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ROLE OF ARTIFICIAL INTELLIGENCE IN CLIMATE CHANGE PREDICTION AND RISK MANAGEMENT

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Abstract:

Climate change is one of the most pressing and rapidly developing problems that needs to be addressed by mankind, and involves serious threats to natural systems, socio-economic security and human health. Greater intensity and frequency of climate-related hazards reveal the inadequacies of traditional methods of predicting for climate change, as well as of conventional risk-reduction mechanisms. In this framework, AI constitutes a precious technological weapon to reinforce the prediction and the management of climate risk. In this article, we examine the role of Artificial Intelligence in terms of several AI-enabled techniques and tools which are also includes as Machine Learning, Deep learning based models; Climate Modeling Systems (CMS); Remote Sensing technologies; Big Data Analytical methods; Early Warning systems (EWS) and Disaster Risk Reduction (DRR) frameworks. It also explores the incorporation of AI in climate governance frameworks, climate change adaptation planning and sustainable development planning. The article also discusses how the use of AI in climate governance is fraught with issues such as data quality, algorithmic bias, transparency and accountability, ethical considerations, capacity limitations of institutions, and lack of access to state of the art technologies especially in developing nations. Finally, challenges for a responsible and effective application of artificial intelligence to increase the accuracy of climate change prediction, and to better manage climate risk at both national and international levels are suggested. This publication seeks to contribute to the ongoing discussion about one possible use of AI as a supportive instrument for decision-making and environmentally resilient & sustainable governance.

Keywords: Artificial Intelligence, Climate Change Prediction, Climate Risk Management, Machine Learning, Early Warning Systems, Climate Governance, Sustainable Development

Introduction:

With global climate systems undergoing rapid and unprecedented changes, the issue of climate change prediction and climate risk management has become a central concern of environmental governance at both international and national levels *(IPCC, 2021)*. Climate change is no longer a far off or theoretical scenario rather; it appears on different geographical and temperature scales in the forms of higher temperatures, erratic rainfall periods, rising the level of the sea and more frequent dangerous events such as floods, droughts, cyclones and heat waves (Abatzoglou et al., 2019). These events have accelerated environmental destruction and socio-economic vulnerabilities, particularly in developing countries where insufficient adaptation capacity exists. This is where scientific instruments and innovations are crucial in enabling a better comprehension of the dynamics and impacts of climate, thus providing more effective administrations dealing with climate-related risks (Carleton & Hsiang, 2016).

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AI has become a transformative technology that finds application in predicting and managing the risks associated with climate change. AI is a field that attempts to have computer-based systems perform tasks commonly requiring human intelligence, such as learning, pattern recognition, prediction and decision making (McGovern et al., 2017). In climate science, AI is being increasingly utilized in the form of machine learning (ML) algorithms, deep-learning models as well as data-driven analytics platforms deciphering large amounts of climatic, environmental and socio-economic datasets (Chen et al., 2020). By learning about these relationships, sophisticated climate models will be developed that are grounded not primarily in physics but in AI methodologies. These AI-enabling techniques provide the capacity to detect and explore complex patterns and relationships embedded within climate systems well outside the capabilities of conventional statistical/modeled approaches (Krakauer et al., 2017).

Artificial Intelligence for climate change prediction has seen a significant increase in interest in its capability to enhance the accuracy and resolution of climate models and predictions (Liu et al., 2020). Climate prediction in the past has been based on physical models and historical observation data which have limitations in considering the non-linear interactivities and uncertainties that are inherent to climate systems (Hewitson, Griggs, & Peart, 2014). Artificial Intelligence also makes predictions stronger by assimilating diverse information for instance satellite data, remote sensing observations and meteorological records and historic climate. This demonstrates accurate and authentic predications for climate change trends.

It also participates in the early warning mechanisms for disaster preparedness and adaptive responses (Cui et al., 2022). Machine learning-backed risk assessment methods can help identify vulnerable zones, forecast potential damages and allocate resources in a timely and effective manner during weather-related disasters (Gao et al. 2021). In fact, these kinds of applications may greatly contribute to reducing human, economic and environmental damages while enabling the provision of proper emergency responses and making well-informed decisions (United Nations, 2022). Meanwhile, as the hazard level due to climate change keeps increasing, AI integration into risk management systems will be crucial in order to enhance not only resilience but also the capacity for adaptation (Fankhauser et al. 2022).

