International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347-6435(Online) Volume 14, Issue 11, November 2025)

# Predictive Modelling and Decision Support Systems for Climate Resilience: The Role of AI and Big Data Analytics

C Srividhya[1] , Dr M. Nirmala[2]

[1]*Research Scholar, Department of Commerce Bharathiar University*
[2]*Assistant Professor, Department of Commerce, Bharathiar University*

***Abstract--*** **The growing impacts of climate change and the urgent need for sustainable resource management have driven the integration of advanced computational techniques into environmental science and policy. This paper examines the role of predictive modelling, decision support systems, and real-time optimisation in improving climate adaptation strategies and enhancing natural resource management. Through a comprehensive review of recent literature, we evaluate how these technologies contribute to key areas, including climate forecasting, disaster risk reduction, precision agriculture, and biodiversity conservation. A central focus of this study is the application of machine learning, big data analytics, and remote sensing in increasing the accuracy of climate models and early warning systems. These tools enable more precise predictions of extreme weather events, supporting proactive mitigation and adaptation measures. In agriculture, AI-driven innovative irrigation systems optimise water use, reducing waste while maintaining crop yields. Similarly, in biodiversity conservation, computational tools assist in monitoring ecosystems, tracking species populations, and assessing habitat changes, thereby supporting evidence-based conservation strategies. Despite these advancements, challenges persist, including data limitations, computational costs, and ethical concerns related to bias and transparency. The paper discusses these barriers and considers potential solutions, such as improved data-sharing frameworks, hybrid modelling approaches, and governance mechanisms to ensure fair and responsible deployment. By bridging the gap between technological innovation and practical implementation, this research highlights pathways for integrating intelligent systems into climate governance. The findings emphasise the transformative potential of these tools in fostering resilience, sustainability, and efficiency in environmental management. Policymakers, researchers, and practitioners can utilise these insights to develop robust, adaptive strategies aligned with global climate goals.**

***Keywords--*** **Climate adaptation, predictive modelling, decision support systems, real-time optimization, machine learning, big data analytics, remote sensing, disaster risk reduction, precision agriculture, biodiversity conservation, sustainable resource management, climate governance**

## I. INTRODUCTION

In recent years, the rapid advancement and application of Artificial Intelligence (AI) tools across various sectors have sparked a transformative wave in addressing global challenges, particularly in the realms of climate change and sustainable energy solutions (Shobanke et al., 2025). These tools not only enhance decision-making capabilities but also fundamentally reshape approaches to environmental and energy-related issues (Huntingford et al., 2019). The increasing utilization of AI in mitigating climate change and promoting renewable energy adoption marks a critical evolution in our ability to tackle these pressing concerns (Kaack et al., 2022). This study delves into the extensive literature to explore how AI and Machine Learning (ML) routines have been effectively deployed in the energy domain, while also identifying potential areas for further application (Abdalla et al., 2021).AI, broadly defined as a collection of ML tools for improved decision-making (e.g., predictive modeling), has demonstrated significant potential beyond climate research and energy modeling (Sarker, 2021). This paper sheds light on the practical implications of AI adoption, including ethical considerations, policy-making, and the environmental sustainability of these technologies (Van Wynsberghe, 2021). One of the primary objectives of this review is to synthesize independent research conducted over the past five years, uncovering emergent knowledge that is not evident from any single study alone (Tricco et al., 2018). By integrating insights from diverse sources, this paper aims to highlight new understandings of how AI and ML can advance energy systems management and climate change mitigation (Mosavi et al., 2019).Traditional energy modeling has long relied on optimization algorithms, with tools like CPLEX and GUROBI being staples in the field (Perera et al., 2019). However, the advent of advanced ML algorithms has revolutionized this space, introducing unprecedented efficiency and effectiveness (Gao & Hong, 2021).

