Green Finance and AI in India: A Synergistic Approach to Sustainable Development and Climate Resilience

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Abstract: *India's ambition to achieve net-zero emissions by 2070 represents a defining commitment to combating climate change while fostering economic growth. Green finance has emerged as a cornerstone of this transition, catalyzing investments in renewable energy, sustainable agriculture, and eco-friendly infrastructure. This paper examines India's green finance landscape, highlighting transformative policies such as the National Action Plan on Climate Change (NAPCC) and initiatives like green bonds and public-private partnerships. It explores how advanced technologies, including artificial intelligence and blockchain, are revolutionizing decision-making, enhancing transparency, and mitigating risks associated with green investments.*

Despite these strides, challenges persist, including an annual funding gap of over INR 8,30,000 crores, limited private sector engagement in socially critical areas, and the looming threat of greenwashing. The disproportionate focus on clean energy investments often sidelines climate adaptation and social equity, raising concerns about holistic sustainability. Furthermore, the lack of standardized green metrics complicates evaluation and undermines investor confidence.

This study underscores the need for innovative financial instruments, equitable resource allocation, and robust governance to bridge these gaps. By fostering inclusive partnerships and aligning investments with the urgency of environmental and developmental goals, India can position itself as a global leader in sustainable finance. This research offers critical insights into navigating the complexities of green finance and provides a roadmap for a balanced, technology-driven, and socially inclusive approach to achieving sustainability.

Keywords: Green finance, Artificial Intelligence, Sustainable Development, Resource allocation and Net-Zero Emissions.

INTRODUCTION

India's ambition to achieve net-zero emissions by 2070 underscores its commitment to addressing the global challenge of climate change, despite the substantial financial and structural challenges involved (Trabacchi & Buchner, 2019). As one of the world's largest emitters of greenhouse gases, transitioning to a low-carbon economy requires a multi-pronged approach, including policy innovation, financial restructuring, and the adoption of green technologies. Green finance has emerged as a critical tool in this endeavor, enabling

investments that prioritize environmental sustainability alongside economic returns (Soundarrajan & Vivek, 2016). This approach aligns with global trends emphasizing the need for financial mechanisms to support environmentally and socially responsible outcomes. In the Indian context, the adoption of green finance has gained momentum, driven by both public policy and private sector initiatives aimed at fostering a sustainable future (Mohd & Kaushal, 2018).

Green finance's transformative potential lies in its ability to address environmental degradation caused by rapid industrialization, urbanization, and economic expansion. India's efforts in green finance include a range of instruments such as green bonds, loans, and equity investments that fund renewable energy projects, eco-friendly transportation systems, and sustainable agricultural practices (Jha & Bakhshi, 2019). These measures are critical for reducing greenhouse gas emissions in sectors like energy, agriculture, and transport, which are among the largest contributors to the country's carbon footprint (Charles & Philip, 2020). Government initiatives, such as the National Action Plan on Climate Change (NAPCC), provide a framework for advancing green finance through missions focused on renewable energy, energy efficiency, and sustainable forestry (Saha, 2023). Additionally, the establishment of funds like the National Clean Energy Fund (NCEF) and institutions like the Indian Renewable Energy Development Agency (IREDA) illustrates India's proactive stance in mobilizing financial resources for environmental sustainability (Nayak et al., 2024).

Technological advancements significantly enhance the effectiveness of green finance. Tools such as artificial intelligence, big data, and blockchain are revolutionizing the way financial risks associated with climate change are assessed and managed. AI aids in evaluating the environmental and social impacts of investments, while blockchain technology ensures transparency and accountability in the allocation of funds for green projects (Aggarwal, 2023). These innovations not only bolster investor confidence but also address issues like greenwashing, which undermines the credibility of green finance initiatives (Kumar et al., 2022). Moreover, big data analytics facilitates supply chain traceability and the identification of areas where companies can improve resource efficiency, further aligning investment portfolios with sustainable development goals (Hemanand et al., 2022).

The private sector's role in advancing green finance is equally significant. With the growing demand for sustainable solutions, venture capital firms and private equity investors are increasingly channeling resources into start-ups and early-stage companies that prioritize environmental impact (Ping & Shah, 2023). The issuance of Green Social, Sustainability, and Sustainability-linked (GSSS) bonds has also expanded, reflecting a burgeoning market for environmentally and socially responsible investments (Nawaz et al., 2021). Public-private partnerships, supported by regulatory measures such as 100% Foreign Direct Investment (FDI) in renewable energy projects, demonstrate the synergy required to scale up green finance efforts and attract both domestic and international capital (Invest India, 2023).

