

Innovation and Disruptive Technologies for Sustainable and Climate Finance

Miriam Sosa¹, Antonina Ivanova^{2*}

¹Economics Department, Universidad Autonoma Metropolitana (UAM-Iztapalapa), Mexico City, Mexico

²Economics Department, Autonomous University of Baja California Sur, La Paz, Mexico

Email: *msosac87@hotmail.com

How to cite this paper: Sosa, M., & Ivanova, A. (2025). Innovation and Disruptive Technologies for Sustainable and Climate Finance. *Modern Economy*, 16, 1401-1419. <https://doi.org/10.4236/me.2025.169065>

Received: March 26, 2025

Accepted: September 12, 2025

Published: September 15, 2025

Copyright © 2025 by author(s) and Scientific Research Publishing Inc.

This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).

<http://creativecommons.org/licenses/by/4.0/>



Open Access

Abstract

This study explores how disruptive technologies, and financial innovations can strengthen climate and sustainable finance by addressing persistent structural, institutional, and social barriers. Using a systematic literature review, the research analyzes academic and policy sources to explore the integration of tools such as blockchain, artificial intelligence, and decentralized finance into climate finance frameworks. The central hypothesis is that these innovations enhance the transparency, accessibility, and effectiveness of climate finance, particularly in developing economies. Findings suggest that innovation can improve fund traceability, stakeholder inclusion, and project evaluation, contributing to more equitable and resilient financing mechanisms. However, technological adoption faces limitations related to regulatory gaps, technical capacity, and institutional resistance. The article's originality lies in linking disruptive innovation to climate justice and proposing a framework for more just and efficient financial architecture. It contributes to climate policy, finance, and development debates by bridging technological potential with sustainability goals.

Keywords

Climate Finance, Innovation, Disruptive Technology, Sustainability, Global Justice

1. Introduction

Climate change represents an unprecedented global crisis, one that reveals deep asymmetries in responsibility and vulnerability. Industrialized nations, as the primary historical emitters of greenhouse gases, contrast starkly with developing countries that contribute minimally yet suffer disproportionately from climate

impacts (Fuje et al., 2023; European Parliament, 2024). This structural imbalance has grounded international climate governance in principles of equity, such as the “common but differentiated responsibilities” enshrined in the United Nations Framework Convention on Climate Change in 1992 (UNFCCC). Within this normative framework, climate finance has emerged as a cornerstone for promoting climate justice and supporting the mitigation and adaptation efforts of resource-constrained nations (United Nations, 2021; United Nations, 2024).

Despite commitments reaffirmed through multilateral agreements, from the Rio Summit to the Paris Agreement, financial flows from the Global North to the Global South remain inconsistent, insufficient, and vulnerable to geopolitical disruptions. The U.S. withdrawal from the Paris Agreement under the Trump administration, alongside the rollback of over 140 environmental measures, exposed the fragility of climate finance as a cooperative mechanism and undermined progress toward the \$100 billion annual climate finance target (Articles 8-12, Paris Agreement). These shifts not only weakened multilateral leadership but also fostered a fragmented landscape increasingly shaped by geopolitical competition, where climate finance is wielded as an instrument of economic and technological influence.

Concurrently, fossil-fuel-dependent economies, particularly in Latin America, face structural constraints that limit their ability to transition towards sustainable models. Even when political commitments to climate cooperation exist, fiscal dependencies and extractive economic legacies restrict the transformative potential of climate finance (Bruckmann, 2021). Furthermore, existing climate finance frameworks are hindered by persistent barriers such as limited transparency, weak monitoring systems, and exclusionary funding criteria (World Bank, 2022). Marginalized actors, especially Indigenous communities, women, and microenterprises, remain underrepresented in decision-making processes and face restricted access to funding mechanisms.

To address these multifaceted challenges, this research conducts a systematic literature review of academic, institutional, and policy-based sources to evaluate the transformative potential of financial innovation and disruptive technologies in reshaping climate and sustainable finance. This method enables a comprehensive and critical synthesis of current knowledge, allowing for the identification of gaps, trends, and emerging tools. Specifically, the study investigates how technologies such as blockchain for traceable fund allocation, artificial intelligence (AI) for project evaluation, and decentralized finance (DeFi) mechanisms can enhance transparency, expand access, and improve institutional trust within climate finance ecosystems.

Global justice is a central concern in climate finance, especially in ensuring that vulnerable and historically marginalized communities are not left behind. Emerging technologies like blockchain, AI, IoT, and big data have the potential to directly support this goal by promoting greater access, transparency, and equity.

For instance, blockchain’s decentralization can reduce barriers to funding in

underserved regions, while AI and big data improve the targeting of resources to those most in need. IoT adds accountability by enhancing real-time monitoring of climate projects. When used thoughtfully, these tools don't just make systems more efficient—they help make them fairer.

The central hypothesis is that these innovations can address entrenched structural inefficiencies and unlock new pathways toward more equitable, efficient, and impactful climate finance. Exploring the intersection of technological disruption and sustainable finance, this study contributes to the growing literature that is looking for actionable, justice-centered solutions to the persistent limitations of current climate finance models. It argues that innovation is not merely a complement to existing mechanisms but a necessary condition for achieving both the scale and justice required to confront the global climate emergency.

The structure of the paper is organized as follows. The second section outlines the research methodology adopted for the systematic literature review. The third section examines the evolution and current imperatives of climate finance. The fourth section explores both public and private sources that underpin climate finance mechanisms. The fifth section analyzes emerging instruments and technological innovations, including blockchain, AI, and DeFi, within the climate finance landscape. The final section concludes the study by summarizing key insights and suggesting a future research agenda.

2. Methodology

This study employs a systematic literature review (SLR) to investigate the role of disruptive technologies, specifically blockchain, artificial intelligence (AI), and decentralized finance (DeFi), in enhancing climate and sustainable finance. The SLR methodology is selected for its capacity to synthesize existing research, identify theoretical gaps, and structure emerging knowledge, particularly where interdisciplinary convergence is critical. Methodological guidance was drawn from PRISMA protocols and leading examples in the literature (Parmentola et al., 2022; Benson et al., 2024).

The research design was guided by three questions: how these technologies are being integrated into climate finance; what institutional, regulatory, and technical barriers hinder adoption; and whether evidence supports the hypothesis that innovation improves transparency, accessibility, and efficiency. These questions informed the criteria for searching, screening, and analysis.