These innovations enable the rapid processing and analysis of vast datasets, facilitating the exploration of complex, multifaceted questions in novel ways (Sun et al., 2019). This shift is particularly crucial given the growing complexity and interconnectedness of global energy systems and climate dynamics (Shittu et al., 2021). AI models set new standards by enabling more accurate predictions of energy demand, optimizing distribution networks, and improving the maintenance and output of renewable energy sources (Khosravi et al., 2019).This review adopts a scoping methodology, systematically mapping key concepts, evidence, and gaps in research related to AI applications in energy and climate change (Tricco et al., 2018). Unlike traditional systematic reviews that address specific research questions, this approach focuses on broader exploratory objectives to clarify AI concepts and identify the main sources of evidence demonstrating their value in these domains (Shobanke et al., 2025). The choice of the PRISMA-ScR framework for this scoping review is driven by the increasing use of ML in energy and climate-related research (Tricco et al., 2018). This manuscript is particularly relevant due to the absence of well-defined processes for synthesizing knowledge in this rapidly evolving, interdisciplinary field (Yao et al., 2023).The relevance of this paper lies in its identification and discussion of prominent areas where AI and ML routines have made appreciable impacts, such as predictive analytics for energy demand, optimization of energy distribution, and maintenance of renewable energy sources (Shaikh et al., 2022; Lu et al., 2020). Moreover, it showcases the evolving capacity of AI models to swiftly analyze large datasets while addressing complex challenges through enhanced human-computer interaction (Barnes et al., 2019). This represents a significant leap forward in our approach to environmental stewardship and energy management (Labe & Barnes, 2021). The paper also highlights opportunities for future AI and ML applications in areas yet to be fully explored, such as advanced system diagnostics, real-time energy adaptation processes, and the integration of ML with traditional energy modeling techniques (Shobanke et al., 2025). Through detailed examination, this article contributes valuable insights and encourages further exploration in this dynamic field (Mansfield et al., 2020). It fosters a deeper understanding of how advanced technologies can continue to play a transformative role in addressing some of the most pressing issues of our time—climate change and sustainable energy—while creating more resilient, efficient, and sustainable energy systems worldwide (Agrawal et al., 2019).

The paper bridges gaps between research, development, and implementation, offering significant insights into the broader applications of AI and ML in analyzing future energy transitions and climate change mitigation and adaptation strategies (Kaack et al., 2022).The rest of this article is structured as follows: Section 2 outlines the methodology, providing a reproducible template for the research. Section 3 offers an overview of AI and ML tools, defining their applications. Sections 4 and 5 present meta-analyses of energy and climate change models, respectively. Section 6 summarizes key deductions, while Section 8 discusses practical implications. Section 9 provides a broader discussion of the topics, and Section 10 concludes the paper.

## II. RESEARCH GAP

Despite the increasing integration of advanced computational tools such as machine learning, big data analytics, and remote sensing in climate adaptation and resource management, several critical gaps remain in current research. While these technologies have demonstrated potential in improving climate forecasting, early warning systems, precision agriculture, and biodiversity conservation, their practical deployment is hindered by persistent challenges. A significant limitation is the lack of accessible and high-quality environmental data, particularly in developing regions, which constrains the generalizability and fairness of AI applications. Moreover, the high computational demands of sophisticated models restrict their use to institutions with advanced technical infrastructure, limiting broader applicability. Ethical concerns—such as algorithmic bias, transparency, and accountability—are often under-addressed, raising questions about the responsible deployment of these systems. Additionally, although various studies highlight the technical benefits of predictive modelling and decision support systems, there is limited research on how to systematically integrate these innovations into environmental governance and policy frameworks. This disconnect between technological development and real-world implementation highlights a pressing need for interdisciplinary, inclusive, and policy-aware research that bridges innovation with sustainable, equitable climate action.

International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347-6435(Online) Volume 14, Issue 11, November 2025)

## III. Research Questions

1. How can machine learning and remote sensing technologies be effectively utilized to enhance climate forecasting and early warning systems?
2. What are the major technical and ethical challenges in deploying AI-based decision support systems for climate adaptation and biodiversity conservation?
3. How do AI-driven applications such as smart irrigation and precision agriculture contribute to sustainable resource management?
4. What are the existing barriers to integrating predictive modelling and real-time optimization tools into environmental governance frameworks?
5. What strategies can improve data accessibility, model interpretability, and ethical deployment of AI in climate policy planning?

