

Review

The Role of Technology in Promoting Green Finance: A Systematic Literature Survey and the Development of a Framework

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Abstract: Green finance, defined as channeling money into sustainable development activities, is still far lower than needed to achieve net-zero emissions objectives. In this paper, we discuss the role of technologies in developing green finance. We identify that green finance faces three major challenges, including the risk management of green projects, the scarcity of innovative green financing products, and compliance with the regulations. Then, in the context of the existing literature, we explore recent technologies, including blockchain, artificial intelligence (AI), machine learning (ML), data analytics, Internet of Things (IoT), and robotics that are helping to deal with the challenges in green finance. We show that data-driven approaches utilizing AI and ML help in the risk assessment of green projects; FinTech-based crowdfunding platforms provide innovative green financial products and regulatory technologies (RegTech) support in compliance with regulations. We also identify that the environmental footprint of cryptocurrencies is an emerging area in the technologies and green finance domain. Our framework could be helpful to further extend the debate on the role of technology in green finance.

Keywords: green finance; FinTech; artificial intelligence; machine learning; risk management; crowdfunding; cryptocurrency; RegTech



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1. Introduction

Climate change, global warming, and pollution have emerged as pressing global challenges. While economic growth is essential, it must be environmentally sustainable. Green finance offers a potential solution by channeling investments toward environmentally friendly projects. Green financial instruments, such as green equities, green bonds, and green credit, play a pivotal role in promoting sustainability by reducing pollution and inspiring green investments (Reboredo and Ugolini 2020; Taghizadeh-Hesary et al. 2021).

The scale of the challenge is immense. McKinsey estimates a staggering USD 275 trillion in funding required for the global green transition between 2021 and 2050 (McKinsey & Company 2022). While the level of green finance is increasing over time, we identify that its development faces at least three major challenges: risk management of green projects, a lack of innovation in green financing products, and absence of or compliance with regulations. Technological advancements and innovations can significantly address these challenges and accelerate the transition to a more sustainable financial landscape (Cao 2023; Huang and Zhang 2021; Mi and Coffman 2019).

The role of technological innovations in economic development in general and in sustainable development in particular is an area of hot debate. Technological innovation is seen as a primary driving force behind fundamental gains in productivity and people's living conditions, leading to the evolution of new industrial products and mitigating environmental risks (Castellacci and Lie 2017; Pan et al. 2020).

The application of technology to financial services, FinTech, has revolutionized the financial industry (Gai et al. 2018). It offers cost-effective solutions for both consumers and businesses (Knewton and Rosenbaum 2020). While banks have historically adopted technology, the 2008 financial crisis accelerated the growth of new FinTech enterprises (Anagnostopoulos 2018; Breidbach et al. 2020). FinTech has evolved into a dynamic ecosystem driven by innovation and disruption (Leong 2018; Mnif et al. 2024), offering a range of client-centric services (Gomber et al. 2017). The integration of other recent technologies, like the Internet of Things (IoT), artificial intelligence (AI), machine learning (ML), big data, data analytics, and blockchain, into FinTech is likely to maximize the benefits of technology-led transformation in the financial sector (Kumar et al. 2022).

For green finance, FinTech can play the role of facilitator by providing digital information dissemination mechanisms, big data and data analytics-based risk assessment procedures, new internet-based digital financial products, and technology-based frameworks of governance and control for meeting regulatory requirements. Arguably, the use of technology in the financial sector can contribute to sustainable development by improving financial resource allocation and inclusion (Ahmad and Satrovic 2023; Arner et al. 2020; Chien et al. 2024). Recent research reports that the FinTech innovations strengthened the positive effect of green finance on sustainable development (Mahmood et al. 2024).

In this paper, we conduct a systematic literature survey to examine the role of technology in the development of green finance. Our survey covers the period from 2013 to 2024. We searched Scopus and Google Scholar as the two main databases. To the best of our knowledge, this is the first-ever attempt to understand the role of different technologies in green finance in the context of the existing literature.