The increasing dependence of climate governance on Artificial Intelligence, however, presents important challenges and questions as well. Data accessibility, quality and availability, algorithmic transparency, ethical responsibility and disparities in technological access are challenges to both the effectiveness of AI-based solutions as well as equitable use of these technologies (Doshi-Velez & Kim 2017). These critical issues are exacerbated in low- and middle-income countries, where infrastructure as well as institutional capacity may be deficient (Khan et al., 2020). Overcoming these challenges requires a more thoughtful incorporation of Artificial Intelligence into the extant legal, institutional and policy settings to harmonize technological advances with principles of sustainability, fairness and environmental justice (see also Zhang & Liang, 2021).

This paper seeks to understand the role of Artificial Intelligence in climate change early-warning and risk analysis taking into account its applications, merits and demerits as part of an overarching environmental governance framework (Anderson et al., 2022). It aims to investigate how AI can improve climate predictions, assist with risk assessment and management and contribute to sustainable development goals (Vinuesa et al., 2020). The article also discusses the

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difficulties in implementing AI-driven tools and outlines three strategies to enhance the responsible and effective use of these technologies for combating climate change.

Artificial Intelligence Framework for Climate Change Prediction:

With the emergence of artificial intelligence (AI) as a holistic ecosystem comprising various interlinked technologies and analytic tools, it provides useful means for improving climate change prediction and managing climate risks in synergy (Rolnick et al., 2019). Like international environmental law, which is developed through treaties, conventions, and institution building, the AI framework works through specialized tools, models and systems that target various aspects of climate analysis (Anderson et al., 2022). These AI-enabled pieces come together to enhance understanding of the climate system, predict future scenarios, and provide information for risk-based decision support (McGovern et al., 2017).

Machine Learning and Climate Modeling:

Artificial Intelligence via Machine Learning has become a ubiquitous technique employed in climate change prediction.. It is the science of getting algorithms to behave in a certain way without explicitly programming it (Chen et al., 2020). Machine Learning is utilized in climate science in order to analyze weather data historically so that all patterns can be identified, and that prediction modelling can be derived for temperature changes (Liu et al., 2020), precipitation conditions, or extreme weather patterns. These models are superior to traditional models for climate prediction since they are able to account for non-linear relationships and uncertainties which are difficult to deal with in more traditional physical-based models (Hewitson et al., 2014). They help to bridge the gap between coarse-resolution global climate models and regional, local monitoring system measures, with more accurate predictions necessary for managing risk locally and planning adaptation (Bergstrom et al., 2021). Machine Learning continually learns and updates, gradually improving the quality of climate predictions accuracy (McGovern et al., 2017).

Deep Learning and Pattern Recognition:

In climate research, large and high-dimensional datasets have prompted the use of Machine Learning (ML) techniques for prediction tasks. Deep Learning algorithms, especially multi-hidden-layer artificial neural networks (HANNs), are used to analyze large information datasets retrieved from satellite imagery, remote sensing platforms and atmospheric measurements (Liu et al., 2020). These models are well suited for capturing complex spatial and temporal patterns that might be missed by standard analysis methods (Jain et al., 2018).

In climate change forecasting, Deep Learning is widely applicable for image-based research problems such as cloud formation sic identification, storm tracking detection, glacier estimation and land-use exchange evaluation (Bergstrom et al., 2021). It improves predictive accuracy and offers early warning by revealing anecdotal indicators for climate anomalies and extreme events. Such a guideline is crucial to predicting unexpected climate hazards including cyclones, floods, and heat waves (Cui et al., 2022).

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Remote Sensing and Big Data Analytics:

Remote Sensing technologies are part of the Artificial Intelligence framework in climate analysis (Gao et al., 2021). Satellites, drones and sensor networks produce ongoing datasets on land surface temperature, sea-level rise, vegetation cover and atmospheric composition (IPCC, 2021). This hug amount of data is processed and analysed through Big Data Analytics in Artificial Intelligence systems to real-time monitor the activity, and long-term trends can be estimated for such type of hypes (Rolnick et al., 2019).