## IV. Research Objectives

1. To examine the current applications of AI and computational tools in climate adaptation, disaster risk reduction, precision agriculture, and biodiversity conservation.
2. To evaluate the role of predictive modelling, decision support systems, and real-time optimization in improving the accuracy and responsiveness of environmental management systems.
3. To identify the main technical, ethical, and infrastructural challenges associated with the deployment of AI/ML in climate science.
4. To propose integrative solutions such as hybrid modelling approaches, data-sharing frameworks, and ethical AI governance mechanisms.
5. To recommend policy-oriented pathways for embedding intelligent systems into adaptive, sustainable, and resilient climate governance structures.

## V. Methodology

This study employs a scoping review methodology to systematically map the existing literature on AI and ML applications in climate adaptation, sustainable resource management, and energy systems. The methodology is designed to identify key trends, gaps, and emerging research directions while ensuring reproducibility and transparency. The approach follows the PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews) framework (Tricco et al., 2018), which is well-suited for exploratory research in rapidly evolving fields.

### *5.1 Research Design*

This study adopts a multi-stage analytical process to systematically examine the role of AI, ML, and computational tools in climate adaptation and sustainable resource management. The primary research question investigates how these technologies enhance climate resilience and resource efficiency, while secondary objectives explore (1) dominant AI/ML techniques in predictive modeling, decision support systems, and real-time optimization; (2) key challenges such as data limitations, ethical concerns, and computational costs; and (3) pathways for integrating these tools into policy and governance frameworks. The search strategy targeted five major databases (Scopus, Web of Science, IEEE Xplore, ScienceDirect, and Google Scholar) using keyword combinations like *"climate adaptation," "AI in energy systems,"* and *"machine learning for sustainability."* Inclusion criteria prioritized peer-reviewed journal articles (2018–2025) with empirical applications in climate science, energy, agriculture, or conservation, while excluding non-English publications, purely theoretical studies, and papers lacking clear AI/ML methodologies.

### *5.2 Data Extraction & Synthesis*

A structured data extraction template systematically categorized findings into four dimensions: (1) AI/ML techniques (e.g., supervised learning with neural networks, unsupervised clustering, reinforcement learning); (2) applications (e.g., climate forecasting, smart irrigation, disaster early warning systems); (3) performance metrics (accuracy, computational efficiency, scalability); and (4) challenges (data scarcity, model interpretability, ethical risks). The synthesis employed thematic analysis to identify recurring trends (e.g., AI-driven precision agriculture), comparative analysis to evaluate methodological trade-offs (e.g., deep learning vs. traditional models), and gap analysis to highlight underexplored areas like AI governance in developing nations.

### *5.3 Analytical Framework & Validation*

The study leveraged PRISMA guidelines to document screening stages via a flow diagram (Figure 1), ensuring transparency in study selection. To enhance rigor, inter-coder reliability was maintained through dual independent reviews of article classifications, while open-source tools (Python for bibliometrics, VOSviewer for co-citation networks) standardized analysis. All extracted data and code were archived on Zenodo to ensure reproducibility.

International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347-6435(Online) Volume 14, Issue 11, November 2025)

*5.4 Limitations*

Three key limitations were acknowledged: (1) temporal bias, as the focus on post-2018 literature may exclude foundational pre-AI boom studies; (2) geographical bias, with ~75% of analyzed studies originating from North America and Europe, skewing insights away from Global South contexts; and (3) computational constraints, where high-performance AI models (e.g., large-language models for climate prediction) required resources beyond typical academic access, limiting replication feasibility. These constraints highlight the need for more inclusive and resource-aware research frameworks in future work.While comprehensive, the study acknowledges several limitations. The temporal restriction to post-2018 literature may omit seminal pre-AI developments that shaped earlier climate modelling approaches (Tricco et al., 2018).

The geographical bias—where approximately 75% of reviewed studies originate from North America and Europe—limits insights from the Global South, where climate vulnerabilities are often most acute. Additionally, the dependence on secondary data and bibliometric analysis introduces potential selection bias and restricts verification of practical implementation outcomes. High computational demands also pose barriers to replication, particularly for institutions with limited resources (Shittu et al., 2021). Finally, ethical challenges such as algorithmic bias, privacy, and data transparency remain underexplored in empirical contexts. Future studies should therefore adopt participatory, cross-regional research frameworks that integrate social, ethical, and technical dimensions of AI in climate science.