The search strategy involved querying major academic databases, Scopus, Web of Science, SSRN, and MDPI, using combinations of terms such as “climate finance,” “blockchain,” “artificial intelligence,” “DeFi,” and “systematic review.” Policy reports and grey literature from institutions such as the UNFCCC and World Bank were included to enrich the scope.

Inclusion criteria required studies to be peer-reviewed, published between 2020 and 2024, written in English and Spanish, and substantively address the interaction between climate finance and at least one of the three technologies. Exclusion

criteria eliminated articles lacking policy or financial relevance, as well as duplicates and publications predating the adoption of relevant technologies.

The systematic literature review (SLR) process initially yielded approximately 80 articles, which were screened for relevance and quality based on predefined inclusion and exclusion criteria. Ultimately, 38 articles were included in the final analysis. Adding this summary of the quantitative results enhances the methodological transparency and rigor of the study, in line with best practices for SLRs.

3. Evolution, Scope, and the Imperative for Innovation

Since 2009, developed nations pledged \$100 billion annually to support climate action in developing economies. This target was only met in 2022 (\$115.9 billion mobilized), with funding skewed toward middle-income nations via loans rather than grants (United Nations). The Paris Agreement (2015) established a new financing goal exceeding \$100 billion/year, tailored to evolving needs. At **COP29 (2024)**, parties agreed to triple climate finance to developing countries, targeting \$300 billion annually by 2035 (UNFCCC, 2024).

The scale of need is monumental: emerging markets and developing economies (excluding China) require \$2.4 trillion annually by 2030 to meet climate goals, quadrupling current investment levels. At least \$1 trillion/year must originate from international public and private sources (United Nations, 2022).

3.1. Adaptation: An Underfunded Frontier

Climate change exacerbates humanitarian crises triggered by extreme weather. An estimated 3.6 billion people reside in high-vulnerability zones, with global warming projected to cause 250,000 additional annual deaths between 2030-2050 from malnutrition, malaria, diarrhea, and heat stress. Direct health costs may reach \$2 - 4 trillion/year by 2030, disproportionately affecting regions with fragile health systems (WHO, 2021).

Adaptation finance remains critically under-resourced. Two-thirds of adaptation funding takes the form of loans (not grants), imposing unsustainable debt burdens on low-emission, high-vulnerability nations. Despite a COP26 commitment to mobilize \$40 billion/year for adaptation, multilateral and bilateral flows to developing countries fell 15% in 2021 (\$21 billion). UN estimates indicate adaptation needs exceed current international public finance by 10 - 18 times (United Nations, 2024).

3.2. Reconstruction, Loss, and Damage Prevention

Early warning systems (EWS) are vital for preventing climate-related fatalities, yet only 50% of countries have them. The *Early Warnings for All* initiative aims for universal EWS coverage by 2027—a feasible goal given global internet (95%) and mobile phone (75%) penetration (United Nations, 2022). Such systems yield high returns: an \$800 million investment can avert \$16 billion/year in losses. The initiative's total cost (\$3.1 billion, or \$0.50/person) encompasses education, forecast-

ing, communication, and disaster response (United Nations, 2022).

Loss and damage (L&D) financing addresses irreversible climate impacts increasingly devastating emerging and developing economies (EMDEs). Severe droughts or storms reduce real GDP growth by >1% in EMDEs and diminish tax revenues (Fuje et al., 2023). Newman and Noy (2023) estimated climate-related L&D costs at \$2.8 trillion for 2019-2020. Although COP27 (2022) established an L&D fund, current pledges (\$765.6 million from 27 contributors) remain insufficient against escalating needs (UNCC, 2025).

4. Climate Funding

4.1. Public Sources

International public finance constitutes a foundational pillar of this system, primarily originating from the national budgets of developed nations. These resources are channeled through bilateral and multilateral institutions, with oversight conducted via the United Nations Framework Convention on Climate Change (UNFCCC) reporting systems and the monitoring frameworks established by the OECD (Benavides et al., 2022; Perez Baez et al., 2023). The deployment of instruments such as grants, concessional loans, and specialized insurance mechanisms represents key modalities for advancing projects within lower-income countries.

Within this structure, Multilateral Development Banks (MDBs) and bilateral agencies serve as critical platforms for financial innovation. MDBs aggregate capital contributions from multiple member countries to execute projects of regional or global scope, thereby functioning as conduits for innovative financing solutions (Zhu & Li, 2021). Conversely, bilateral agencies, funded by a single nation, implement programs aligned with their strategic priorities, often leveraging innovative approaches tailored to specific regions, sectors, or emerging technologies (Anastasio, 2021).

4.2. United Nations Framework Convention on Climate Change (UNFCCC)

The Global Environment Facility (GEF), established over three decades ago, serves as the financial mechanism of the United Nations Framework Convention on Climate Change (UNFCCC) and plays a key role in addressing pressing global environmental challenges. It has provided over \$25 billion in direct funding and mobilized an additional \$145 billion in co-financing to support developing countries in fulfilling their international environmental commitments. Through specialized instruments such as the Global Biodiversity Framework Fund (GBFF), the Least Developed Countries Fund (LDCF), and the Special Climate Change Fund (SCCF), the GEF has financed more than 6000 projects worldwide. Over 55% of its resources have been allocated to climate change and biodiversity, reflecting global priorities. Its inclusive governance includes 186 countries, civil society, Indigenous communities, and youth and women's groups. Countries such as China,

Brazil, India, Mexico, and Colombia have been among the primary beneficiaries due to their environmental vulnerability and strategic relevance.

The Adaptation Fund, created in 2010 under the Kyoto Protocol, stands as a vital multilateral mechanism focused on enhancing climate resilience in developing nations. It has financed over 230 locally tailored projects, directly benefiting more than 45 million people. A distinctive feature of the fund is its promotion of institutional autonomy through Direct Access and Enhanced Direct Access, allowing accredited national entities to design and manage their own climate adaptation initiatives. Its financing model combines voluntary contributions from public and private actors with an innovative 2% levy on Certified Emission Reductions (CERs) from the Clean Development Mechanism.

To date, the Adaptation Fund has allocated more than \$1.2 billion to 176 projects globally, with a thematic focus on sectors such as agriculture, water resource management, and food security. The distribution of funds reflects a prioritization of climate-vulnerable regions: Africa receives the largest share (36%), followed by Asia-Pacific (28%), and Latin America and the Caribbean (21%).

Alongside the Adaptation Fund, the Green Climate Fund (GCF), established in 2012 and operational since 2015, constitutes a central pillar of the international climate finance architecture. While the Adaptation Fund emphasizes local ownership and capacity-building, the GCF operates at a broader scale. As of March 2025, the GCF has approved 297 projects totaling \$16.6 billion in investment.