The AI technique applied to Remote Sensing offers the efficient processing for large scale datasets which is uninterested manually (Bergstrom et al., 2021). AI-assisted analysis AI technologies support climate change prediction by recognizing deviations from regular patterns in the climate and monitoring environmental deterioration at varying levels (Gao et al., 2021). This information is critical for risk assessment, resource planning and policy formulation, especially for climate-vulnerable regions (Khan et al., 2020).

Early Warning Systems and Predictive Analytics:

Early Warning Systems play vital role to the instance of the use of Artificial Intelligence in climate risk management (Cui et al., 2022). Through the skillful use of artificial intelligence that powers predictive analytics, AI-based systems aid in detecting weather-related threats in a timely manner by processing weather data, hydrological measurements, and environmental readings (McGovern et al., 2017). These systems produce alerts and predictions that help governments, institutions, and communities to prepare for and respond to disasters (United Nations, 2022).

AI advances early warning systems by increasing the speed of forecasting, decreasing uncertainty and providing for scenario-based risk analysis (Abatzoglou et al., 2019). AI-enabled technologies play very crucial role in predicting and measuring the probability of extreme events occurring and their associated impacts, therefore reducing potential loss of life, damage to infrastructure, and economic dislocation (Cui et al., 2022). The efficacy of such systems relies on the ongoing incorporation of reliable information and alignment of technological outputs to institutional response (Anderson et al., 2022).

Decision Support Systems for Climate Governance:

Artificial Intelligence also supports decision support systems that facilitate policy and organizational aspect of climate risks management (Vinuesa et al. 2020). They apply predictive data, risk assessments and socio-economic indicators to contribute to informed decision taking (Fankhauser et al., 2022). AI-powered decision support tools facilitate the assessment of policy options, prioritization of interventions and efficient deployment of resources to address climate threats (Anderson et al., 2022).

AI promotes adaptive capacity and resilience planning by combining scientific predictions with governance schemes (Zhang & Liang, 2021). Such systems serve to support the evidence-based approach, better articulate public health objectives and improve the linkage between scientific bodies, regulators and emergency management authorities (United Nations, 2022). But the

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benefits depend on transparency, accountability, and on making sure human judgment is serving as gatekeepers for automatic decisions (Doshi-Velez & Kim, 2017).

Principles Guiding the Use of Artificial Intelligence in Climate Change Prediction and Risk Management:

There are several fundamental principles that regulate how AI should be utilized for responsibly, effectively and sustainably creating forecasts of the climate crisis through its application (Anderson et al. 2022). Just like international Environmental laws establish the framework within which the structural regulation of the use of environmental space takes place, so too should normative principles underpin AI's use in environmental governance, making sure these technologies are agents of sustainability and improvements in the welfare of humans, as well as building long term capabilities (Vinuesa et al., 2020). Their principles serve as a conceptual framework for the governance of AI-enabled climate solutions and the risks involved in their misuse or misapplication (Zhang & Liang, 2021).

The principle of sustainable development is one of the most important principles related to AI in climate decision-making. This principle is all about striking the right compromise between technological advancement, environmental conservation and social-economic progress (Fankhauser et al., 2022). Artificial Intelligence (AI) for climate change prediction require to satisfy the needs of the present situations without detracting from the ability of future generations to satisfy their own needs (IPCC, 2021). This means that AI-enabled climate models and risk assessment tools need to focus on sustainable use of resources, climate adaptation actions and long-term environmental planning over short term technological and economic gains (Vinuesa et al., 2020).

The precautionary principle is closely associated with sustainable development and has been widely used in both climate change forecasting and risk assessment (Hewitson et al., 2014). Climate systems are uncertain, complex and have possibly irreversible effects. According to the precautionary principle, there is an obligation to act even in the absence of full scientific certainty if potentially serious harm exists which give potential harm to public health or the environment and which lack of full scientific strategy that should not be used as a reason for postponing such measures to prevent environmental damage (IPCC, 2021). AI improves the operationalization of this principle by early identification of climate risks and by delivering predictive warnings that enable decision-makers to act prior damage becomes irreversible (Rolnick et al., 2019).