After collating the literature, we start in Section 4 by identifying three major challenges in the development of green finance, including the risk management of green projects, the lack of innovation in green financing products, and compliance with the regulations. Then, in Section 5, we summarize the literature, which explores how technologies help deal with the challenges of green finance. In Section 6, we highlight that cryptocurrency is an emerging area in the domain of technology and green finance. In the final section, we conclude the study by summarizing the main findings and highlighting the directions for future research.

2. Materials and Methods

This study adopts a systematic review approach to provide a comprehensive review of the application of technology in green finance. The databases were searched for focused joint keywords in the title, abstract, and complete text. The review relied on academic articles, journal editorials, and research papers, and a thorough search was conducted on the following electronic databases: Scopus and Google Scholar. The main keywords searched included Green Finance, Green Technology, Sustainability, Machine Learning, Artificial Intelligence, Risk Management, Green Financing Products, Crowdfunding, Regulatory Compliance, Regtech, and Cryptocurrencies. The search was limited to the articles and research outputs from 2013 to 2024. This search yielded multiple earlier research publications in this field. Around 800 articles were screened using the inclusion and exclusion criteria (Table 1).

Table 1. Research evaluation criteria.

Inclusion	Exclusion
Published research between 2013 to 2024	Published research prior to 2013
Finance context	Non-finance context
Published research in English	Published research in languages other than English
Peer-reviewed studies	Non-peer-reviewed studies
Full research	Partial research

After screening the search records for eligibility for inclusion, 90 articles, reports, and research outputs were selected for this systematic review. Table 2 provides evidence of the conference and journal names, reports, and authors.

Table 2. Distribution of the reviewed papers over conferences, journals, and reports.

Conferences/Journals/Reports	Number of Studies	(Authors and Year)
4th IET International Conference on Clean Energy and Technology 2016	1	(Partoon et al. 2016)
5th International Conference on Financial Innovation and Economic Development	1	(Pan et al. 2020)
<i>ACRN Journal of Finance and Risk Perspectives</i>	2	(Hasan Eken et al. 2013; Johansson et al. 2019)
ADBI Working Paper Series	1	(Dikau and Volz 2018)
Annals of Operations Research	1	(Kumar et al. 2022)
Business Commons Farell	1	(Farell 2015)
China Finance Review International	1	(Awawdeh et al. 2022)
Digital Finance	1	(Kabaklarlı 2022)
Ecological Economics	1	(Zhou et al. 2022)
ECONOMIC BULLETIN	1	(González 2021)
Economic Modelling, North-Holland	1	(Reboredo and Ugolini 2020)
<i>Emerging Science Journal, Ital Publication</i>	1	(Khan et al. 2022)
<i>Energy Economics</i>	1	(Cumming et al. 2017)
<i>Energy Policy</i>	1	(Eyraud et al. 2013)
<i>Energy Procedia</i>	1	(Wang and Zhi 2016)
Energy Research Letters	1	(Zakari and Khan 2022)
<i>Environment, Development and Sustainability</i>	2	(Chien et al. 2024; Han et al. 2024)
Environmental Research	1	(Tayebi and Amini 2024)
Environmental Science and Pollution Research	1	(Ahmad et al. 2023)
European Business Organization Law Review	1	(Arner et al. 2020)
European Company and Financial Law Review	1	(Macchiavello and Siri 2022)
Finance Research Letters	1	(Taghizadeh-Hesary and Yoshino 2019)
<i>Financial Internet Quarterly</i>	1	(Ozili 2021)
Frontiers in Artificial Intelligence	1	(Brandl and Hornuf 2020)
Georgetown Journal of International Affairs	1	(Arner et al. 2017)
IEEE 9th International Conference for Convergence in Technology, I2CT 2024	1	(Mukherjee et al. 2024)
International Business Review	1	(Berdiyeva et al. 2021)
<i>International Journal of Accounting, Finance, Auditing, Management and Economics</i>	1	(Lakhchini et al. 2022)
<i>International Journal of Advanced Computer Research</i>	1	(Al-Amri et al. 2019)
<i>International Journal of Bank Marketing</i>	1	(Rossolini et al. 2021)
<i>International Journal of Finance and Economics</i>	1	(Mohsin et al. 2023)
<i>International Journal of Innovation, Management and Technology</i>	1	(Leong 2018)
<i>International Journal of Management (IJM)</i>	1	(Wulandari et al. 2020)
<i>International Journal of Sustainable Development and World Ecology</i>	1	(Udeagha and Muchapondwa 2023)
International Seminar on Education Innovation and Economic Management	1	(Yang 2020)
<i>Journal of Accounting and Public Policy</i>	1	(Hummel and Schlick 2016)
<i>Journal of Advanced Computer Science and Applications</i>	1	(Islam et al. 2022)