4.3. Mobilizing Private Capital through Sustainable Finance: A Strategic Pillar of Climate Finance

Sustainable finance has emerged as a key strategy to mobilize private capital for climate action. It is defined by the integration of environmental, social, and governance (ESG) criteria into all types of investment projects, with a particular emphasis on financial instruments that generate positive social and environmental outcomes. These mechanisms, such as green bonds, sustainability-linked loans, and blended finance structures, operate within specific governance frameworks and have proven essential for scaling up private sector participation in climate initiatives (Zairis, Liargovas, & Apostolopoulos, 2024).

Climate finance itself is a broader framework that seeks to channel resources toward both climate change mitigation and adaptation. Unlike traditional financing, it is inherently collaborative, requiring coordinated action across public, private, national, and international actors. A key objective is to support a just transition, ensuring social inclusion, decent work, and stakeholder dialogue are central to climate policies and investments (Oliver Yébenes, 2024).

Given the scale of the climate crisis, public funding alone is insufficient. Hence, climate finance mechanisms increasingly rely on diverse instruments, grants, concessional loans, thematic bonds, guarantees, and climate risk insurance, to attract private investment (Kalinowski, 2024). The importance of private sector involvement has been emphasized repeatedly in global climate discourse, as their partic-

ipation not only supplements funding but also brings innovation, risk-sharing, and long-term scalability to climate solutions.

4.4. Eco-Entrepreneurship as Financial Innovation Tool in Climate Finance

Eco-entrepreneurship, understood as the creation or management of business ventures that combine environmental responsibility with economic profitability, plays a growing role in the broader strategy to mobilize private capital for climate action. These ventures often rely on eco-innovation, which [Rennings \(2000\)](#) defines as the development and implementation of products, processes, or services that contribute to environmental sustainability. Financial mechanisms such as green venture capital and climate crowdfunding have emerged as critical tools to support these early-stage initiatives, especially those operating without formal business structures or traditional access to credit.

Unlike conventional financing, these instruments are tailored for concept-stage projects and startups led by small teams. As such, evaluation criteria focus not on financial returns alone but on environmental alignment and transformative potential. However, multiple barriers hinder their growth, ranging from weak entrepreneurial networks and limited investor knowledge on clean technologies to the absence of unified standards for assessing sustainability ([Randjelovic et al., 2003](#); [Sabbi & Karampini, 2019](#)).

Among these instruments, green venture capital has gained prominence in sectors like renewable energy and sustainable agriculture. In 2023, nearly \$50 billion was invested globally in climate-tech startups, with Europe receiving 42% of the total. In contrast, Latin America captured only 2.7%, while fintech dominated the region's venture capital landscape. On the other hand, climate crowdfunding, a digital alternative based on small individual contributions through donation-based or equity platforms, has grown from \$55 million in 2013 to \$2.5 billion by 2023 ([LAVCA, 2024](#)). Despite representing just 0.55% of global climate-tech finance, this model is democratizing access to capital for projects in renewable energy, sustainable mobility, circular economy, and agroecology. With over 165 dedicated platforms across 30 countries, crowdfunding remains a promising vehicle for scaling grassroots climate innovation.

5. Emerging Schemes and Technologies in Climate Finance

Addressing climate change requires large-scale financial resources, and it has become increasingly clear that public capital, while essential, is insufficient to drive a global transition toward sustainable and resilient economies. In this context, one of the main challenges lies in mobilizing private finance for green projects, particularly in developing countries, where investment conditions tend to be more complex and risk-prone.

On the supply side of climate finance, there remains a significant shortfall of capital directed toward climate initiatives in emerging regions. This gap is largely

driven by the perception of high risk among investors, stemming from factors such as political and regulatory instability, inadequate infrastructure, and heightened exposure to extreme climate events. These perceptions elevate the cost of capital through higher risk premiums.

On the demand side, many developing countries face structural barriers that hinder their access to climate finance on fair terms. These include low credit ratings, high interest rates, and heavy sovereign debt burdens, all of which constrain their fiscal space to invest in mitigation and adaptation strategies without compromising macroeconomic stability (Bhattacharya & Stern, 2021). Moreover, the limited availability of “bankable” or financially viable projects, along with unclear regulatory frameworks, further discourages private sector involvement (Garcia et al., 2021). Consequently, while developed economies can access green credit under favorable terms, the most vulnerable countries often pay significantly more for equivalent financing (OECD, 2022).

Another critical obstacle is the physical risk exposure of these economies. Prolonged droughts, floods, and hurricanes not only impair repayment capacities and creditworthiness but also lead to capital flight and credit contraction. According to the IPCC (2022), developing countries could lose up to 25% of their annual GDP by 2050 in the absence of urgent adaptation measures. This vulnerability has contributed to a sharp increase in climate insurance premiums in recent years (Banxico, 2024).

5.1. Solutions and Innovative Mechanisms

To overcome these challenges, innovative financial strategies are needed to reduce the cost of climate finance and de-risk green investments. Some of the most effective mechanisms include:

- Concessional loans with below-market interest rates;
- Grants and donations from multilateral institutions and international climate funds;
- Risk-transfer instruments, such as credit guarantees and climate insurance;
- Carbon market-linked instruments, including emissions trading schemes and environmental taxes (UNDP, 2023).

Among these, results-based financing (RBF) has emerged as one of the most promising tools. Unlike traditional funding models, RBF conditions fund disbursement on the verified achievement of specific outcomes, rather than financing inputs or activities. This enhances efficiency and better aligns incentives between funders and implementing entities (Morvelli et al., 2023).

RBF can be applied from both the supply and demand perspectives. On the supply side, notable tools include innovation prizes and payments for ecosystem services. On the demand side, conditional cash transfers are used to promote sustainable practices. Hybrid instruments, such as impact bonds or green technology vouchers, combine both approaches (Instiglio & Groba, 2018).

This approach has proven particularly effective in areas such as REDD+, sus-

tainable agriculture, and clean energy. Its strength lies in the transparency and traceability of impact, though successful implementation requires strong institutional and technical capacities (Carrasco et al., 2024).

5.2. Examples of Innovative Climate Mechanisms Integrating Multiple Instruments

Financial innovation in the climate domain has led to the development of hybrid mechanisms that combine various instruments to accelerate the transition toward sustainable development. A notable example is the sustainability bond issued by the Inter-American Development Bank (IDB Climate), the first of its kind globally to link its interest rate to specific environmental performance indicators. Unlike traditional bonds that impose penalties for failing to meet targets, this instrument employs a positive incentive logic: if pre-defined climate and conservation indicators are met and verified by independent parties, the issuer may receive a reimbursement of up to 5% of financing costs, thus encouraging compliance through rewards rather than sanctions (IDB, 2024).