Prevention is the second most prominent guiding norm in the use of Artificial Intelligence towards managing climate risk. This idea's underlying principle is prioritizing environmental damage avoidance over post-harm consequences' management (Abatzoglou et al., 2019). Preventive action Artificial Intelligence can also serve as a tool in the preventive response to risk by highlighting growing threats to climate, assessing areas at risk and allowing early measures through systems of alert (pre-warning) and models of prediction (Kum et al., 2023). Through greater accuracy and timeliness in predictive climate modeling, AI enhances proactive measures to prevent the negative impact of extreme climatic phenomena, natural hazards, not to mention trends of long-term climate change (see, for example McGovern et al., 2017).

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This is also true for the governance of Artificial Intelligence in climate change (Khan et al., 2020). Climate change hits developing nations and marginalized communities the hardest, which frequently have little access to modern technology. The common but differentiated responsibility principle acknowledges disparities in technological capability, resources, and historical guilt with regards to climate change (IPCC, 2021). Applied to Artificial Intelligence, this principle entails advocating for equitable access to AI-based climate technologies, data and knowledge (Anderson et al., 2022).

Rather than these domain considerations, explaining AI can be used to encourage transparency and accountability in the deployment of AI for climate prediction and risk management (Doshi-Velez & Kim, 2017). In this case, as well as in others involving AI systems, the "black box" nature of the system can also cause issues regarding trustworthiness, bias and responsibility for decision making (Zhang & Liang, 2021). To effectively govern the climate agenda AI-based predictions and recommendations must be transparent, scientifically sound, and human-interpretable (Vinuesa et al., 2020). Accountability technologies can be used to verify that AI-augmented decisions, such as electronic health record entries like any other procedures in clinical assessment/decision making, are consistent with legal, ethical and institutional obligations (Anderson et al., 2022).

In addition, the ecosystem approach presents a critical guiding principle for AI applications in climate governance (Bergstrom et al., 2021). CC impacts interrelated ecological, social and economic systems, and AI applications need to respect these associations (IPCC, 2021). AI-based climate models should thus take into account ecosystem-level consequences, nature-society interactions and combined environmental implications (Gao et al., 2021).

Adaptive management is also increasingly applicable to AI-based solutions to climate change (Fankhauser et al., 2022). Climate change is a collection of systems that, when combined together, create a system of systems; in turn, governance responses to climate change must be flexible and responsive (Hewitson et al., 2014). AI can allow adaptive management by allowing continuous updates to climate predictions, incorporating new data, and improving risk analysis and assessments (Rolnick et al., 2019). The flexibility for adjusting strategies as climate conditions change and new threats arise is a major benefit of this method (McGovern et al., 2017).

Cross-cropped, these principles constitute a normative basis for the safe and responsible application of Artificial Intelligence within climate change prediction and risk management. They verify that AI-based technologies do not work as technical tools alone, but rather as the instruments taking place within ethical, legal and governance frameworks to materialize climate resilience and sustainable development (Vinuesa et al., 2020).

Institutional and Policy Framework for Artificial Intelligence in Climate Risk Management:

The application of AI in areas as variable as climate change prediction and monitoring, and risk management takes place within a broader institutional and policy context that frames the way in which technical solution are conceived, applied, monitored (Anderson et al., 2022). At international and national levels, institutions of climate governance, scientific bodies and policy instruments are increasingly acknowledging the importance of having data-driven and AI solutions to address climate risks (Vinuesa et al., 2020). Nevertheless, the successful application of AI technology cannot be achieved without legal, organizational and administrative safeguards which have the power to transform technological possibility into practice (Zhang & Liang, 2021).

At the international level, an integration of AI-based methods into climate governance frameworks on global assessment and adaptation planning is slowly being forged (IPCC, 2021). AI-based climate modeling, scenario building and risk analysis for policy consideration and long-term planning are becoming indispensable to scientific organizations and research institutes (McGovern et al., 2017). Such institutional arrangements allow for sharing climate data, technological knowledge and best practices across borders ultimately building the collective capacity for climate change prediction and risk management (Rolnick et al., 2019). However, the lack of binding legal norms that directly control the use of Artificial Intelligence in managing climate governance is a large gap (Anderson et al., 2022).