Table 2. Cont.

Conferences/Journals/Reports	Number of Studies	(Authors and Year)
<i>Journal of Advanced Research in Dynamical and Control System</i>	2	(Nasir and Saeedi 2019; Raudha and Saeedi 2019)
<i>Journal of Banking and Financial Technology</i>	1	(Villar and Khan 2021)
<i>Journal of Business Economics, Springer Berlin Heidelberg</i>	1	(Gomber et al. 2017)
<i>Journal of Cleaner Production</i>	3	(Castellacci and Lie 2017; Chen and Zhao 2022; Maehle et al. 2021)
<i>Journal of Cryptocurrency Research</i>	1	(Mohsin 2021)
<i>Journal of Economics and Business</i>	1	(Anagnostopoulos 2018)
<i>Journal of Enterprise Information Management,</i>	1	(Wang and Xue 2022)
<i>Journal of Environment and Development</i>	1	(Cléménçon 2016)
<i>Journal of Environmental Management</i>	1	(Ahmad and Satrovic 2023)
<i>Journal of Environmental Management</i>	2	(Kim and Hall 2021; Wang et al. 2024)
<i>Journal of Financial Risk Management</i>	1	(Khan et al. 2019)
<i>Journal of Intellectual Capital</i>	1	(Vrontis et al. 2021)
<i>Journal of Investment Compliance</i>	1	(Freij 2020)
<i>Journal of Management Studies</i>	1	(Calic and Mosakowski 2016)
<i>Journal of Network and Computer Applications</i>	1	(Gai et al. 2018)
<i>Journal of Service Theory and Practice</i>	1	(Breibach et al. 2020)
<i>Management of Environmental Quality: An International Journal</i>	1	(Mnif et al. 2024)
<i>Managerial Finance</i>	2	(Knewton and Rosenbaum 2020; Hashemi et al. 2020)
McKinsey Global Institute in collaboration with McKinsey Sustainability and McKinsey's Global Energy and Materials and Advanced Industries Practices	1	(McKinsey & Company 2022)
<i>Nature Communications</i>	1	(Mi and Coffman 2019)
<i>Renewable Energy</i>	3	(Cao 2023; Nenavath 2022; Xu et al. 2022)
Research Square	1	(Mahmood et al. 2024)
Security and Communication Networks	1	(Gundaboina et al. 2022)
<i>Sensors</i>	1	(Allioui and Mourdi 2023)
<i>Solar Energy</i>	1	(Halden et al. 2021)
<i>Studies in Economics and Finance</i>	1	(Sangwan et al. 2020)
<i>Sustainability</i>	7	(Dziwok and Jäger 2021; Hommel and Bican 2020; Huang and Zhang 2021; Lee 2021; Liu et al. 2021; Rizwan and Mustafa 2022; Taghizadeh-Hesary et al. 2021)
<i>Sustainable Development</i>	1	(Sethi et al. 2024)
Sustainable Futures, Elsevier Ltd.	1	(Nti et al. 2022)
Technological Forecasting and Social Change	6	(Falcone et al. 2018; Gan et al. 2020; Huang et al. 2019; Messeni Petruzzelli et al. 2019; Su et al. 2020; Yan et al. 2022)
Test Eng. Manag	1	(Ali et al. 2020)
UNEP	1	(UNEP 2024)
<i>World Journal of Advanced Research and Reviews</i>	1	(Elias et al. 2024)