Another key initiative is the Climate Finance Lab, a collaborative platform designed to foster financial solutions that attract private investment into environmental projects in developing countries. The Lab operates through cross-sector partnerships, open calls for innovative ideas, and the support of a global network of stakeholders. As of March 2025, the platform had supported the development of 78 financial instruments, mobilizing nearly \$4 billion, including \$1.3 billion from its network and \$1.6 billion from private sector contributions (Climate Finance Lab, 2025).

Among the Lab's standout innovations is the price risk mechanism, which blends insurance and financing to protect smallholder farmers against agricultural price volatility while promoting sustainable practices. Another highlighted initiative is the parametric insurance and trust fund for páramo ecosystems, designed to ensure rapid financial responses to wildfires or other extreme conditions, thus supporting the restoration and conservation of these critical high-altitude ecosystems.

In terms of credit access for small businesses, the Carbon Neobank initiative offers tailored financial schemes for micro, small, and medium-sized enterprises (MSMEs) in Africa. These schemes not only fund renewable energy projects but also enable participating businesses to generate additional revenue through carbon credit production. The model combines co-financing with local banks and concessional support, thereby offering more competitive lending terms.

Guarantees have also proven to be crucial tools in mobilizing capital for climate projects. In July 2024, the World Bank Group launched an innovative guarantee platform managed by the Multilateral Investment Guarantee Agency (MIGA). This platform aims to enhance the effectiveness of available climate financing by introducing new instruments tailored to sustainable development challenges (World Bank Group, 2024).

Furthermore, the World Bank recently proposed a performance-linked financing scheme, where loan terms, such as interest rates or additional support, are conditioned on achieving more ambitious climate and biodiversity targets than those required under existing international agreements. This model aligns financial incentives directly with measurable environmental outcomes (World Bank Group, 2024).

5.3. Climate Finance and Disruptive Technologies

In the face of the growing urgency to address climate change, the pressure to adequately finance solutions and strategically allocate resources has intensified. Within this context, it has become essential to develop agile and efficient systems capable of integrating diverse streams of relevant data—ranging from human and species displacement, public health crises, and climate variability to greenhouse gas emissions. Such integration enables the generation of collective knowledge and supports evidence-based decision-making, ultimately guiding climate investments with greater precision.

Institutions such as Copernicus, the Green Climate Fund (GCF), and the Bank of Spain have highlighted the critical role that emerging technologies can play in this space. Tools such as artificial intelligence (AI), big data analytics, and Internet of Things (IoT)-enabled sensors hold significant potential to transform how climate finance is allocated, monitored, and evaluated. The following section explores some of the most promising technologies and the sectors where their application may generate the greatest impact.

5.3.1. Big Data and Artificial Intelligence

Artificial intelligence and big data analytics have become key allies in enhancing climate finance systems, particularly in improving the targeting and monitoring of climate funding. These technologies enable more precise identification of regions and sectors most in need of support, as well as those demonstrating measurable progress. This, in turn, fosters more equitable and efficient decision-making in the deployment of climate resources.

By combining tools such as IoT-connected sensors, satellite imagery, and predictive analytics, it becomes possible to monitor real-time environmental changes, anticipate risk scenarios, and uncover interdependencies among economic, social, and climate-related variables. This technological synergy supports the design of scientifically grounded mitigation and adaptation policies. Moreover, the knowledge generated by these technologies enhances the response capacity of governments and financial institutions, equipping them with robust technical evidence to support sustainable practices (Papadopoulos & Balta, 2022; Kumar et al., 2025). Some examples of Big Data applications to climate finance are presented in **Diagram 1**.

5.3.2. Machine Learning (ML) and Climate Finance

The growing availability of large-scale data has paved the way for new approaches

to understanding and managing climate finance, with machine learning (ML) emerging as one of the most promising tools in this field. By processing vast amounts of environmental, economic, and financial data, ML can uncover complex, often non-linear, relationships among key variables. This capacity is crucial for designing sustainable public policies and investment strategies (Alonso-Robisco et al., 2024).

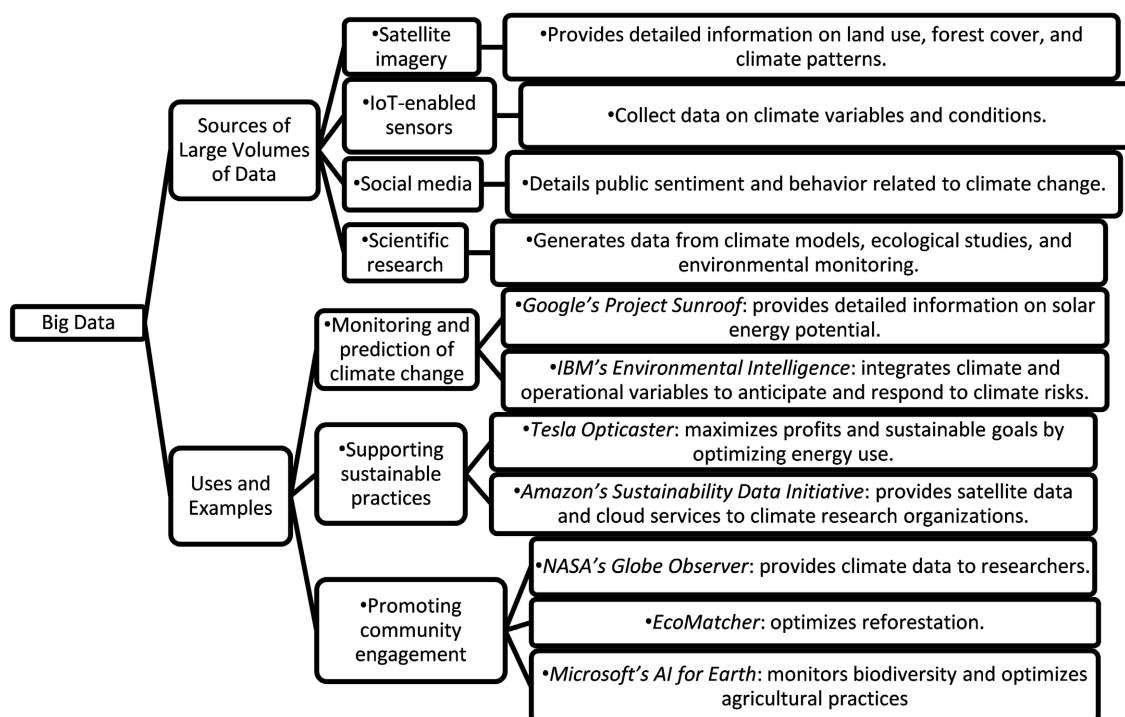


Diagram 1. Big data applications to climate finance. Source: Own elaboration based on Ecomatcher (2024).