At the international level, there are various frameworks for institutionalization of AI in climate risk management and these often have been integrated into existing environmental, climate and disaster management regulations (Khan et al., 2020). The UN (2022) notes that ministries in governments in charge of climate change, environmental regulation, science and technology, and disaster management are key intermediaries when it comes to integrating AI tools for climate prediction and risk assessment. National meteorological departments, environmental protection agencies and disaster managements are already using AI for weather forecasts, predicting floods, monitoring droughts and early warning systems (Cui et al., 2022). They are the main intermediaries between advances in science and implementing public policy (Fankhauser et al., 2022).

Policy approaches focusing on climate adaptation and disaster risk reduction present a critical inroad for the AI integration (IPCC, 2021). Climate action plans, disaster risk management plans and sustainable development policies at the national level are increasingly focusing on advanced technology application for enhanced resilience and preparedness (Vinuesa et al., 2020). For these goals, AI can contribute by enhancing the precision of climate predictions and facilitating the real-time monitoring of environment status as well as response mechanisms to climatic emergencies (Gao et al., 2021). Yet, incorporation of AI in policy is often ad-hoc and falls short on regulatory clarity, as well as on strategic planning (Zhang & Liang, 2021).

Institutional capacity matters temperamentally in which AI-based climate risk management is effective (Khan et al., 2020). Some developing countries have challenges in terms of technical capacity, data infrastructure and funding (Anderson et al., 2022). These constraints may prevent successful uptake and retention of AI-enabled climate systems, even with their broad promise (Rolnick et al., 2019). Capacity building, training and institutional reinforcement are therefore necessary to allow AI to make a positive contribution to climate governance instead of strengthening existing inequalities (United Nations, 2022).

Moreover, coordination between institutions is critical to effective climate risk management (Fankhauser et al., 2022). Prediction and response to climate change are in several sectors, including atmosphere and the water cycle as well as hydrology (including river management), agriculture, land use planning, and human health (IPCC, 2021). AI systems consequently should be reconciled across institutions to foster holistic and consistent risk management strategies (Vinuesa et al., 2020). Poor inter-agency cooperation, and siloed governance may hinder the utility of AI-driven tools and prevent meaningful contributions to climate resilience (Anderson et al., 2022).

Data governance is also central to the institutional architecture for AI for Climate Risk Management (Doshi-Velez & Kim, 2017). AI systems depend heavily on the availability of accurate, timely, and full-scope data for functioning (Gao et al., 2021). Policymakers and business operators need to have effective data sharing, data quality and information security policies if AI is to effectively support climate solutions (Zhang & Liang 2021). However, data is often fragmented, unequal access is sometimes an issue, and there is generally a lack of standard protocols; thus, these issues create multiple barriers to fully leveraging AI's potential for predicting climate conditions (Khan et al 2020).

Overall, Despite growing recognition by the institutional and policy framework of the use of AI for climate change prediction and risk management, challenges remain regarding regulations, capability, coordination, and data governance, (2022). The understanding of the challenges will necessitate a more structured and integrated paradigm for aligning technological innovation and climate policy objectives, legal accountability and sustainable development objectives ( ) In order to successfully address the above. (Vinuesa, 2020)..

Role of Artificial Intelligence in Climate Change Prediction and Risk Management:

AI – particularly in the form of machine and deep learning techniques – has taken a major and growing role in climate change prediction and risk management strengthening scientific analysis, improving policy responses, and ensuring institutional readiness to face these risks (Rolnick et al., 2019). Just as international environmental law sets benchmarks and enforcement regimes for implementing biodiversity protection, AI is a force multiplier that enables climate governance with predictive accuracy, risk evaluation and well-informed decision-making (Anderson et al., 2022).

Enhancement of the prediction of climate change and modeling capability is one of the main functions for Artificial Intelligence to play in this task (McGovern et al., 2017). AI-based models are trained to use large-scale datasets from meteorological stations, satellite data, oceanic sensors and historical climate archives (IPCC, 2021). Artificial Intelligence is able to discover complicated correlations and non-linear cross-interactions in climate systems, enhancing the accuracy of long-term climate predictions and short-range weather forecasts (Liu et al., 2020). Such improved predictions enable policy makers and agencies to be more proactive in anticipating climate change and extremes, therefore improving the readiness for and planning on adaptions (Hewitson et al., 2014).

