 990 publications were screened based on leaving **278 articles** for full-text assessment. Following eligibility evaluation, 104 studies were excluded because they lacked sufficient methodological rigor, focused on highly localized case studies without broader relevance, or did not directly address climate resilience, environmental protection, ecosystem restoration, or sustainability governance. Finally, 78 studies and international reports were included in the qualitative synthesis.

2. Evolution of Generative AI in Climate Science

Generative AI differs from conventional predictive AI by creating new data samples that resemble real-world observations. GANs, Diffusion Models, and Transformers enable generation of realistic climate scenarios, environmental simulations, and uncertainty estimates.

Table 1. Evolution of AI Technologies for Climate Applications

Period	Technology	Major Applications
1980–2000	Expert Systems	Weather prediction
2000–2015	Machine Learning	Climate data analysis
2015–2020	Deep Learning	Remote sensing, forecasting
2020–2023	GANs and VAEs	Climate simulation
2023–Present	Generative AI and LLMs	Climate scenario generation, policy support



Fig 2. Conceptual Framework of Generative AI for Climate Prediction

Generative AI for Climate Change Prediction

1. Climate Data Augmentation

Climate datasets often contain missing observations and spatial inconsistencies. Generative AI models can create synthetic datasets that preserve statistical properties of observed climate records.

Benefits include:

- Improved model training
- Enhanced regional climate projections
- Better uncertainty quantification

2. Extreme Weather Forecasting

Deep generative architectures are increasingly used for forecasting:

- Floods
- Heatwaves
- Droughts
- Hurricanes
- Wildfires

These models integrate meteorological observations, satellite imagery, and Earth-system simulations to improve prediction accuracy.

Table 2. Generative AI Applications in Climate Forecasting

Climate Event	AI Model	Expected Benefits
Floods	GANs	High-resolution forecasting
Droughts	Transformers	Long-term prediction
Heatwaves	Diffusion Models	Uncertainty estimation
Wildfires	LLM-integrated systems	Early warning
Cyclones	Hybrid AI Models	Real-time forecasting

3. Digital Twin Climate Systems

Digital twins are virtual representations of environmental systems continuously updated using real-time observations.

Applications:

- Climate adaptation planning
- Urban sustainability
- Coastal resilience assessment

Smart watershed management

4. **Research Gap Analysis**

Table 3. Research Gap Analysis in Generative AI for Climate Science

Study Area	Existing Status	Research Gap
Climate Forecasting	High accuracy regional predictions	Limited explainability
Flood Prediction	Real-time monitoring available	Poor transferability across regions
Water Resource Management	AI-based optimization	Lack of policy integration
Biodiversity Monitoring	Satellite-based analysis	Sparse ecological datasets
Climate Digital Twins	Emerging technology	Computational complexity
LLM Applications	Rapid growth	Hallucination and reliability concerns

The literature indicates that while predictive AI models have matured significantly, the integration of Generative AI with climate adaptation policy remains underdeveloped. Furthermore, few studies have addressed the environmental footprint associated with large-scale AI deployment.

Environmental Resource Management Using Generative AI

1. **Water Resource Management**

Water scarcity is intensifying due to climate variability.

Generative AI assists in:

- Reservoir optimization
- Demand forecasting
- Groundwater assessment
- Drought management

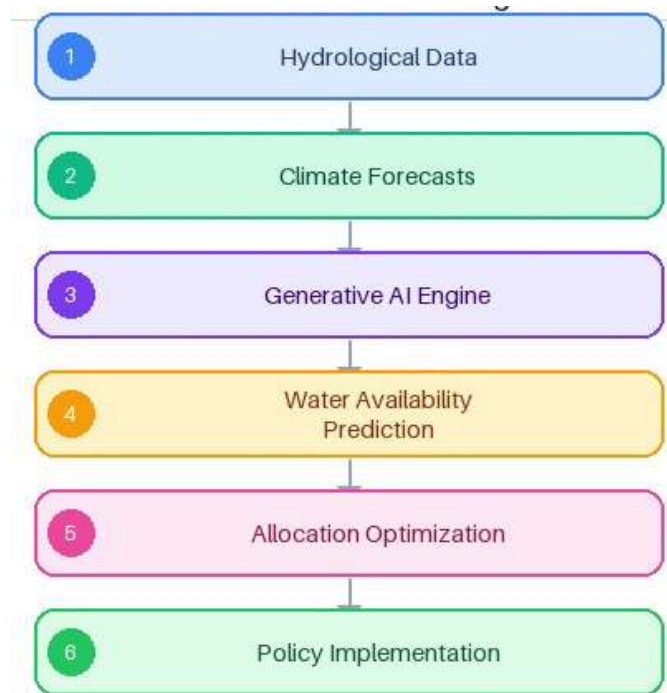


Fig 3. AI Based Water Resource Management Framework

2. **Sustainable Agriculture**

Agriculture contributes significantly to climate vulnerability.

