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Original article

GOVERNING AI'S SUSTAINABILITY: RISKS, CURRENT RESPONSES, AND PATHWAYS FOR IMPROVED GOVERNANCE

GOBERNANDO LA SOSTENIBILIDAD DE LA IA: RIESGOS, RESPUESTAS ACTUALES Y CAMINOS PARA UNA MEJOR GOBERNANZA

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Abstract

Artificial intelligence development presents significant sustainability challenges across environmental, social, and economic dimensions, demanding more coordinated and systematic governance approaches. However, existing governance responses remain fragmented and reactive, with limited capacity for proactive, lifecycle-wide risk management. To address these issues, sustainability risks associated with AI are examined by analyzing key risk dimensions, evaluating current governance responses, and identifying directions for improvement. A structured review of literature and policy frameworks clarifies persistent limitations, including the absence of operational tools, inconsistent standards, and insufficient cross-sectoral coordination. To help close these gaps, the concept of an AI Green Index is proposed as

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an adaptable framework of traceable and comparable indicators, supporting the identification, assessment, and management of multidimensional AI sustainability risks for improved governance performance. By mapping these challenges, evaluating existing responses, and outlining concrete pathways forward, the work aims to inform policy design and promote the development of more effective, consistent, and inclusive strategies for sustainable AI governance.

Key Words: artificial intelligence governance, sustainability risks, policy and regulatory responses, sustainable development strategies, index design.

Resumen

El desarrollo de la inteligencia artificial presenta importantes desafíos de sostenibilidad en las dimensiones ambiental, social y económica, lo que exige enfoques de gobernanza más coordinados y sistemáticos. Sin embargo, las respuestas de gobernanza existentes siguen siendo fragmentadas y reactivas, con una capacidad limitada para la gestión proactiva de riesgos a lo largo del ciclo de vida. Para abordar estos problemas, se examinan los riesgos de sostenibilidad asociados a la IA mediante el análisis de las dimensiones de riesgo clave, la evaluación de las respuestas de gobernanza actuales y la identificación de líneas de mejora. Una revisión estructurada de la literatura y los marcos de políticas aclara las limitaciones persistentes, como la ausencia de herramientas operativas, la inconsistencia de los estándares y la insuficiente coordinación intersectorial. Para contribuir a cerrar estas brechas, se propone el concepto de un Índice Verde de IA como un marco adaptable de indicadores trazables y comparables que respalde la identificación, evaluación y gestión de los riesgos multidimensionales de sostenibilidad de la IA para un mejor desempeño de la gobernanza. Al mapear estos desafíos, evaluar las respuestas existentes y delinear vías concretas de avance, el trabajo busca fundamentar el diseño de políticas y promover el desarrollo de estrategias más efectivas, consistentes e inclusivas para la gobernanza sostenible de la IA.

Palabras clave: gobernanza de la inteligencia artificial, riesgos de sostenibilidad, respuestas políticas y regulatorias, estrategias de desarrollo sostenible, diseño de índices**.**

Introduction

Artificial intelligence (AI), as an emerging general-purpose technology with broad application potential, is reshaping global economic and social development. Its widespread adoption across sectors is not only seen as a critical driver of innovation and productivity but is also closely linked to progress toward the United Nations Sustainable Development Goals (SDGs).[1] However, the rapid diffusion of AI also introduces sustainability risks related to energy consumption, resource use, social equity, and structural economic impacts. This has led to growing attention on integrating AI's sustainability risks into the global governance agenda.[2]

These sustainability risks are complex systemic challenges spanning environmental, social, and economic dimensions.[3] Firstly, AI training and deployment process require significant electricity and water resources, resulting in substantial resource consumption and carbon emissions.[4] Moreover, hardware production and frequent iterations contribute to the growing issue of electronic waste and other ecological impacts that are increasingly coming under scrutiny.[5] Secondly, ethical concerns have also

emerged around privacy protection, algorithmic bias, fairness concerns, and labor conditions in AI development and deployment.[6,7] Furthermore, the global deployment of AI technologies may exacerbate the digital divide and increase market concentration, which threatens equitable development within the global economy.[8]

To address these challenges, governments, international organizations, and industry stakeholders have proposed multi-level governance responses in recent years. Various international and regional principles, along with guidelines, have established fundamental ethical and policy frameworks for sustainable AI governance.[9] At the same time, corporations and researchers have developed practical tools to operationalize AI-related sustainability principles, such as energy efficiency optimization, carbon emissions accounting, and algorithmic fairness assessments, among others.[10–12] However, these governance responses remain fragmented, often lacking actionable tools and effective cross-sectoral integration. As a result, the development of systematic AI sustainability risk management frameworks and globally comparable standards is hindered.