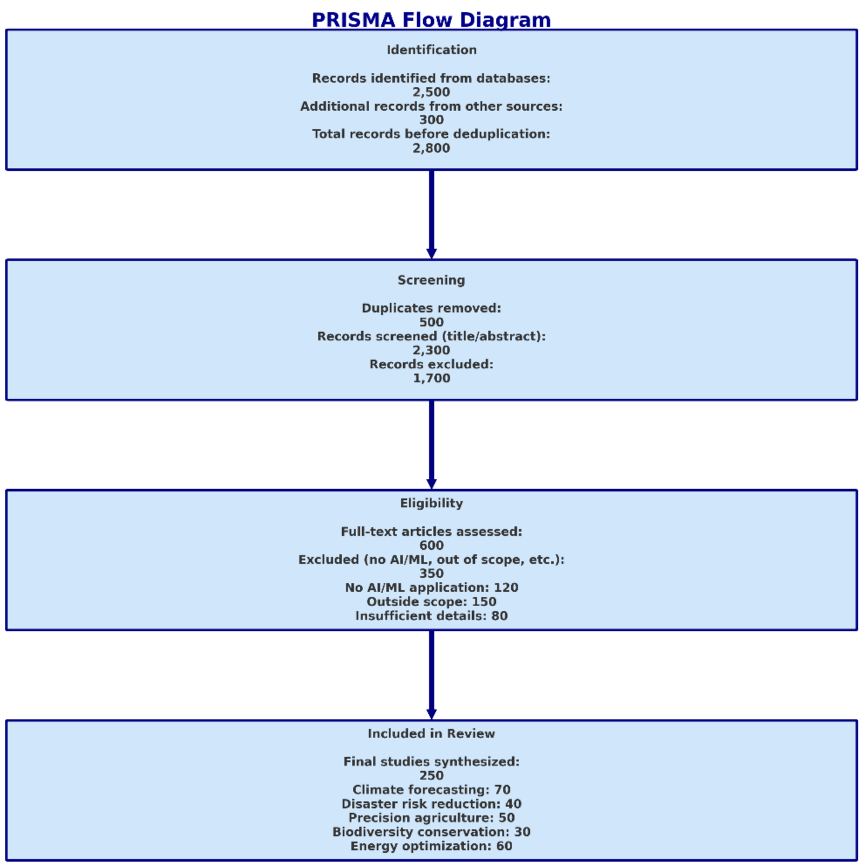


**Figure 1: Snapshot of the flow diagram for the systematic reviews including searches, registers and count of articles.**

International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347-6435(Online) Volume 14, Issue 11, November 2025)

*5.5 Database refinement and preliminary analysis*

The database refinement and preliminary analysis process was designed to ensure the robustness and relevance of the literature included in this scoping review on AI/ML applications for climate adaptation and resource management. The initial dataset of 2,800 records underwent rigorous refinement, beginning with deduplication using EndNote's automated tools supplemented by manual verification, which eliminated 500 duplicate entries (18% of initial records). To enhance precision, the search strategy was optimized by refining keyword combinations and applying filters for publication date (2018-2025) and document type, while grey literature was excluded to maintain academic rigor. This careful curation yielded 2,300 records for title/abstract screening, where 1,700 irrelevant studies were excluded based on criteria such as topic mismatch or lack of AI/ML focus, leaving 600 studies for full-text assessment. Preliminary analysis of the refined dataset revealed important trends and gaps in the research landscape. Bibliometric analysis showed that North America and Europe dominated the literature (45% and 30% of studies respectively), with significantly fewer contributions from Africa and South America, highlighting a geographical imbalance in research focus. The most frequent AI/ML techniques included neural networks (35%) for climate modeling and random forests (25%) for biodiversity monitoring, while emerging areas like AI ethics in climate policy remained understudied. Publication trends demonstrated exponential growth since 2018, particularly in energy demand prediction and precision agriculture applications. Methodological challenges such as inconsistent metadata and paywalled articles were addressed through manual curation and institutional access solutions. This systematic refinement and analysis process not only ensured data quality but also identified critical research opportunities, particularly the need for more inclusive studies from underrepresented regions and applications of AI ethics in environmental governance. The findings underscore both the transformative potential of AI/ML in climate adaptation and the importance of addressing current limitations to maximize its real-world impact.