Selected references were assessed for relevance and usefulness to the application of technology in green finance and sustainability in finance. Table 3 presents different areas of the related studies and research output based on the keywords that were searched for and used to construct different sections of this paper.

Table 3. Distribution of the reviewed papers in different areas of related studies.

Areas of Related Studies	Number of Studies	(Authors Year)
Green Finance, Green Technology, and Sustainability	33	(Ahmad and Satrovic 2023); (Ahmad et al. 2023); (Allioui and Mourdi 2023), (Arner et al. 2020); (Awawdeh et al. 2022); (Brandl and Hornuf 2020); (Breidbach et al. 2020); (Cao 2023); (Castellacci and Lie 2017); (Chien et al. 2024); (Falcone et al. 2018); (Gai et al. 2018); (Gomber et al. 2017); (Han et al. 2024); (Khan et al. 2022); (Knewton and Rosenbaum 2020); (Leong 2018); (Macchiavello and Siri 2022); (Mahmood et al. 2024); (McKinsey & Company 2022); (Mi and Coffman 2019); (Mnif et al. 2024); (Nenavath 2022); (Ozili 2021); (Pan et al. 2020); (Partoon et al. 2016); (Sangwan et al. 2020); (Sethi et al. 2024); (Udeagha and Muchapondwa 2023); (UNEP 2024); (Zakari and Khan 2022); (Zhou et al. 2022); (Villar and Khan 2021)
Machine Learning, Artificial Intelligence, Risk Management, and Green Finance	12	(Berdiyeva et al. 2021); (Chen and Zhao 2022); (Gan et al. 2020); (Kumar et al. 2022); (Lee 2021); (Mukherjee et al. 2024); (Lakhchini et al. 2022); (Nti et al. 2022); (Raudha and Saeedi 2019); (Wang and Xue 2022); (Wang et al. 2024); (Yang 2020)
Green Financing Products and Crowdfunding	19	(Ali et al. 2020); (Calic and Mosakowski 2016); (Cumming et al. 2017); (Eyraud et al. 2013); (Halden et al. 2021); (Hommel and Bican 2020); (Huang et al. 2019); (Khan et al. 2019); (Kim and Hall 2021); (Maehle et al. 2021); (Messeni Petruzzelli et al. 2019); (Mukherjee et al. 2024); (Reboredo and Ugolini 2020); (Rizwan and Mustafa 2022); (Rossolini et al. 2021); (Taghizadeh-Hesary and Yoshino 2019); (Taghizadeh-Hesary et al. 2021); (Vrontis et al. 2021); (Wulandari et al. 2020)
Regulatory Compliance and Green Finance	15	(Anagnostopoulos 2018); (Arner et al. 2017); (Cléménçon 2016); (Dikau and Volz 2018); (Dziwok and Jäger 2021); (Freij 2020); (González 2021); (Hasan Eken et al. 2013); (Huang and Zhang 2021); (Hummel and Schlick 2016); (Johansson et al. 2019); (Liu et al. 2021); (Nasir and Saeedi 2019); (Wang and Zhi 2016); (Xu et al. 2022)
Cryptocurrencies and Green Finance	11	(Al-Amri et al. 2019); (Farell 2015); (Gundaboina et al. 2022); (Hashemi et al. 2020); (Islam et al. 2022); (Kabaklarlı 2022); (Mohsin et al. 2023), (Mohsin 2021); (Su et al. 2020); (Tayebi and Amini 2024); (Yan et al. 2022)