AI applications include:

- Crop yield forecasting
- Precision irrigation
- Soil health assessment
- Pest outbreak prediction

These technologies enhance climate-smart agriculture and food security.

3. **Forest and Biodiversity Conservation**

Generative AI supports:

- Deforestation monitoring
- Habitat mapping

- Species distribution modeling
- Carbon stock assessment

AI-assisted remote sensing enables near-real-time environmental monitoring

4. Comparative Analysis of Generative AI Models

Table 4. Comparison of Generative AI Architectures for Climate Applications

Model	Strengths	Limitations	Environmental Applications
GANs	High-resolution data generation	Training instability	Weather simulation
VAEs	Latent space representation	Lower image quality	Climate reconstruction
Transformers	Long-range dependency modeling	High computational cost	Climate forecasting
Diffusion Models	Superior generative quality	Slow inference	Extreme weather simulation
LLMs	Natural language reasoning	Hallucinations	Environmental governance

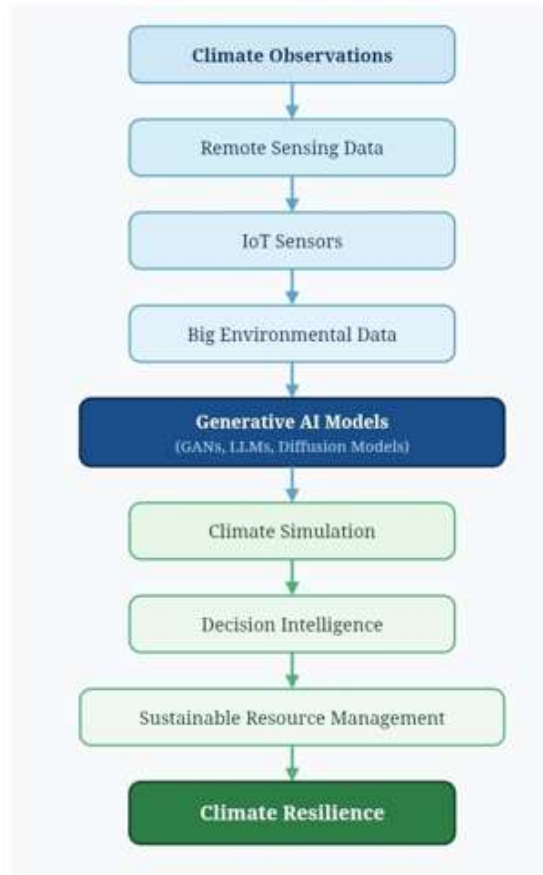


Figure 4. Generative AI Ecosystem for Climate Change Prediction

Large Language Models for Environmental Decision Support

Large Language Models (LLMs) provide novel capabilities:

- Automated environmental reporting
- Climate risk communication
- Policy analysis
- Stakeholder engagement

LLMs can transform scientific findings into actionable recommendations for policymakers and environmental managers.

Table 5. Potential Applications of LLMs in Environmental Governance

Application Area	Function
Climate Policy	Scenario analysis
Disaster Management	Decision support
Water Governance	Resource allocation
Biodiversity Conservation	Knowledge synthesis
Environmental Education	Public awareness

Challenges and Limitations

1. **Data Quality Issues**

Climate datasets often suffer from:

- Missing observations
- Spatial heterogeneity
- Sensor errors

Poor data quality may reduce model reliability.

2. **Explainability and Trust**

Many generative models operate as "black boxes."

Challenges include:

- Limited interpretability
- Policy acceptance issues
- Regulatory barriers

Explainable AI (XAI) frameworks are therefore necessary.

3. **Environmental Cost of AI**

Training large generative models requires significant:

- Energy consumption
- Water usage
- Data center infrastructure

These environmental impacts must be balanced against sustainability benefits.