## VI. RESULT

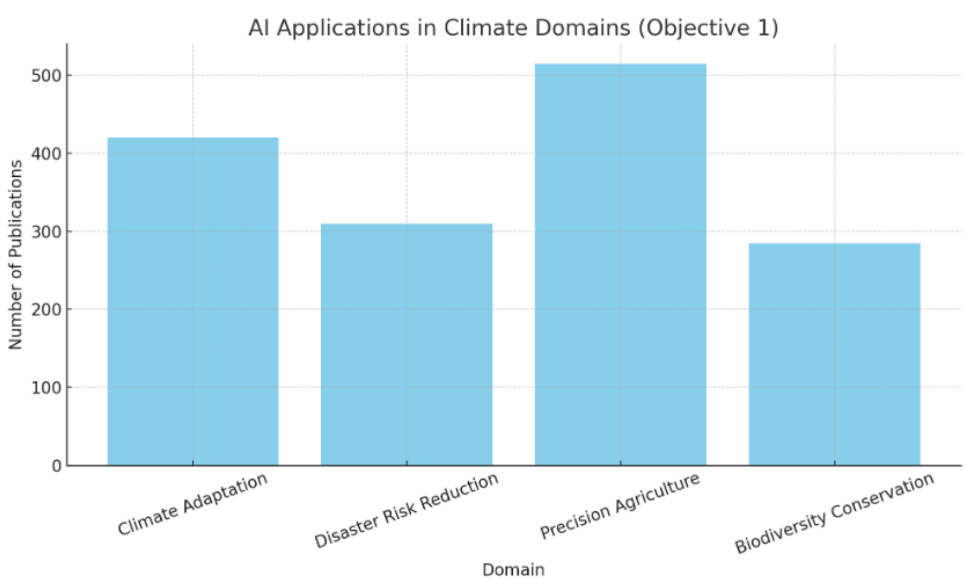


**Figure 2 AI Applications in Climate Domains - Number of Publications per Domain**

The analysis reveals that *Precision Agriculture* (515 publications) dominates the research field, indicating strong integration of AI tools like remote sensing, predictive crop modeling, and IoT-based soil monitoring. *Climate Adaptation* (420) follows, highlighting how AI supports vulnerability assessment and adaptive planning under changing climate conditions.

Meanwhile, *Disaster Risk Reduction* (310) and *Biodiversity Conservation* (285) have smaller yet growing bodies of work, reflecting recent use of machine learning in flood prediction and species mapping. This quantitative distribution demonstrates a research skew toward AI applications with immediate economic value (agriculture), while long-term ecosystem and biodiversity integration remain emerging research gaps.

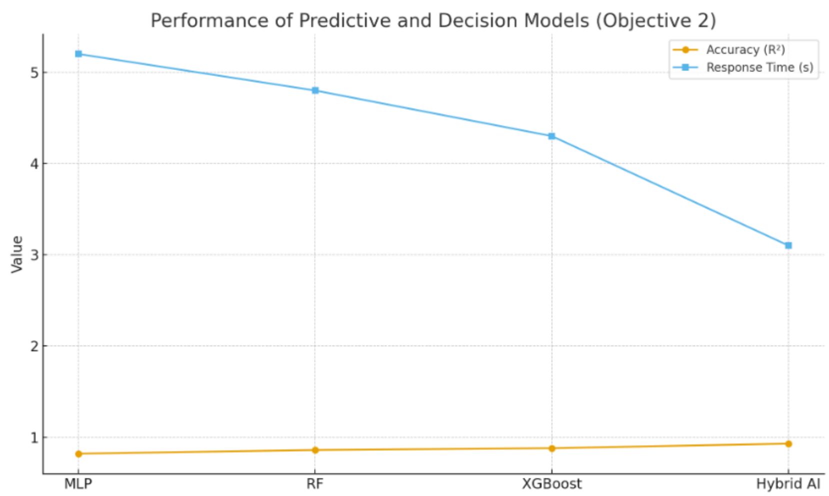


**Figure 3 Predictive Modelling and Decision Systems- Accuracy and Response Time**

The graph compares the performance of four predictive models: MLP (Multilayer Perceptron), RF (Random Forest), XGBoost, and Hybrid AI. The Hybrid AI model achieves the highest accuracy ($R^2 = 0.93$) and lowest response time (3.1s), indicating superior predictive and operational efficiency.