Considering these issues, there is an urgent need for a multi-dimensional, systematic review and assessment of AI sustainability risks and existing governance efforts. Such an evaluation is crucial to identify current limitations and inform the design of actionable, cross-sectoral improvements. This paper aims to address this need through a comprehensive analysis of the literature and policy developments. It first offers an in-depth overview of the various dimensions of AI sustainability risks, followed by an examination and evaluation of recent governance responses at multiple levels. Finally, it identifies key limitations and proposes actionable recommendations for future improvements, providing a structured foundation for both policy-making and academic research in sustainable AI governance.

Mapping Major Sustainability Risks of AI

AI technology holds enormous potential for innovation, but it also brings concrete challenges across environmental, social, and economic dimensions.[2] These are not incidental side effects that technology will resolve on its own. Instead, they are critical issues that demand targeted, multidimensional responses in governance and policy design.[13] **Figure 1** illustrates the major sustainability risks of artificial intelligence across different dimensions.

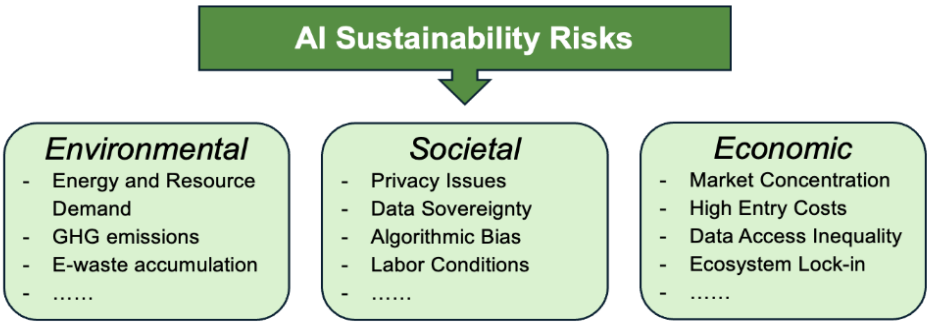

Figure 1. Key Environmental, Societal, and Economic Challenges of AI
Source: own elaboration

- **Environmental Dimension**

AI's environmental impacts stem from its substantial demands for energy, water, and critical materials, which shape patterns of resource consumption and generate environmental externalities. Training and deploying AI models require large-scale parallel computation and stable operating conditions, contributing to growing electricity demand and greenhouse gas (GHG) emissions.[11,14] Recent research estimates that training a single large language model can emit around 300,000 kg of CO_2—the equivalent of 125 round-trip flights between New York and Beijing.[15]

Data centers and high-performance computing facilities also depend heavily on water-based cooling systems to maintain stable temperatures, leading to considerable annual water consumption that can stress local supplies.[4,16] At the same time, the rapid evolution of AI algorithms drives frequent hardware replacement cycles, resulting in a sustained buildup of electronic waste.[17] The manufacturing of these components can further cause ecological damage through resource extraction and production processes.[18]

- **Societal Dimension**

AI's social challenges revolve around personal rights, group fairness, and the integrity of the information environment, making these critical risk areas that must be identified and managed throughout technology deployment. AI systems depend on extensive collection and use of personal data, yet existing privacy protections, consent mechanisms, and data sovereignty frameworks often prove inadequate in cross-border and cross-platform contexts. Users frequently have limited control over how their information is collected, shared, and used.[19,20]

Biases present in training data can be amplified in model outputs, resulting in discriminatory outcomes based on gender, race, or geography.[21] Furthermore, the AI industry often relies on outsourced and gig-based labor for essential tasks such as data labeling and content moderation, creating a large class of "micro-task" workers who typically lack stable income and sufficient social protectio.[22]