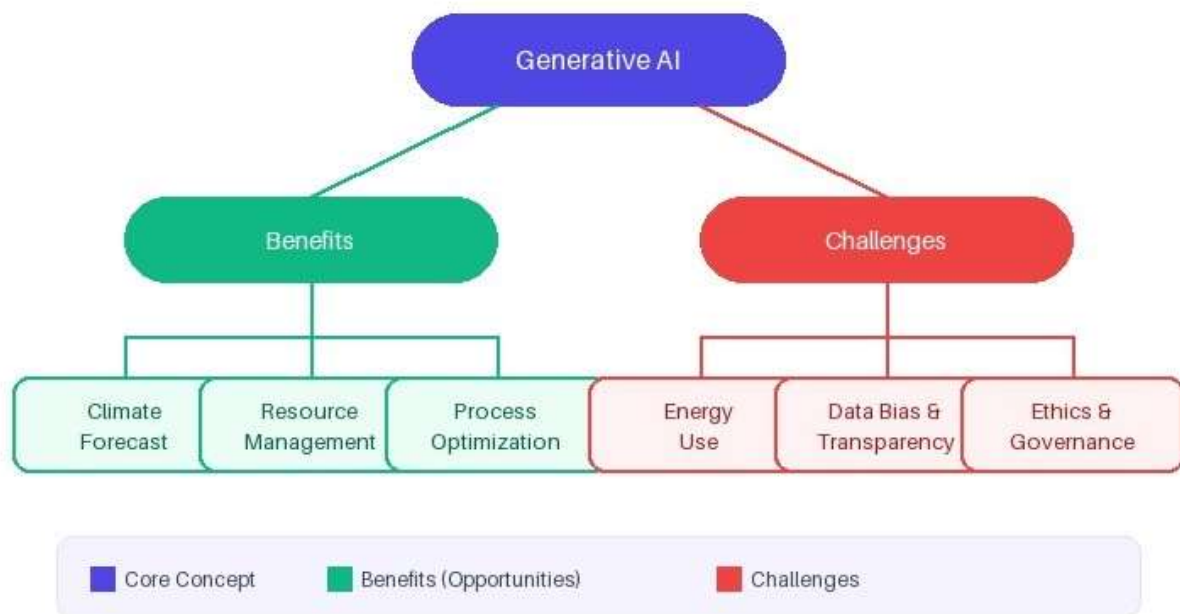


Fig 5. Opportunities and Challenges of Generative AI

Sustainable Framework for Responsible AI Deployment

A sustainable AI framework should incorporate:

Technical Dimensions

- Explainable AI
- Green AI architectures
- Federated learning

Environmental Dimensions

- Carbon accounting
- Renewable-energy-powered data centers
- Energy-efficient algorithms

Governance Dimensions

- Regulatory compliance
- Transparency
- Ethical standards

Social Dimensions

- Inclusivity
- Climate justice
- Stakeholder participation

Sustainable Development Goals (SDGs) Alignment

Generative AI contributes directly to several United Nations Sustainable Development Goals (SDGs).

Table 6. Sustainable Development Goals Mapping

SDG	Contribution of Generative AI
SDG 6	Water resource optimization
SDG 7	Renewable energy forecasting
SDG 11	Climate-resilient smart cities
SDG 12	Sustainable resource utilization
SDG 13	Climate action and adaptation
SDG 15	Biodiversity conservation

Policy Recommendations

To maximize societal benefits of Generative AI in climate governance, policymakers should:

- Develop Green AI regulations.
- Establish environmental AI auditing frameworks.
- Promote open climate datasets.
- Encourage renewable-energy-powered AI infrastructure.
- Integrate AI-based climate forecasting into national adaptation plans.
- Develop ethical governance standards for environmental AI systems.

Future Research Directions

The next generation of climate intelligence systems is expected to integrate:

- ❖ Foundation Models for Earth Systems.
- ❖ AI driven Climate Digital Twins.
- ❖ Quantum-AI Hybrid Models.
- ❖ Multimodal model Environmental Intelligence system.
- ❖ Autonomous Climate Monitoring Networks.
- ❖ Explainable Generative AI (XGenAI).
- ❖ Carbon-Neutral AI Computing Platforms. Climate-resilient smart cities.
- ❖ Sustainable Generative AI architectures.
- ❖ Explainable climate forecasting models.
- ❖ Integration of quantum computing and AI.

These developments could revolutionize climate resilience planning and environmental sustainability management worldwide.

Conclusion

Generative AI represents a paradigm shift in climate change prediction and environmental resource management. By integrating advanced machine learning techniques with environmental datasets, AI systems can improve climate forecasting, optimize resource allocation, strengthen disaster preparedness, and support evidence-based policymaking. Nevertheless, concerns regarding transparency, ethical governance, and environmental impacts of AI infrastructure must be addressed through sustainable implementation frameworks. Future developments in explainable and energy-efficient Generative AI will likely play a critical role in advancing global climate resilience and environmental sustainability.

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Conflicts of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper

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