In the management of climate-related disasters, early warning is also one massively critical role that is played by AI (Cui et al., 2022). Predictive analysis using AI allows the detection of disasters such as floods, droughts, cyclones, heat waves and wildfires in a timely manner (Abatzoglou et al., 2019). Artificial Intelligence generates alerts based upon the real-time environmental data and historical trends to facilitate early evacuation, emergency preparedness and resource mobilization (United Nations, 2022). These systems decrease uncertainty and lead time thus reducing the loss of life, infrastructure destruction and economic devastation incurred from weather related disasters such as those due to climate change (McGovern et al., 2017).

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In risk assessment of climate, AI provides support on finding vulnerable regions, populations and infrastructures (Gao et al., 2021). AI-based risk models use environmental, sociodemographic, and spatial data to evaluate exposure, sensitivity, and adaptive capacity (Khan et al. This is important as it enables governments and institutions to prioritize high risk areas, develop targeted adaptation strategies and use resources more effectively (Fankhauser et al., 2022). AI has helped in evidence-based planning for climate resilience and disaster risk reduction by way of scenario-based simulations (Rolnick et al., 2019).

It can help mitigate and adaptation to the climate through strengthening monitoring and compliance (Bergstrom, Hiller, Wallin & C., 2021). Regularly tracking of climate-related drivers and impacts (e.g., deforestation, land-use change, sea level rise, air quality) is necessary to ensure effective implementation of climate policy (IPCC 2021). Real-time monitoring of environmental changes has been achieved through remote sensing and data analytics using AI methods, which allows authorities to evaluate policy effectiveness and respond in a timely manner to new threats (Gao et al., 2021). This monitoring capability enhances transparency and accountability in climate governance entities (Anderson et al., 2022).

Moreover, AI is key to addressing climate adaptation and mitigation planning (Vinuesa et al., 2020). AI powered tools support the optimization energy systems, realising climate smart agriculture, water resources management and resilient urban infrastructure development (Shukla et al., 2022). Artificial Intelligence allows not only to model alternative future climate scenarios, but also to assess policy options, and helps decision-makers in developing strategies that diminish vulnerability and improve adaptive capacity (Fankhauser et al., 2022).

International collaborations and collaborative work on research show how the importance of Artificial Intelligence in predicting climate change is increasing (Rolnick et al., 2019). Joint research projects contribute to making the exchange of climate information, AI model and expertise across borders possible (IPCC, 2021). This collaboration improves the world's ability to understand climate threat and response together by creating adaptation-by-translation (Shelman, 2014) with developing nations who can access AI driven insights into climate risk and learn from these technologies as they evolve.

Despite these major contributions, if AI is to play a role in climate risk intervention, it will require proper interfacing with institutional structures and human decision-making (Doshi-Velez & Kim 2017). AI framework is not self-supporting, the model serves as a decision support per Pokorny et al., 2018 and helps supporting authorities, scientists or responders with real-time trustworthy information (McGovern et al., 2017). As a result, its performance relies on governance mechanisms that can guarantee transparency and the ethical use of the system (Zhang & Liang, 2021).

Overall, AI is a key tool for enhancing forecasting and risk management of climate change. Increasing predictions' reliability, aiding early warning at different time-scales, enhancing risk assessment and informing policy-making, AI advances climate resilience and adaptive governance (Vinuesa et al., 2020). Yet others insist that this function must be supported by robust institutional frameworks, political will and governance arrangements to enable realization of technology's benefits in a fair manner (Anderson et al., 2022).

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Challenges in the Use of Artificial Intelligence for Climate Change Prediction and Risk Management:

While there is rising capacity for AI and its ability to improve models of climate change prediction and the management of risks associated with climate, several challenges obstruct its successful and fair application (Anderson et al., 2022). These challenges are multi-fold concern including technological, institutional, legal, ethical and socio-economic issues as well as governance (Zhang & Liang, 2021). These ensure that Artificial Intelligence contributes to climate resilience rather creating new vulnerabilities (Vinuesa et al., 2020).