- **Economic Dimension**

Economic challenges reflect the ways AI development influences resource distribution, market structure, and global equity. Building and deploying AI systems require vast data resources, high-performance computing infrastructure, and significant capital investment, which tend to concentrate technological capabilities and market power in a small number of large platform companies.[23,24]

The acquisition, processing, and legal use of high-quality data also involve significant costs, placing smaller firms and less developed regions at a clear competitive disadvantage in AI research, development, and service delivery.[25] Moreover, dominant platforms further reinforce their market position through the control of interface standards, allocation of computing resources, and integration of extensive ecosystems, locking in technological pathways and reducing opportunities for new entrants and diverse forms of innovation.[26]

Governance Response to the Sustainability Risks AI

- **International and Regional Level**

International and regional level responses to sustainable AI governance are organized through multilevel mechanisms, including intergovernmental initiatives, international forum agenda-setting, and regional regulations. These frameworks address core issues such as environmental protection, social equity, and economic inclusion, providing a policy foundation to align technological innovation with global sustainable development goals.

At the global level, the Organization for Economic Co-operation and Development (OECD)'s *AI Principles*, released in 2019, represent the first internationally endorsed AI governance standard, explicitly promoting the values of "inclusive growth, sustainable development and well-being".[27] In 2021, the United Nations Educational, Scientific and Cultural Organization (UNESCO) adopted the *Recommendation on the Ethics of Artificial Intelligence*, which was approved by 194-member states. This recommendation emphasizes preventing environmental harm and systematically incorporates key values such as human rights, fairness, and cultural diversity.[28] The International Telecommunication Union (ITU)'s *AI for Good* platform also promotes AI applications aligned with the Sustainable Development Goals (SDGs), focusing on energy efficiency, climate adaptation, and social inclusion.[29]

At the regional level, the European Union's proposed *Artificial Intelligence Act (AI Act)* adopts a risk-based regulatory framework that bans the most dangerous uses, imposes strict oversight on high-risk applications, safeguards fundamental rights and safety, and supports innovation and market compliance.[30] Recent G7 and G20 AI governance agendas, building on the OECD *AI Principles*, continue to emphasize safety, controllability, and sustainability, prioritizing environmental impacts, social trust, and fairness in international policy discussions.[31,32]

Overall, international and regional government responses rely on a diverse set of laws, policy frameworks, and regulatory guidelines that cover environmental, social, and economic dimensions. These responses demonstrate a spectrum from binding compliance to voluntary guidance, establishing an essential foundation for global cooperation and policy alignment in sustainable AI governance.

- **Corporate and Community Level**

In the global push for sustainable AI governance, both corporations and communities play indispensable roles. Through self-regulatory principles, strategic commitments, collaborative mechanisms, and the development of tools and standards, these multi-level governance responses not only complement existing national regulations and international initiatives but also provide concrete pathways and support for the realization of sustainable development goals in technological innovation and application.

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At the community level, technology developers and research communities have translated governance principles and policy requirements into actionable practices through the development of open-source tools and methods. In the environmental domain, tools and computation methods help quantify, monitor, and predict energy consumption and carbon emissions during model training, supporting energy efficiency optimization and sustainable design considerations.[10,35] In the social dimension, tools for algorithmic bias detection and fairness assessment as well as documentation standards are continuously proposed and refined, enhancing transparency, accountability, and the identification and mitigation of potential biases during the development process.[12,36]

Overall, the collaboration between corporate commitments and community-driven tool development forms a crucial self-regulatory system for AI sustainable governance. While these initiatives largely rely on voluntary compliance and reputation mechanisms for enforcement, they play a vital role in fostering the development of practical standards, enhancing industry-wide responsibility, and complementing formal governance frameworks.

Challenges and Future Directions for Sustainable AI Governance

- **Limitations of Current Governance Approaches**

Despite a range of global and regional efforts to promote sustainable AI governance, existing measures still face limitations.