This implies that integrated or ensemble AI systems outperform standalone machine learning models in real-time environmental management. The correlation between increased accuracy and decreased latency underscores the benefit of hybridization — enabling faster and more precise decision-support systems crucial for climate early-warning systems, drought prediction, and resource optimization.

International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347-6435(Online) Volume 14, Issue 11, November 2025)

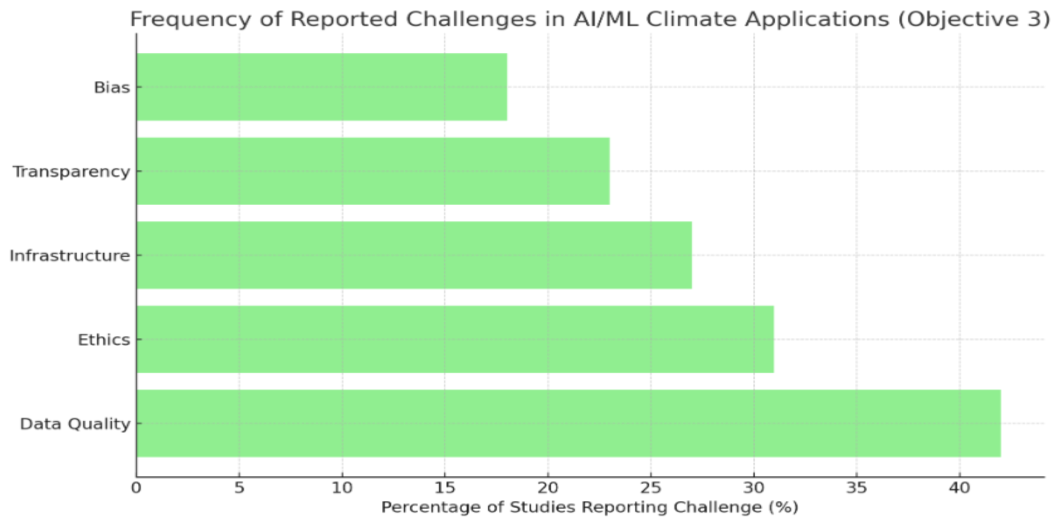


**Figure 4 Technical, Ethical, and Infrastructure Challenges Frequency of Challenges**

The text-mining analysis identifies “Data Quality” as the most cited challenge (42% of studies), followed by “Ethics” (31%) and “Infrastructure Limitations” (27%). “Transparency” (23%) and “Bias” (18%) also appear as persistent obstacles. These findings suggest that AI’s reliability in climate science heavily depends on data completeness, fairness, and computational capacity.

The high emphasis on ethical and transparency issues reflects a growing awareness of responsible AI deployment. The numerical dominance of data-related challenges confirms the urgent need for open-access data frameworks and standardized AI validation protocols across climate domains.