The progress of ML has been further propelled by the rise of green fintech, an industry that merges technological innovation with sustainability objectives (Macchiavello & Siri, 2022). One of ML's main strengths lies in its ability to detect hidden patterns, thereby enabling the identification of climate and social risks embedded in investment portfolios. For instance, Rolnick et al. (2022) demonstrate that deep learning techniques enhance the construction of sustainable portfolios by prioritizing low-emission firms and optimizing investment timing.

There are already concrete examples of ML applications at various levels. Akomea-Frimpong et al. (2021) used ML to explore the drivers of green investment in banking institutions, while Plakandaras et al. (2018) modeled climate change as a geopolitical risk affecting asset valuation. Al-Sartawi et al. (2021) emphasize the transformative potential of technologies like AI, ML, and blockchain in building more sustainable financial systems.

In particular, Huang et al. (2021) argue that ML could reshape how institutions such as the Green Climate Fund (GCF) manage their resources, enabling real-time monitoring of outcomes, identifying optimal beneficiaries, addressing information

gaps, and forecasting project impacts (see **Diagram 2**). These capabilities significantly enhance the transparency, efficiency, and effectiveness of climate finance.

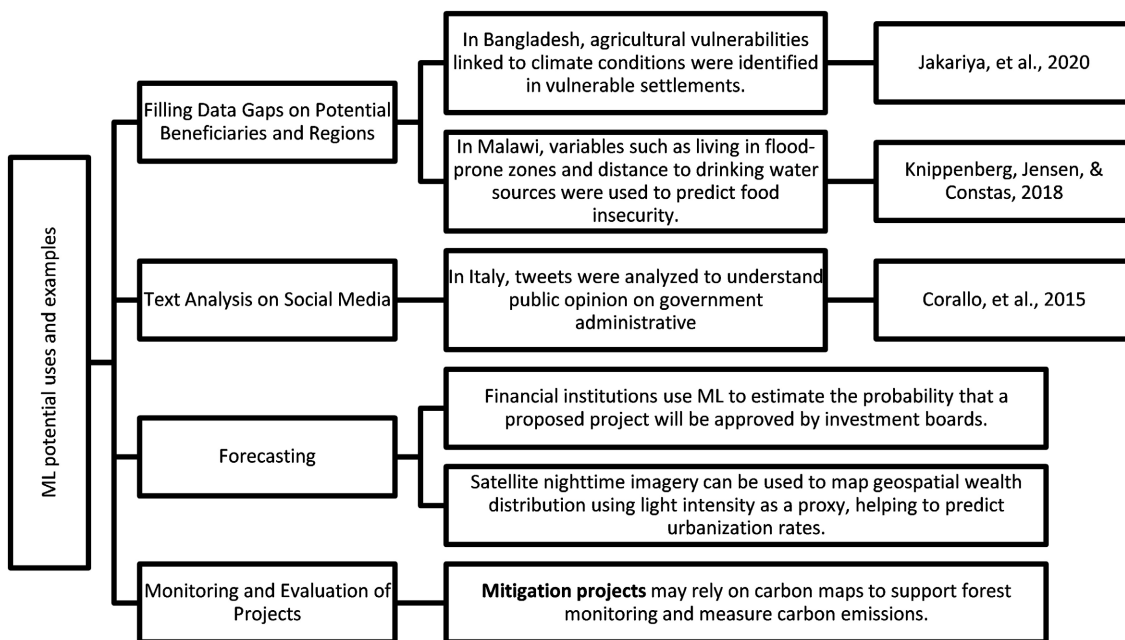


Diagram 2. ML potential uses and examples. Source: Own elaboration based on Huang et al. (2021).

5.3.3. Internet of Things (IoT) and Climate Action

The Internet of Things (IoT) has emerged as a key enabler in the global response to climate change. Its ability to connect sensors, devices, and digital systems creates an intelligent network capable of monitoring a wide range of environmental, economic, and operational variables in real time. This interconnectivity not only enhances the efficiency of natural resource use but also strengthens adaptive capacity to climate impacts in both urban and rural contexts.

One of the most impactful applications of IoT in sustainable finance is its integration with green bonds. Through smart sensors and interconnected devices, the environmental performance of funded projects can now be monitored continuously and with high precision. This technological advancement enables the verification of tangible environmental benefits, fostering greater transparency and investor confidence (Panerai, 2016).

The ongoing development of IoT presents new opportunities for both public and private actors to adopt more effective approaches in addressing climate challenges. From smart water management and energy system optimization to biodiversity monitoring, IoT offers adaptive solutions across diverse sectors and priorities. In this sense, it acts not only as a technical tool but as a bridge linking climate action with technological innovation that delivers measurable social and environmental impact.

Diagram 3 presents specific examples of how IoT can be applied across various sectors:

Agriculture	IoT technologies optimize agricultural productivity through the use of sensors and drones that enhance water efficiency, increase crop yields, and reduce reliance on chemical inputs. Additionally, they support livestock management and supply chain monitoring, helping to reduce emissions and food waste.
Transport and Energy	In the transport and energy sectors, IoT devices reduce emissions and improve the operational efficiency of vehicle fleets and electric systems. At the household level, smart meters enable more conscious and sustainable energy consumption.
Environmental Monitoring	IoT sensors enable real-time tracking of air and water quality as well as other key environmental indicators. These systems facilitate rapid responses to ecological threats and contribute to better environmental governance.
Biodiversity Conservation	Tracking devices allow for more accurate monitoring of wildlife species, strengthening conservation efforts against climate-related and anthropogenic threats. This improves both data quality and intervention strategies in conservation programs.
Natural Disaster Management	IoT plays a critical role in early detection of extreme weather events such as floods and droughts. It also enhances the ability of utility providers to respond swiftly, helping to protect critical infrastructure and reduce overall vulnerability.

Diagram 3. IoT application examples.

The application of Internet of Things (IoT) technologies for monitoring, tracking, real-time measurement, and preventive action across multiple sectors enables more informed decision-making, enhances accountability, and helps minimize costs while maximizing benefits. Moreover, IoT facilitates efficient monitoring of funded projects, supports continuous evaluation, and helps identify opportunities for improvement in both ongoing and prospective climate initiatives.