Limitations of International Principles and Frameworks

International and regional organizations have provided strategic direction for global AI governance by articulating broad principles and ethical commitments. While these initiatives have successfully elevated the global discourse on responsible AI, they largely remain at the level of aspirational guidelines, lacking the concrete operational tools and quantitative standards needed for practical implementation.

Moreover, these frameworks often fail to specify clear pathways for implementation or establish mechanisms for effective cross-sectoral integration. The absence of operational details and interdisciplinary coordination has limited their ability to support tangible governance actions. Furthermore, the lack of enforceable obligations and harmonized requirements has contributed to fragmented and inconsistent governance outcomes across various countries and regions, undermining the effectiveness of global AI governance efforts.

Delayed Tools and Absence of Unified Standards

Current AI governance tools primarily focus on post-hoc assessment and remediation, with limited capacity for proactive, lifecycle-wide risk management. These tools typically monitor and mitigate impacts only after AI systems have been deployed, rather than facilitating the integration of sustainability considerations during the design and development stages. This reactive approach makes it difficult to anticipate potential risks and address them in the early phases of AI deployment.

Compounding this issue is the lack of consistent industry standards. Much of the existing governance infrastructure depends on voluntary corporate commitments and market-driven incentives, often leading to highly variable adoption across organizations and regions. The absence of binding, harmonized standards and quantitative evaluation tools further complicates meaningful cross-border and cross-sectoral comparisons, thereby hindering coordinated governance efforts. Without a unified framework, AI governance practices remain fragmented, obstructing the development of effective, transparent, and comparable assessments of sustainability impacts.

- **Suggestions for Strengthening Future Governance**

To address the limitations of current responses, future governance needs to fundamentally strengthen its systemic and collaborative foundations.

First, the development of widely accepted, internationally comparable assessment standards is crucial. Such standards would facilitate consistent dialogue and benchmarking across countries and industries on environmental, social, and economic dimensions. This is not only essential for effective evaluation and accountability but also provides a shared language for policy design and global risk management. These standards should also be flexible enough to accommodate the rapidly evolving nature of AI technology, while ensuring they are actionable and enforceable.

Second, governance approaches need to transition from reactive measures to proactive integration, embedding sustainability considerations into the design and development of the AI lifecycle from the outset. Achieving this shift will require countries and regions to establish more formal cross-sectoral cooperation mechanisms, promoting information sharing and joint decision-making among regulators, industry stakeholders, and research communities. This will help dismantle existing barriers between governance structures and technological development.

Thirdly, greater international coordination of laws, regulations, and standards is necessary to prevent the emergence of regional governance silos or new technological barriers. Additionally, efforts should focus on capacity building and knowledge sharing to ensure that low- and middle-income countries can participate in, adapt to, and benefit from a globally coherent system of sustainable AI governance.

Finally, establishing mechanisms for long-term monitoring and feedback is critical to ensure that AI governance remains dynamic and adaptable. As AI technologies continue to evolve, it is essential that governance frameworks evolve accordingly. A continuous monitoring process should be set in place to track the effectiveness of AI governance in addressing sustainability risks over time, enabling adjustments and improvements based on empirical data and real-world impacts. These mechanisms should be inclusive, allowing stakeholders from all sectors to provide input on challenges faced and potential solutions. This long-term approach will ensure that AI governance remains responsive to future developments and continues to serve the global community's sustainability goals.

- **Practical Tool Exploration: AI Green Index**

Based on the above analysis, when designing a comprehensive and effective governance model for sustainable artificial intelligence, the key step in promoting its implementation is how to use actionable

tools to clearly quantify AI's sustainable risks and support the migration across different systems, industries, and application entities. To address this challenge, this paper proposes the construction of an Artificial Intelligence Green Index (AI Green Index) as an initial exploration.

The core objective of the AI Green Index is to structurally model and present the sustainability mechanisms and key components involved in AI operations through a traceable and comparable set of indicators. This index aims to fill gaps in existing international governance frameworks, particularly by addressing the current limitations in sustainable AI governance, which often lack specific implementation pathways and mechanisms for cross-domain integration. The AI Green Index is designed to provide actionable frameworks for various governance entities, enabling them to identify, assess, and address multidimensional sustainability risks throughout the development and deployment of AI systems. **Figure 2** illustrates the translation framework of the AI Green Index as a structural governance tool.