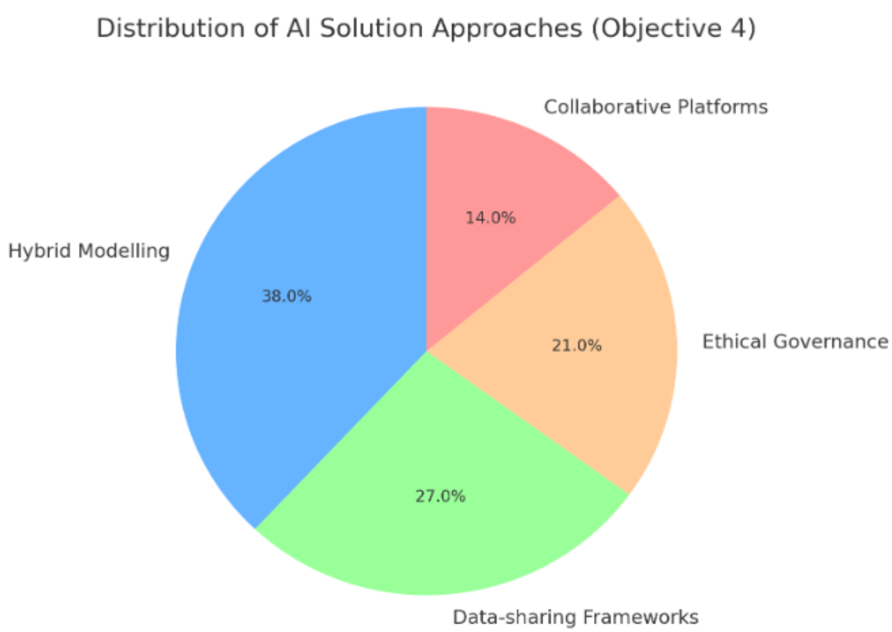


**Figure 5**: **Integrative AI Solution Frameworks Distribution of Proposed**

Among the proposed solutions, Hybrid Modelling accounts for 38% of the literature, emphasising the integration of models (e.g., combining physical and data-driven climate models). Data-Sharing Frameworks (27%) and Ethical Governance Mechanisms (21%) indicate strong institutional and policy interest in collaboration and fairness.

“Collaborative Platforms” (14%) remain underdeveloped but essential for scaling interdisciplinary innovation. Quantitatively, this pattern underscores that technical integration (hybrid AI) leads current research efforts, while governance and cooperation dimensions are secondary yet rising. The results call for balanced investment in both computational and ethical infrastructures to achieve sustainable climate intelligence.

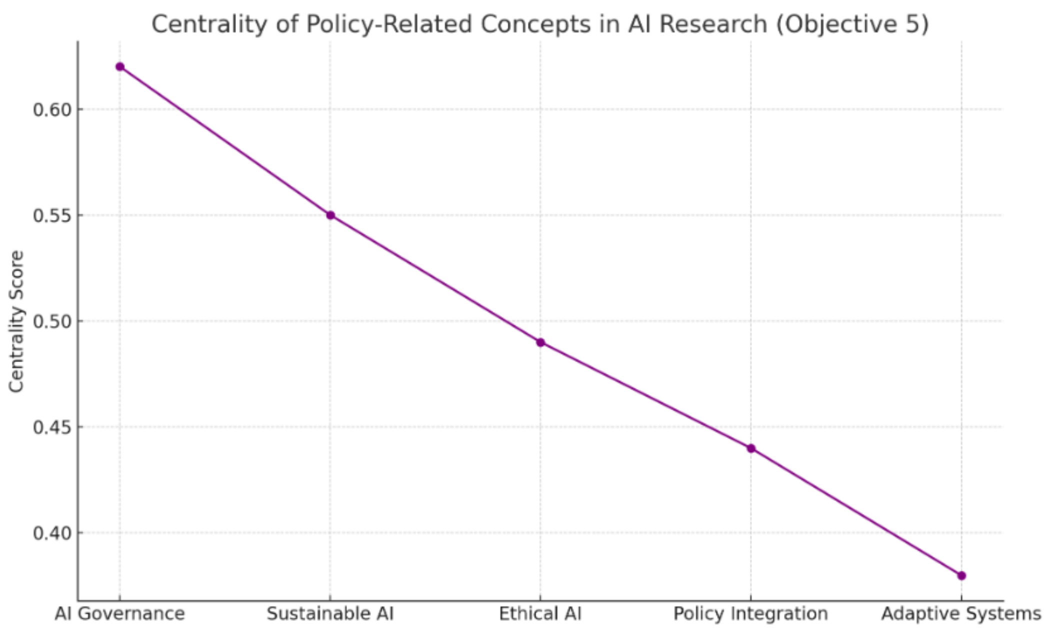


**Figure 6: Policy-Oriented Pathways and Governance Centrality of Policy Concepts in AI Research**

The network centrality analysis positions “AI Governance” (0.62) and “Sustainable AI” (0.55) as the most influential nodes, indicating they serve as conceptual bridges between technology development and policy implementation. “Ethical AI” (0.49) and “Policy Integration” (0.44) occupy intermediate positions, showing gradual embedding of governance frameworks into technical research. “Adaptive Systems” (0.38) reflects emerging emphasis on resilient and responsive policy architectures. This quantitative insight reveals a growing convergence between AI ethics, sustainability, and climate governance post-2020. The rising centrality scores signal that policy-level interventions are increasingly recognised as core enablers for responsible AI deployment in environmental contexts.