5.3.4. Blockchain as Infrastructure for Climate Action

Blockchain technology is rapidly gaining recognition as a critical tool in transforming environmental markets due to its ability to deliver traceability, transparency, and data integrity. This decentralized infrastructure enables the secure recording of data on carbon emissions avoided or captured—particularly valuable in voluntary carbon markets. When integrated with complementary technologies such as remote sensors, satellite data, and artificial intelligence, blockchain strengthens digital systems for measurement, reporting, and verification (dMRV), thereby improving the reliability of environmental impact assessments (Mzoughi et al., 2024).

A particularly innovative use of blockchain is the implementation of smart contracts, which automate payments and incentive distributions based on verified outcomes. This automation significantly lowers transaction and administrative costs, ensuring that funds are channeled directly to those generating environmental value, ranging from rural communities to clean energy projects and ecosystem conservation efforts (Silkose & Nygaard, 2025).

Within this evolving context, a new paradigm known as Web3 has emerged, emphasizing decentralization and user empowerment over data and digital assets. Regenerative finance (ReFi), a concept flourishing within this ecosystem, aims to redefine the traditional, extractive economic model into one that actively restores

ecosystems, equitably distributes economic value, and strengthens local social fabric (WEF, 2023).

ReFi initiatives applied to climate action include carbon accounting platforms, green tokens, decentralized autonomous organizations (DAOs), and open marketplaces that fund ecological restoration, biodiversity conservation, and carbon offsetting. Projects such as Regen Network, Toucan, and MOSS. Earth and KlimaDAO are already leveraging these technologies to value ecosystem services and promote regenerative practices (WEF, 2023).

Beyond unlocking new avenues for climate finance, blockchain also paves the way for greater civic engagement. Through the tokenization of natural assets, individuals and organizations can actively participate in environmental markets, democratizing access and decentralizing decision-making. This not only diversifies investment sources but also empowers local communities, particularly those safeguarding natural territories, with a stake in the management and outcomes of these resources (Schloesser & Schulz, 2022; Campbell-Verduyn, 2024).

In sum, blockchain and regenerative finance are not merely emerging technologies; they represent a transformative vision for climate finance, one that is more inclusive, transparent, and rooted in planetary regeneration. Their long-term success will depend on ethical implementation and the development of robust regulatory frameworks that guide these innovations toward equitable and lasting impact for all stakeholders involved.

6. Concluding Remark

This study critically examined how disruptive technologies and financial innovations can reshape the climate finance landscape, particularly in the Global South. Through a systematic literature review of academic and policy sources, it was established that tools such as blockchain, artificial intelligence (AI), and decentralized finance (DeFi) possess transformative potential to enhance the transparency, inclusivity, and efficiency of climate finance mechanisms. The evidence suggests that these technologies contribute significantly to improving fund traceability, facilitating stakeholder participation, and strengthening impact evaluation, all of which are crucial for achieving climate justice and meeting global sustainability targets.

While financial technologies such as blockchain, AI, IoT, and big data offer transformative potential for addressing climate change, it is equally important to consider their potential negative externalities. For instance, blockchain technology, particularly that based on proof-of-work consensus mechanisms (e.g., Bitcoin), is known for its substantial energy consumption, which may offset some of the environmental gains it seeks to enable. Although newer, more energy-efficient protocols like proof-of-stake are emerging, the environmental impact of blockchain remains a critical concern.

Similarly, AI-driven climate finance systems, while powerful in optimizing resource allocation and risk assessment, carry the risk of algorithmic bias. If not

carefully monitored, these systems may inadvertently disadvantage marginalized communities or underrepresented regions due to biased training data or opaque decision-making models.

Moreover, the widespread deployment of IoT devices raises questions around e-waste and data security, while big data infrastructures demand significant computational resources, which may carry their own carbon footprint. Recognizing and addressing these issues is essential for ensuring that the integration of these technologies into climate finance frameworks is both effective and ethically responsible.

Despite their potential, several systemic limitations constrain the widespread adoption of these innovations. Key barriers include regulatory fragmentation, limited institutional capacity, and the persistence of exclusionary funding structures that hinder access for vulnerable communities. Moreover, high financial risk premiums and underdeveloped capital markets in many developing countries continue to disincentivize private investment in green projects. These obstacles underscore the need for robust policy frameworks, de-risking instruments, and capacity-building programs that align digital innovation with equitable financing outcomes.

From a policy perspective, this research supports a shift from traditional climate finance modalities toward innovation-driven, decentralized, and performance-based models. It recommends that policymakers foster interoperability between emerging technologies and conventional finance by establishing regulatory sandboxes, enhancing transparency protocols, and promoting inclusive digital infrastructure. Additionally, targeted incentives, such as results-based financing, smart contracts, and green impact bonds, should be scaled up to reward verified environmental and social outcomes. International coordination is essential to harmonize standards and support countries with limited technological capacity in accessing these opportunities.

For financial institutions, the findings highlight the imperative to integrate AI and machine learning into climate risk analysis and investment decision-making processes. Banks, development finance institutions, and asset managers must begin to treat digital climate tools not as ancillary systems, but as core components of their sustainability strategies. Leveraging blockchain for transparent fund disbursement and decentralized finance for broadening access to green credit are particularly relevant for institutions operating in underserved markets. Institutional investors are also encouraged to adopt metrics that incorporate ESG alignment and digital innovation readiness into their portfolio assessments, with a stronger emphasis on community-level impact.

Looking ahead, future research should explore the long-term effectiveness of these technological interventions, particularly in low-income regions. Comparative studies are needed to evaluate the scalability of blockchain-enabled climate funds, AI-based early warning systems, and DeFi-driven financial inclusion programs. Finally, interdisciplinary research linking digital innovation to ecological

restoration, biodiversity finance, and circular economy will be vital in designing the next generation of inclusive and adaptive climate finance architectures.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