Data availability, quality and accessibility represent one of the most challenging aspects (Gao et al., 2021). To provide effective predictions and risk assessments, Artificial Intelligence approaches require substantial accurate data to operate correctly (Rolnick et al., 2019). In several areas, especially countries with developing population like India climate data is either scattered, outdated or inadequate (Khan et al., 2020). Unrecorded historical weather, restricted satellite access and non-standardised data collection all hinder the utility of AI applied to climate models (IPCC 2021). Low-quality data is likely to produce incorrect predictions and a decrease of trust of stakeholders in AI based decision-support systems (Doshi-Velez & Kim, 2017).

Technological and infrastructural constraints are major barriers, as well, to the implementation of AI (Anderson et al., 2022). The development and use of AI-enabled technologies necessitates: (i) computational infrastructure, (ii) adequate human resources, and (iii) ongoing systems maintenance (McGovern et al., 2017). Many developing nations in the world have yet to develop technical capacity for designing, implementing and maintaining AI-powered climate prediction tools (Khan et al., 2020). Artificial Intelligence in climate governance is also constrained by the expense of computing resources, software development needs and technical knowledge, especially in low resource environments (Rolnick et al., 2019).

Another rather new and rapidly rising concern, associated with AI, especially its deep learning-based models, is the lack of transparency and interpretability (Doshi-Velez & Kim, 2017). AI models are at times called "black box" systems because it is literally impossible to understand their decision-making process (Zhang & Liang, 2021). Transparency is an absolute must when one is using AI to model climate change risks and management - if there is none accountability reliability and public trust will be at risk (Vinuesa et al. 2020). Besides, if the underlying logic and assumptions are not clear or made public, policy makers and institutional actors may be reluctant to rely on AI-generated forecasts (Anderson et al. 2022).

Ethical considerations and biases in algorithms will almost certainly represent dilemmas for the responsible use of artificial intelligence (Zhang & Liang, 2021). AI systems trained on incomplete or biased data might produce biased decisions with negative consequences primarily affecting vlnerable populations, countries, or communities (Abeler et al. 2020). Climate risk management biases can lead to an unequal distribution of resources, vulnerable groups being uncovered, and policy responses that are off-target (Fankhauser et al. 2022). Ethics also imply that AI-based climate solutions must be thoughtfully made, kept under control, and assessed to ensure they are just and inclusive (Doshi-Velez & Kim, 2017).

Legal and regulatory gaps constitute part of the issues as the world is trying to figure out how to put Artificial Intelligence into climate governance (Anderson et al. 2022). Around the world there are no complete legal systems allowing use of AI in decision-making and the environment and climate action (Zhang & Liang, 2021). Issues of liability, accountability, and data ownership as well as decision authority are mostly still unresolved (Vinuesa et al. 2020). Without clear-cut norms and standards, use of AI-based climate forecasting systems might raise issues of who is responsible in case of errors, overestimating, or reasonable policy failures (Doshi-Velez & Kim, 2017).

Failing to effectively harness the potential of Artificial Intelligence in the context of climate risk management is, among other things, due to the fact that different institutions work separately without much coordination or communication (Fankhauser et al . 2022. Predicting and reacting to what climate change effects will be is the responsibility of many different sectors through different institutions, e.g. environment disaster management agriculture water resources and urban planning (IPCC, 2021). If these different sectors/ institutions fail to cooperate, it may lead to duplication of work, AI tools not being fully utilised and insufficient policy responses (Anderson et al. 2022). Without integrated governance frameworks, the potential of Artificial Intelligence cannot be harnessed, at least not fully (cf. Vinuesa et al. 2020).

The socio-economic hardships have made these problems worse (Khan et al., 2020). There is a lack of understanding and acceptance in public toward AI applications to climate change solutions (Zhang & Liang, 2021). At times AI-based interventions can be seen by communities as alien and unattainable in technical terms, or at least not designed on their needs (United Nations, 2022). To address this gap, inclusive participation and capacity building is needed to ensure transparent communication in the way Artificial Intelligence supports community-based climate adaptation work (Fankhauser et al, 2022).