However, the green finance landscape in India is not without its challenges. A major hurdle is the lack of standardized definitions and metrics for what constitutes "green" investment, creating inconsistencies and complicating the evaluation of financial instruments (Sarangi, 2018). This ambiguity increases the risk of greenwashing and undermines investor trust. Regulatory bodies like the Reserve Bank of India (RBI) and the Securities and Exchange Board of India (SEBI) have initiated measures to improve transparency and standardization, such as green deposit frameworks and the introduction of environmental, social, and governance (ESG) mutual fund categories (Saha, 2023). These steps aim to streamline green finance practices and bolster confidence in their environmental impact.

The integration of green finance into India's economic strategy offers several benefits, including the promotion of sustainable development, enhancement of energy security, and reduction of carbon emissions. It also opens up opportunities for global collaborations and innovative financing solutions that align with

international climate goals (Schmucki & Matthews, 2024). While challenges remain, the growth of green finance reflects a broader commitment to fostering a low-carbon economy. By leveraging technology, enhancing regulatory frameworks, and fostering partnerships, India is well-positioned to accelerate its green transition and contribute meaningfully to global sustainability efforts. This pathway not only aligns with the nation's economic and environmental aspirations but also sets a precedent for integrating sustainability into financial systems globally.

THE CONCEPTUAL FRAMEWORK

This research integrates green finance, artificial intelligence (AI), and sustainable development within India's context, grounded in theories like the Triple Bottom Line Framework, Innovation Diffusion Model, and Transformative Capacity Theory. Green finance involves financial flows directed toward sustainable projects such as renewable energy, sustainable agriculture, and eco-friendly infrastructure, supported by mechanisms like green bonds, blended finance models, and public-private partnerships. AI enhances the effectiveness of green finance through advanced risk analysis, resource optimization, ESG compliance monitoring, and the creation of inclusive digital lending platforms, addressing challenges like data quality and algorithmic biases. Together, green finance and AI align to drive sustainable development, balancing economic growth, environmental sustainability, and social equity. Policy instruments play a crucial role in this interplay, with regulatory tools ensuring transparency, economic incentives promoting innovation, and informational mechanisms fostering collaboration and capacity-building. This dynamic interaction facilitates reinforcing existing systems, transforming structures through innovation, and, when necessary, displacing inefficient practices with advanced, AI-driven solutions. The framework provides a comprehensive pathway to bridge investment gaps, integrate advanced technologies, and ensure equitable resource distribution, thereby supporting India's journey toward achieving its sustainability goals.

METHODOLOGY

The methodology of this study adopts a multidisciplinary approach to examine the interplay of green finance, artificial intelligence (AI), and sustainable development in the Indian context. A critical realist framework underpins the research, emphasizing the examination of structures, mechanisms, and their interactions to identify causal relationships. The study relies on secondary data analysis, synthesizing insights from government policy documents, financial reports, academic literature, and case studies to construct a robust theoretical foundation. It employs a qualitative approach to identify and interpret patterns in green finance flows, policy implementation, and AI-driven technological advancements.

To ensure a comprehensive understanding, the study integrates frameworks like the Triple Bottom Line, Innovation Diffusion Model, and Transformative Capacity Theory to conceptualize the interconnections between financial mechanisms, technological integration, and sustainable outcomes. Policy instruments regulatory, economic, and informational are analyzed to understand their impact on mobilizing green finance and advancing AI applications in sustainability-focused projects. By examining the contributions and limitations of existing policy measures and technology adoption, the methodology provides a critical lens to evaluate gaps in financing, governance, and equitable resource distribution. This approach facilitates the identification of pathways for optimizing financial flows and leveraging AI for achieving India's sustainable development goals, while addressing systemic challenges like greenwashing and private sector engagement.

ESTIMATED REQUIREMENT VS. ACTUAL GREEN FINANCE FLOWS IN INDIA

The data reveals a persistent shortfall between the estimated requirement of INR 11,00,000 crores annually and the actual flows, which peaked at INR 2,70,000 crores by 2023–2024. This gap reflects structural inefficiencies in mobilizing adequate resources, particularly from the private sector. Climate Finance Theory suggests that the limited use of financial instruments like green bonds and blended finance models hampers private investment growth. While private contributions have increased from 35% in 2015 to 50% in 2023–

2024, this remains insufficient to close the funding gap. The data underscores the urgent need for policy reforms to incentivize private sector participation and explore international funding channels.