- Akomea-Frimpong, I., Jin, X., & Osei-Kyei, R. (2021). Developing a Financial Risk Maturity Model for Public-Private Partnership Projects. In *37th Annual Conference of ARCOM* (pp. 6-7).
- Alonso-Robisco, A., Bas, J., Carbo, J. M., de Juan, A., & Marques, J. M. (2024). Where and How Machine Learning Plays a Role in Climate Finance Research. *Journal of Sustainable Finance & Investment*, *15*, 456-497. <https://doi.org/10.1080/20430795.2024.2370325>
- Al-Sartawi, A., Al-Okaily, M., Hannon, A., & Khalid, A. A. (2021). Financial Technology: Literature Review Paper. In *The International Conference on Global Economic Revolutions* (pp. 194-200). Springer International Publishing.
- Anastasio, M. D. (2021). La configuración del financiamiento climático internacional: Conceptos, mecanismos y fuentes de recursos. *Ecogralia*, *5*, 1-9.
- Banxico (2024). *Reporte de Estabilidad Financiera—Primer Semestre 2024*. <https://www.banxico.org.mx/publicaciones-y-prensa/reportes-sobre-el-sistema-financiero/%7B6E48E53C-CE3E-9D3E-2D0D-A092213E8205%7D.pdf>
- Benavides, J., García, H., Cadena, X., & Salamanca, D. (2022). *Actualización de documento, líneas estratégicas y Plan de acción y Seguimiento (PAS) de la Estrategia Nacional de Financiamiento Climático (ENFC)*. <http://www.repository.fedesarrollo.org.co/bitstream/handle/11445/4390/Repor-Julio-2022-Benavides-et-al.pdf?sequence=1&isAllowed=y>
- Benson, V., Saridakis, G., Adamyk, B., Mishra, T., & Adamyk, O. (2024) *Unravelling Societal Risks of Decentralized Finance: A Systematic Review*. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4862893
- Bhattacharya, A., & Stern, N. (2021). *Cambio climático: Nuestra mejor y última oportunidad*. <https://www.imf.org/external/pubs/ft/fandd/spa/2021/09/pdf/fd0921s.pdf>
- Bruckmann, M. (2021). El pacto verde europeo y las perspectivas de América Latina. In *La geopolítica ambiental de Estados Unidos y sus aliados del norte global* (pp. 319-350). CLACSO. <https://doi.org/10.2307/j.ctv2v88ff9.14>
- Campbell-Verduyn, M. (2024). Conjuring a Cooler World? Imaginaries of Improvement in Blockchain Climate Finance Experiments. *Environment and Planning C: Politics and Space*, *42*, 782-799. <https://doi.org/10.1177/23996544231162858>
- Carrasco, G., Fuentes-Peñailillo, F., Manríquez, P., Rebolledo, P., Vega, R., Gutter, K. et al. (2024). Enhancing Leafy Greens' Production: Nutrient Film Technique Systems and Automation in Container-Based Vertical Farming. *Agronomy*, *14*, Article 1932. <https://doi.org/10.3390/agronomy14091932>
- Climate Finance Lab (2025). *Driving Sustainable Development*. <https://www.climatefinancelab.org/call-for-ideas/2025-2/>
- Ecomatcher (2024). *Sustainable Gifting Guide for 2024*. <https://www.ecomatcher.com/sustainable-gifting-guide-for-2024/>
- European Parliament (2024). <https://www.europarl.europa.eu/portal/en>
- Fuje, H., Yao, J., Choi, S. M., & Mighri, H. (2023). *Fiscal Impacts of Climate Disasters in*

- Emerging Markets and Developing Economies. Working Papers.* International Monetary Fund.
<https://www.imf.org/-/media/Files/Publications/WP/2023/English/wpiea2023261-print-pdf.ashx>
- García, M. L. J., Vieitez, M. D., Berto, M. E. G., Mascle, A. A. L., Hinojosa, S. A., Benavente, F., & Muñoz, J. J. (2021). *Asociaciones Público-Privadas en el sector de agua potable y saneamiento en América Latina y el Caribe.*
<https://publications.iadb.org/publications/spanish/document/Asociaciones-publico-privadas-en-el-sector-de-agua-potable-y-saneamiento-en-America-Latina-y-el-Caribe-Entorno-factores-criticos-de-exito-y-recomendaciones.pdf>
- Huang, D. T., Lee, B., Nassuna, H., & Prowse, M. (2021). *Machine Learning and Its Potential Applications in the Independent Evaluation Unit of the Green Climate Fund: A Scoping Study.*
[https://ueaeprints.uea.ac.uk/id/eprint/81664/1/Lee et al 2021 Machine learning paper top 0.pdf](https://ueaeprints.uea.ac.uk/id/eprint/81664/1/Lee%20et%20al%202021%20Machine%20learning%20paper%20top%200.pdf)
- IDB (2024). *Préstamos basados en políticas.*
<https://www.iadb.org/es/como-trabajar-juntos/sector-publico/prestamos-de-apoyo-reformas-de-politica#:~:text=Los%20PBL%20brindan%20financiamiento%20global.las%20condiciones%20de%20las%20pol%C3%ADticas>
- Instiglio, & Gpoba (2018). *A Guide for Effective Results-Based Financing Strategies.* Commissioned by the Global Partnership on Output-Based Aid (Gpoba).
<https://documents1.worldbank.org/curated/en/265691542095967793/pdf/A-Guide-For-Effective-Results-Based-Financing-Strategies.pdf>
- IPCC (2022). Impacts, Adaptation, and Vulnerability. In H. O. Pörtner, D. C. Roberts, M. Tignor, E. S. Poloczanska et al. (Eds.), *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press. <https://doi.org/10.1017/9781009325844>
- Kalinowski, T. (2024). The Green Climate Fund and Private Sector Climate Finance in the Global South. *Climate Policy*, 24, 281-296.
<https://doi.org/10.1080/14693062.2023.2276857>
- Kumar, S., Sharma, D., Rao, S., Lim, W. M., & Mangla, S. K. (2025). Past, Present, and Future of Sustainable Finance: Insights from Big Data Analytics through Machine Learning of Scholarly Research. *Annals of Operations Research*, 345, 1061-1104.
<https://doi.org/10.1007/s10479-021-04410-8>
- LAVCA (2024). *2024 Latin American Startup Directory & Ecosystem Insights.*
<https://www.lavca.org/research/2024-startup-directory-ecosystem-insights/>
- Macchiavello, E., & Siri, M. (2022). Sustainable Finance and Fintech: Can Technology Contribute to Achieving Environmental Goals? A Preliminary Assessment of 'Green Fintech' and 'Sustainable Digital Finance'. *European Company and Financial Law Review*, 19, 128-174. <https://doi.org/10.1515/ecfr-2022-0005>
- Morvelli, V., Sarmiento Barletti, J. P., & Lasheras, T. (2023). *De la Convención a la práctica: Un análisis de la conceptualización, aplicación y operativización de las salvaguardas de Cancún para REDD+ en Perú.* CIFOR.
- Mzoughi, H., Amar, A. B., Guesmi, K., & Benkraiem, R. (2024). Blockchain Markets, Green Finance Investments, and Environmental Impacts. *Research in International Business and Finance*, 69, Article 102249. <https://doi.org/10.1016/j.ribaf.2024.102249>
- Newman, R., & Noy, I. (2023). The Global Costs of Extreme Weather That Are Attributable to Climate Change. *Nature Communications*, 14, Article No. 6103.
<https://doi.org/10.1038/s41467-023-41888-1>