The phenomenon of climate change in itself adds another layer of complexity (IPCC, 2021). Given the dynamic and stochastic nature of climate systems, there also needs to be ability for advanced AI models to adapt in real time to new data and changing conditions (Hewitson et al., 2014). Models that are not updated to reflect new climate patterns & or models do not consider future climate can become less accurate given the length of time between model training and use (McGovern et al. 2017). It points to the importance of adaptive governance models that enable Artificial Intelligence systems to adapt in light of new climate realities (Rolnick et al., 2019).

Nevertheless, despite the potential that AI offers to inform climate change predictions and risk reduction in a myriad of ways, these challenges demand: strong governance mechanisms, capacity building of institutions, as gad-flies into inadequate ethical safeguard frameworks, and international cooperation are all required (Anderson et al., 2022). In the absence of such measures, AI-applications might underperform or worsen existing inequalities and governance gaps (Vinuesa et al., 2020).

Conclusion:

Climate change is one of the most serious and complex problems challenging human society in the 21st century, posing a threat both to environmental stability and economic development as well as human security at regional levels. The growing uncertainty, severity and frequency of climate-related hazards led to the realization that existing hazard predictions for climate change were limited, as well as existing risk management regimes. This situation has emphasized the importance of playing a role in improving climate change prediction and risk management by using artificial intelligence under these conditions, so that new ways to understand climate dynamics and respond appropriately to risks generated by climate can be opened.

This work has analyzed AI as an assisting and powering tool in climate governance. Artificial Intelligence leverages machine learning, deep learning, remote sensing and big data analytics including early warning systems and decision support mechanisms to improve climate predictions accuracy while improving how we manage climate risks. AI applications also contribute in the development of early warning systems (EWSs), better disaster risk reduction planning, building resilience process and formulation of informed policies for climate change adaptation and mitigation actions.

The analysis has also revealed that the AI is not isolated but embedded within wider institutional, policy and governance contexts. Its success hinges on its integration with pre-existing climate laws, institutional organization, strong data governance principles and a human backstop. While AI greatly enhances our predictive power and analytical efficiency, it cannot supplant human judgment, legal accountability and political responsibility in climate action.

At the same time, this work raises several issues related to the use of AI in forecasting climate change and managing its risk. These include inadequacies in data, technology and infrastructure limitations, as well as ethical considerations, algorithmic bias, transparency gaps, regulatory voids and lack of access to state-of-the-art technologies - especially in developing countries. If not addressed, these challenges could impede the potential of AI for addressing climate and worsen existing inequities in climate vulnerability and adaptive capacity.

The study findings suggest that AI can significantly enhance prediction and risk assessment of climate change when used in a responsible, transparent, and inclusive manner. Its incorporation in climate governance structures has the potential to increase resilience, promote sustainable development and contribute to increased societal ability to foresee and cope with climate risks. Yet unlocking this potential will depend on conscious policy choices, institutions' strengthening, ethical precautions and international collaboration in order for Artificial Intelligence to be a tool supporting collective climate action rather than posing challenges to new governance regimes.

Recommendations:

In light of the above analysis, the following recommendations are proposed:

1. The legal and policy framework should be enhanced to explicitly acknowledge AI in climate governance, where the use of AI must be facilitated with explicit norms about accountability, transparency and ethical standards.
2. Institutional capacities need to be strengthened in terms of technical training, investment in data infrastructure and the development of human resources with skills that can design, operate, and interpret AI-based climate systems.

3. The governance of data must be strengthened across the globe to facilitate provision of high-quality, long-term climate information that maintains respect for national and regional priorities for data availability and ensures security and privacy.
4. AI Climate Tools must be systematically incorporated into national climate adaptation plans, disaster risk management and sustainable development policies for evidence-informed decision making.
5. Collaboration at the global level and technology transfer should be stimulated to ensure access to AI-led climate solutions, especially for developing and climate-vulnerable nations."
6. Ethical and transparency standards should be codify to address for algorithmic bias, explainability of AI models, and public trust in climate decisions ultimately made with a humanin-the-loop of an AI system.
7. Community engagement and public awareness campaigns should be promoted in order to ensure that AI technology for climate risk management facilitates local adaptation strategies and caters to vulnerable groups.
8. 29) Ensure an integrated Climate Science program is responsive to the rapidly changing climate. Monitor, evaluate and adjust AI systems in response to the changing climate for bias or recalibration of models and predictions over time.

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