Table 1. Green financial inflow in India from 2018 to 2023.

Year	Estimated Requirement (INR Crores)	Actual Green Finance Flows (INR Crores)	Public Sector Contribution (%)	Private Sector Contribution (%)
2018-19	11,00,000	1,24,000	65% (81,000 crores)	35% (43,000 crores)
2019–2020	11,00,000	1,24,000	60% (74,400 crores)	40% (49,600 crores)
2020–2021	11,00,000	2,48,000	60% (1,48,800 crores)	40% (99,200 crores)
2021–2022	11,00,000	2,50,000	55% (1,37,500 crores)	45% (1,12,500 crores)
2022–2023	11,00,000	2,70,000	50% (1,35,000 crores)	50% (1,35,000 crores)

Source: CPI & EY US Reports

Clean energy consistently dominates the allocation of green finance, growing from 40% of flows in 2015–2018 to 45% by 2021–2024. This focus aligns with global emission reduction goals but comes at the expense of climate adaptation, whose share has dropped from 10% to 5% over the same period. According to the Triple Bottom Line Framework, this trend prioritizes financial viability over social equity, as clean energy investments often yield higher economic returns. The underfunding of adaptation measures poses risks for vulnerable populations, particularly in agriculture-dependent regions, where climate resilience is crucial. A more balanced allocation is necessary to ensure that social and environmental dimensions of sustainability are adequately addressed. The division of contributions between the public and private sectors highlights disparities in investment priorities. Private sector participation is strong in clean energy (52% by 2021–2024) and energy efficiency (92%), driven by profit potential. However, clean transportation (6% private participation) and climate adaptation (8%) remain heavily reliant on public funding. Public Goods Theory explains this reliance, as these sectors lack direct profitability and require government intervention. Blended finance models, risk-sharing mechanisms, and guarantees could incentivize private investment in socially critical sectors, reducing the fiscal burden on the public sector while ensuring broader investment coverage.

INDIANS' GREEN GROWTH INITIATIVES

India's green growth agenda is driven by both environmental necessity and economic opportunity. Environmentally, the nation is exposed to climate change's effects, such as increasing sea levels and erratic monsoons, which threaten livelihoods and public health. Rapid industrialization and urbanization have also degraded air and water quality (K.S. Kavi Kumar et al., 2012). By making investments in sustainable infrastructure and renewable energy, India aims to become a leader in renewable energy, sustainable manufacturing, and climate-resilient agriculture (Islam and Managi, 2019).

India's commitment to green growth is evident in a variety of initiatives encompassing policy frameworks, technological innovations, and grassroots movements. A key policy is NAPCC which addresses the climate challenges while pursuing developmental goals. The eight main goals of the NAPCC are to promote green India, sustainable solar energy, improved energy efficiency, sustainable habitats, water management, Himalayan ecosystem preservation, and strategic climate action.

The initiative and its objectives have been instrumental in increasing solar installations, bringing down costs in the solar power domain, reducing dependence on finite fossil fuels, and overall energy security in the country. Once completed, the National Solar Mission will make India a major global player in the area of solar energy. The scheme has also created millions of jobs in the economic and social sectors.

Table 2. Budget Allocation for Green growth Initiatives in India.

Name of Green growth Initiatives	Budget Allocation in Crore rupees Year Wise						
	2018	2019	2020	2021	2022	2023	2024
National Solar Mission	4000	4500	4800	5000	5300	5500	5800
national mission for enhanced energy efficiency	2000	2200	2400	2600	2800	3000	3200
National Mission for Sustainable Habitat	1500	1600	1700	1800	1900	2000	2100
National Water Mission	3500	3600	3700	3800	3900	4000	4100
National Mission For Sustaining The Himalayan Ecosystem	1000	1100	1200	1300	1400	1500	1600
GIM The National Mission for a Green India	2000	2100	2200	2300	2400	2500	2600
National Mission for Sustainable Agriculture	3000	3200	3400	3600	3800	4000	4200
National Mission on Strategic Knowledge for Climate Change	1200	1300	1400	1500	1600	1700	1800
Faster Adoption and Manufacturing of (Hybrid) and Electric Vehicles	14000	16000	18000	20000	22000	24000	26000
Swachh Bharat Abhiyan	895	1000	1300	1500	2799.97	5172.83	1987.87

Source: Authors calculations from various.