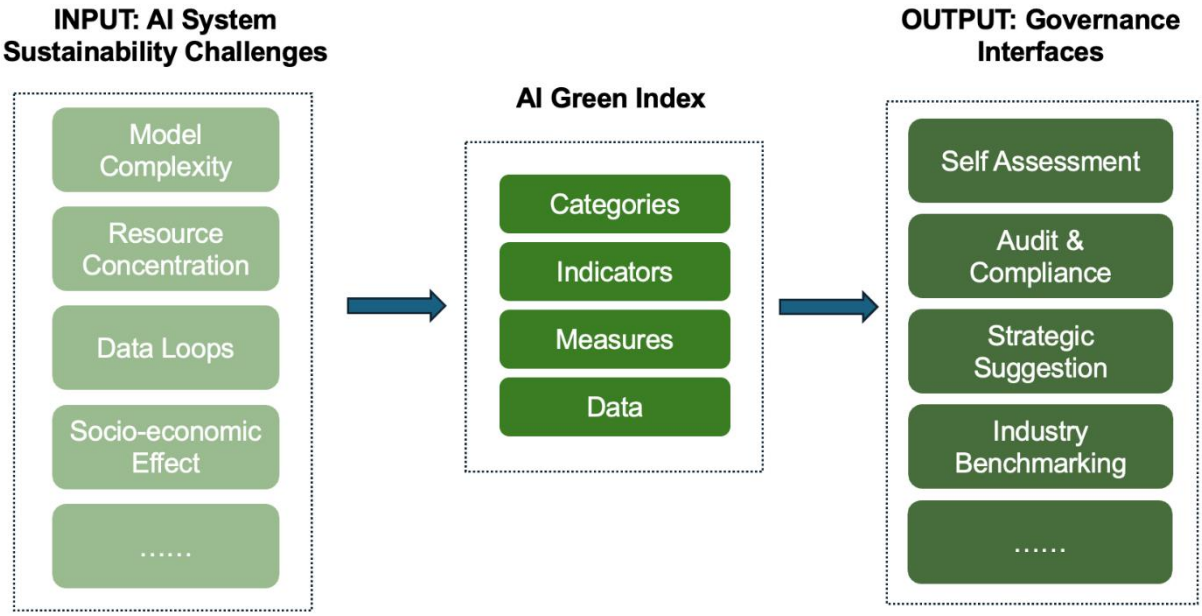

Figure 2 Translation Framework of AI Green Index
Source: own elaboration

Unlike traditional outcome-based indicators that focus on a single dimension, the AI Green Index emphasizes understanding the overall structure of sustainability risks and capturing their multiple dimensions. It integrates these diverse risks while incorporating the flexibility to be able to adapt to different scenarios, enabling the adjustment of weights and priorities according to specific application contexts to meet the needs of various stakeholders.

Moreover, the AI Green Index should adopt an open architecture to support dynamic updates, continuously monitor risk status, and provide timely adjustment recommendations, thus fostering more comprehensive governance practices. In the future, the AI Green Index should also have the potential to develop more targeted subsystems and collaborative mechanisms that are better adapted to different systems and governance contexts.

Conclusions

The rapid development of artificial intelligence presents both significant opportunities and formidable challenges for achieving the Sustainable Development Goals. Its complex risks, spanning environmental, social, and economic dimensions, necessitate a shift away from narrow and fragmented governance perspectives.

This paper systematically reviews the sustainability risks associated with AI and the current governance responses, emphasizing that existing governance systems often lack actionable tools, unified assessment standards, and effective cross-sectoral coordination mechanisms.

Based on these, this paper proposes the concept of AI Green Index as a risk identification and assessment tool embedded in the early stages of system development to assists in identifying and adjusting sustainability risks in operation and provides support for the transformation and response of governance concepts.

Future research could continue to the design and test of adaptable assessment frameworks such as the AI Green Index, evaluating their effectiveness across diverse contexts and sectors. Greater interdisciplinary collaboration will be needed to refine indicators, align technical and ethical considerations, and ensure relevance to different governance systems.

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