- OECD (2022). *Estudios Económicos de la OCDE: México 2022*. OECD Publishing. <https://doi.org/10.1787/8b913f19-es>
- Oliver Yébenes, M. (2024). Climate Change, ESG Criteria and Recent Regulation: Challenges and Opportunities. *Eurasian Economic Review*, 14, 87-120. <https://doi.org/10.1007/s40822-023-00251-x>
- Panerai, A. (2016). *3 Ways the Internet of Things Could Help Fight Climate Change*. World Economic Forum. <https://www.weforum.org/stories/2016/04/3-ways-the-iot-could-help-fight-climate-change/>
- Papadopoulos, T., & Balta, M. E. (2022). Climate Change and Big Data Analytics: Challenges and Opportunities. *International Journal of Information Management*, 63, Article 102448. <https://doi.org/10.1016/j.ijinfomgt.2021.102448>
- Parmentola, A., Petrillo, A., Tutore, I., & De Felice, F. (2022). Is Blockchain Able to Enhance Environmental Sustainability? A Systematic Review and Research Agenda from the Perspective of Sustainable Development Goals (SDGs). *Business Strategy and the Environment*, 31, 194-217. <https://doi.org/10.1002/bse.2882>
- Perez Baez, S. O., Ramos-Martín, A., Mendieta-Pino, C., & El Kori, N. (2023). *Guía de los fondos financieros: Para la realización de proyectos que enfoquen su objetivo en la mitigación al cambio climático dentro del ciclo integral del agua*. Macaronesia. Informe de Proyecto Mitimac. <https://accedacris.ulpgc.es/bitstream/10553/127060/1/232ULPGC2.pdf>
- Plakandaras, V., Gogas, P., & Papadimitriou, T. (2018). The Effects of Geopolitical Uncertainty in Forecasting Financial Markets: A Machine Learning Approach. *Algorithms*, 12, Article 1. <https://doi.org/10.3390/a12010001>
- Randjelovic, J., O'Rourke, A. R., & Orsato, R. J. (2003). The Emergence of Green Venture Capital. *Business Strategy and the Environment*, 12, 240-253. <https://doi.org/10.1002/bse.361>
- Rennings, K. (2000). Redefining Innovation—Eco-Innovation Research and the Contribution from Ecological Economics. *Ecological Economics*, 32, 319-332. [https://doi.org/10.1016/s0921-8009\(99\)00112-3](https://doi.org/10.1016/s0921-8009(99)00112-3)
- Rolnick, D., Donti, P. L., Kaack, L. H., Kochanski, K., Lacoste, A., Sankaran, K. et al. (2022). Tackling Climate Change with Machine Learning. *ACM Computing Surveys*, 55, 1-96. <https://doi.org/10.1145/3485128>
- Sabbi, E., & Karampini, T. (2019). *Venture Capital & Green Ventures: Developing an Understanding of the Investment Decision (Dissertation)*. Digitala Vetenskapliga Arkivet. <https://urn.kb.se/resolve?urn=urn:nbn:se:umu:diva-161360>
- Schloesser, T., & Schulz, K. (2022). Distributed Ledger Technology and Climate Finance. In *Green Digital Finance and Sustainable Development Goals* (pp. 265-286). Springer.
- Silkoset, R., & Nygaard, A. (2025). Leveraging Blockchain and Smart Contracts to Combat Greenwashing in Sustainable Development. *Sustainable Development*, 33, 5874-5889. <https://doi.org/10.1002/sd.3431>
- UNCC (2025). *Pledges to the Fund for Responding to Loss and Damage*. <https://unfccc.int/topics/climate-finance/funds-entities-bodies/fund-for-responding-to-loss-and-damage/pledges-to-the-fund-for-responding-to-loss-and-damage>
- UNDP (2023). *¿Qué es la financiación climática y por qué es necesario incrementarla? Artículos explicativos*. <https://climatepromise.undp.org/es/news-and-stories/que-es-la-financiacion-climatica-y-por-que-es-necesario-incrementarla>
- UNFCC (2024). *COP29 acuerda triplicar la financiación a los países en desarrollo, protegiendo*

vidas y medios de subsistencia.

<https://unfccc.int/es/news/cop29-acuerda-triplicar-la-financiacion-a-los-paises-en-desarrollo-protigiendo-vidas-y-medios-de#:~:text=El%20acuerdo%20de%20financiamiento%20de,por%20sus%20siglas%20en%20ingl%C3%A9s>

United Nations (2021). *Desarrollo Sostenible: Perspectivas de América Latina y el Caribe*. <https://repositorio.cepal.org/server/api/core/bitstreams/a11c94e9-8270-4368-9ee8-f23a54ee2c47/content>

United Nations (2022). *Alertas Tempranas Para Todos*. *Plan de Acción*. <https://www.un.org/es/climatechange/early-warnings-for-all>

United Nations (2024). *¿Por qué debe financiarse la acción climática?* <https://www.un.org/es/climatechange/why-finance-climate-action>

WEF (2023). *Blockchain for Scaling Climate Action*. <https://www.weforum.org/publications/blockchain-for-scaling-climate-action/>

WHO (2021). *Sustainable Development Goals*. <https://www.who.int/europe/about-us/our-work/sustainable-development-goals>

World Bank (2022). *¿Dónde está el dinero? Un llamado a la transparencia del financiamiento climático en la COP27*. <https://blogs.worldbank.org/es/voices/donde-esta-el-dinero-un-llamado-la-transparencia-del-financiamiento-climatico-en-la-cop27>

World Bank Group (WBG) (2024). *2023 Joint Report on Multilateral Development Banks Climate Finance*. <https://doi.org/10.18235/0013160>

Zairis, G., Liargovas, P., & Apostolopoulos, N. (2024). Sustainable Finance and ESG Importance: A Systematic Literature Review and Research Agenda. *Sustainability*, 16, Article 2878. <https://doi.org/10.3390/su16072878>

Zhu, L., & Li, F. (2021). Agricultural Data Sharing and Sustainable Development of Ecosystem Based on Block Chain. *Journal of Cleaner Production*, 315, 127869. <https://doi.org/10.1016/j.jclepro.2021.127869>