The budgetary allocations for India's key national missions from 2018 to 2024 reveal a focused but uneven approach to achieving sustainability goals. On one hand, significant increases in funding for initiatives like the National Solar Mission, NMEEE, and FAME underscore a strategic commitment to energy efficiency, renewable energy adoption, and vehicular emission reduction. On the other hand, relatively modest growth in allocations for critical areas such as ecosystem preservation (NMSHE) and urban sustainability (NMSH) signals a more cautious investment approach, which may reflect constraints in resources or a prioritization hierarchy that could leave some sustainability challenges inadequately addressed.

The data reflects a dual narrative. For well-established technologies, like solar energy under the National Solar Mission (₹4,000 crores in 2018 to ₹5,800 crores in 2024), funding has grown consistently, suggesting confidence in their proven scalability and impact. Similarly, the significant rise in the FAME scheme's budget (from ₹14,000 crores in 2018 to ₹26,000 crores in 2024) indicates a robust response to public demand for cleaner transportation options and global trends toward electrification.

Conversely, the allocations for emerging or less-established areas such as the NMSHE (₹1,000 crores in 2018 to ₹1,600 crores in 2024) and National Water Mission (₹3,500 crores in 2018 to ₹4,100 crores in 2024) exhibit only gradual increases. This conservative trajectory raises critical questions about the adequacy of funding for tackling issues like biodiversity loss and water security, which require immediate and

transformative solutions. Incremental budget changes in these domains may limit the country's ability to respond effectively to fast-evolving challenges posed by climate change and resource depletion.

The fluctuation in Swachh Bharat Abhiyan's budget (from ₹895 crores in 2018, peaking at ₹5,172.83 crores in 2023, and falling to ₹1,987.87 crores in 2024) highlights a reactive funding model based on the campaign's stage and needs. While this reflects adaptability, it also underscores potential inconsistencies in long-term planning for public health and sanitation.

A critical interpretation of this data, framed through the lens of Innovation Diffusion Models, suggests that while resources are flowing robustly to mature and high-visibility sectors, emerging and high-risk areas face underinvestment. Such an approach risks reinforcing the status quo rather than fostering breakthroughs that could accelerate India's transition to a green economy. The limited budget for initiatives like green hydrogen exemplifies this gap, where insufficient early-stage funding may delay the development of transformative technologies critical for decarbonization.

To maximize the efficacy of budgetary commitments, a balanced approach is an essential one that continues to strengthen established programs while significantly enhancing investments in underfunded, high-potential areas. Public funding should act as a catalyst for innovation, de-risking nascent technologies to attract private sector investment and drive broader adoption. This recalibration could ensure that India's green growth strategy is both equitable and forward-looking, aligning financial priorities with the urgency of environmental and developmental challenges.

ARTIFICIAL INTELLIGENCE (AI) AND GREEN FINANCE

Artificial Intelligence (AI) plays a transformative role in advancing green finance in India by enhancing decision-making, optimizing resource allocation, and promoting transparency. AI tools are increasingly utilized to assess the sustainability credentials of projects by analyzing complex datasets, including carbon emissions, energy efficiency, and climate resilience metrics. Such capabilities enable financial institutions to identify and fund green projects more effectively, aligning investment strategies with India's sustainable development goals (Maiti & Tripathi, 2023). Furthermore, AI-driven platforms facilitate risk assessment in green investments, especially in sectors like renewable energy and sustainable agriculture, by providing predictive analytics based on historical and real-time data (Ranjan et al., 2022).

AI also enhances accessibility and inclusivity in green finance by enabling the creation of digital lending platforms that cater to small-scale and rural enterprises. These platforms leverage machine learning algorithms to evaluate creditworthiness in non-traditional ways, such as analyzing alternative financial and behavioral data, thus bridging gaps in funding for green projects at the grassroots level (Sharma & Gupta, 2023). Additionally, AI-powered systems improve regulatory compliance by automating the monitoring and reporting of environmental, social, and governance (ESG) metrics, ensuring accountability and reducing the cost of compliance for financial institutions (Kumar et al., 2021).

Despite its potential, the application of AI in green finance faces challenges, such as data quality issues, lack of standardized ESG metrics, and concerns over algorithmic transparency and biases. Addressing these challenges requires collaborative efforts between policymakers, financial institutions, and technology developers to establish robust frameworks for AI integration in green finance (Sinha & Joshi, 2023).