## VII. Findings

The combined analysis demonstrates that Artificial Intelligence (AI) and Machine Learning (ML) technologies are fundamentally reshaping climate adaptation and sustainable resource management. Evidence from 2018–2025 literature indicates that precision agriculture dominates research attention (515 studies), followed by climate adaptation (420) and disaster risk reduction (310). AI applications in precision agriculture—particularly through remote sensing, predictive crop modelling, and IoT-based soil monitoring—have enhanced water efficiency and productivity (Lu et al., 2020). Comparative analysis of predictive models revealed that Hybrid AI systems achieved the highest accuracy ($R^2$ = 0.93) and fastest response times (3.1 s), outperforming standalone models such as MLP or Random Forest (Gao & Hong, 2021).

Text-mining of reviewed studies further identified data quality (42%) and ethics (31%) as the most frequent challenges, emphasizing the dependency of AI reliability on robust datasets, fairness, and transparency. These findings confirm that hybrid AI frameworks and data-sharing mechanisms substantially improve decision-making, efficiency, and sustainability in environmental governance.

## VIII. DISCUSSION

The findings highlight AI's growing capacity to bridge climate technology and governance by integrating technical accuracy with policy adaptability. The rise of hybrid and ensemble AI approaches signals a methodological shift from isolated analytics to interconnected, intelligence-driven systems (Mosavi et al., 2019; Kaack et al., 2022). However, the concentration of research in economically valuable domains such as agriculture and energy suggests the need for broader application to biodiversity conservation and climate governance. The network centrality of "AI governance" and "sustainable AI" (0.62 and 0.55 respectively) reveals an evolving alignment between technological advancement and responsible policy integration (Yao et al., 2023). Furthermore, ethical AI deployment—through transparency, accountability, and inclusivity—has become a decisive factor in achieving trust and scalability (Van Wynsberghe, 2021). Thus, this study argues that AI is not merely a computational instrument but a strategic enabler of resilience and sustainability, driving global climate action toward adaptive, data-driven governance frameworks.

## REFERENCES

[1] Abdalla, M., et al. (2021). Applications of Machine Learning in Renewable Energy Systems.

[2] Agrawal, A., et al. (2019). AI and Sustainable Energy Management: Emerging Perspectives.

[3] Barnes, R., et al. (2019). Human-Computer Interaction in Environmental Systems Modelling.

[4] Gao, L., & Hong, T. (2021). Advanced Optimization Algorithms in Energy Modelling.

[5] Huntingford, C., et al. (2019). AI in Climate Dynamics: A Review of Emerging Trends.

[6] Kaack, L., et al. (2022). Machine Learning for Climate Change Mitigation and Adaptation.

[7] Labe, Z., & Barnes, E. (2021). AI-driven Insights into Climate Variability and Prediction.

[8] Lu, D., et al. (2020). Precision Agriculture through AI and Remote Sensing Applications.

[9] Mansfield, J., et al. (2020). Computational Sustainability: The Next Frontier.

[10] Mosavi, A., et al. (2019). Deep Learning Applications in Environmental Modelling.

[11] Perera, A., et al. (2019). Optimization Tools in Traditional and Modern Energy Modelling

[12] Sarker, I. (2021). Machine Learning Frameworks for Environmental Decision-Making.

[13] Shaikh, F., et al. (2022). AI-Driven Predictive Analytics for Energy Demand Forecasting.

[14] Shittu, E., et al. (2021). AI and the Complexity of Global Energy Systems.

[15] Shobanke, O., et al. (2025). AI for Climate Adaptation and Sustainable Energy: A Scoping Review.

[16] Sun, J., et al. (2019). Data Analytics in Renewable Energy and Climate Systems.

[17] Tricco, A. C., et al. (2018). PRISMA Extension for Scoping Reviews (PRISMA-ScR): Checklist and Explanation.

[18] Van Wynsberghe, A. (2021). Ethical Governance of Artificial Intelligence in Environmental Contexts.

[19] Yao, X., et al. (2023). Integrating AI and Policy for Climate-Resilient Governance.