Table 4. Contribution of AI in green finance in India from 2010 to 2024

Year	Sector	Contribution in INR Crores	Private Sector Involvement (%)	Public Sector Involvement (%)
2010–2014	Agriculture	₹300 Crores (Initial AI tools and data-driven crop management)	30%	70%
2015–2017	Energy (Renewables)	₹1,000 Crores (AI for solar/wind grid optimization, data analytics)	50%	50%
2018-20	Smart Cities	₹1,500 Crores (AI for waste/traffic management, emission reduction)	60%	40%
2021-2023	Data Centers	2000 Crores (AI-driven green data centers, energy optimization)	70%	30%
2023–2024	Agriculture & Energy	3000 Crores (AI farming models, energy grid optimization, EV)	65%	35%

Source: Author calculation from various source; Indian Council of Agricultural Research (ICAR), World Economic Forum, Ministry of Power, Niti Ayog, MoHUA, Analytics India Magazine, GetFarm.

Artificial Intelligence (AI) has emerged as a transformative force in green finance, shaping India's sustainability landscape by integrating advanced technologies into agriculture, energy, and urban management. However, a critical perspective on AI's role reveals a complex interplay of opportunities and challenges that require innovative strategies and governance to harness its potential effectively.

From 2010 to 2024, the increasing application of AI in sectors such as agriculture, renewable energy, and smart cities demonstrates its capacity to drive efficiencies, reduce emissions, and optimize resource use. For example, AI applications in agriculture have evolved from data-driven crop management (₹300 crores, 30% private sector involvement, 2010–2014) to AI farming models and energy grid optimization (₹3,000 crores, 65% private sector involvement, 2022–2024), signifying growing private sector confidence in these technologies1. Similarly, AI-enabled smart cities projects (₹1,500 crores, 60% private sector involvement, 2018–2020) underscore the use of technology for emission reduction and traffic management, aligning urban growth with sustainability goals.

Despite these advancements, the disproportionate reliance on private sector involvement in AI-driven green finance raises critical concerns about equity and accessibility. While private investment surged to 70% in sectors like green data centers in 2021, public sector participation dwindled to 30%, potentially sidelining marginalized communities and regions that are less attractive to profit-driven investments. This dynamic necessitates policy interventions to ensure balanced participation and equitable access to AI benefits.

Another critical issue is the limited focus on governance and accountability mechanisms in the deployment of AI for green finance. Algorithmic biases, data privacy concerns, and the opacity of AI decision-making processes pose significant risks. Without robust regulatory frameworks, the potential for misuse or inefficiencies in green finance allocations remains high. For instance, AI farming models may favor regions

with better digital infrastructure, exacerbating rural inequalities, unless targeted subsidies or infrastructure development initiatives are implemented.

Furthermore, while AI enhances predictive analytics and resource optimization, its environmental footprint—particularly the energy consumption of AI models and data centers—contradicts its sustainability goals. Although ₹2,000 crores were invested in AI-driven green data centers in 2021, achieving true net-zero energy use in these facilities remains a technological and regulatory challenge.

To innovate in this domain, a systemic recalibration of AI's integration in green finance is essential. This involves fostering public-private partnerships with shared accountability, incentivizing investments in low-profit but high-impact projects, and developing AI systems that are energy-efficient and inclusively designed. Additionally, participatory governance models that involve local communities in AI-driven initiatives can bridge equity gaps and ensure that green finance serves a broader spectrum of society. By critically examining AI's trajectory in green finance, it is evident that while technological advancements offer promising solutions, addressing their inherent disparities and sustainability paradoxes requires a novel and integrative approach. These efforts could position India not only as a leader in deploying AI for green growth but also as a model for inclusive and responsible innovation in the global sustainability movement.

CONCLUSION

Green finance in India is both a dynamic and critical mechanism for achieving the nation's ambitious net-zero emission goals by 2070. The study highlights the significance of combining policy frameworks, public-private collaboration, and technological advancements to foster sustainable development while addressing climate challenges. Government initiatives like the National Action Plan on Climate Change (NAPCC) and innovations such as green bonds demonstrate India's proactive stance in this transition. Yet, persistent gaps between financial needs and actual investments underline structural inefficiencies and call for comprehensive policy reforms to attract private sector involvement and international funding.

Technological tools like AI and blockchain are transforming green finance by enhancing transparency, efficiency, and risk assessment. However, challenges like greenwashing, lack of standardization, and algorithmic biases require robust governance. Public-private partnerships, innovative financial instruments, and equitable budget allocation must be prioritized to bridge gaps in underfunded areas like climate adaptation and water management, ensuring a balanced approach to sustainability.

The interplay of ecological resilience, economic growth, and social equity within India's green finance strategy demands a recalibrated focus that aligns financial flows with urgent environmental and developmental goals. This integrated approach can position India as a global leader in sustainable finance, contributing significantly to international climate action.

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