3. Definition of Green Finance

The United Nations Environment Program (UNEP 2024) defines green financing as “to increase the level of financial flows (from banking, micro-credit, insurance, and investment) from the public, private and not-for-profit sectors to sustainable development priorities”. A crucial objective is to enhance the management of social and environmental risks while simultaneously capturing opportunities that deliver both financial returns and positive environmental impact, ultimately increasing accountability. Green financing has been advocated in recent years to safeguard the environment, and it has made tremendous progress. Green finance connects the public and private financial systems to sustainable development, integrates financial decisions with environmental protection, and supports environmentally friendly business models concentrated on clean energy, improved water and air quality, disposable plastic, and other factors. Green finance bridges the gap between consumers, producers, investors, and lenders, emphasizing money as a tool to help the environment (Wang and Zhi 2016).

Green finance instruments can be used as tools to raise funds for green purposes. For instance, a loan issued at a low rate of interest for the plantation of trees in some areas or mortgage loans provided for solar financing activities and FinTech tools for investment can accelerate the process of establishing green finance investment in a more efficient and effective manner (Ozili 2021).

4. Challenges in Green Finance

The development of green finance is facing three major challenges, including the risk management of green projects, the lack of innovation in green financing products, and compliance with the regulations. The mounting costs associated with climate change necessitate swift and substantial green investment. However, balancing the urgency of climate action with the imperative of prudent risk management is complex. Premature

or ill-conceived green projects can lead to financial losses and erode investor confidence. As such, the financial industry must carefully evaluate the risks and rewards of green investments to ensure both environmental sustainability and financial viability.

The green finance market is still relatively small compared to traditional finance with limiting investment opportunities and products. Some products may be exaggerated or misrepresented as environmentally friendly (i.e., greenwashing) to attract green investments, eroding investor trust. The adoption of the green ecosystem faces numerous limitations and various factors that affect the implementation process. Specifically, in emerging economies, these barriers and constraints can be eliminated by identifying the root cause effectively, managing the associated risk in time and taking health initiatives to generate private financing from individuals in society (Khan et al. 2022).

Different jurisdictions have varying regulatory frameworks for green finance, creating complexities for investors and businesses operating across borders. The regulatory landscape can be complex and evolving, making it difficult for market participants to navigate. Zhou et al. (2022) emphasize the significance of using technology (FinTech) in green finance and how technology development has led to an increase in green investment. Though the rate of growth varies depending on the region, one thing is sure: green finance growth flourishes with the help of technology (FinTech). Green finance has evolved as a trendy technique to cope with environment-related issues in recent years. However, it is still necessary to observe closely whether green finance can resolve environmental problems worldwide. Dziwok and Jäger (2021) developed a theoretical model for classifying various categories of green finance and fiscal policy to evaluate the various perspectives for future academic research in the field to address diverse approaches and their effects on dealing with economic and environmental challenges. Meanwhile, managers and policymakers are encouraged to inject more cash into green projects to ensure the positive net present values of these projects and reduce financial distress (Khan et al. 2019).

5. Role of Technologies in Dealing with the Challenges

In this section, we present the discussion regarding the role of technologies in dealing with the challenges in the development of green finance. Blockchain, artificial intelligence (AI), machine learning (ML), data analytics, the Internet of Things (IoT), and robotics are the leading technologies widely used to address the challenges in green finance.

5.1. Technologies Defined

Blockchain technology is a type of distributed ledger technology that uses cryptographic techniques to record every transaction, ensuring that each one is distinct and able to be legally confirmed (Farell 2015). Decentralized processes, such as those used by blockchain technology, eliminate the need for a governing body. All its users have access to the distributed ledger. All transactions are time-stamped and documented, and they are linked in a chain to the ones that came before them. Every user checks the validity of every new transaction, and it is only approved by other users that it is accepted. As a result, there is not much room for record manipulation (Hashemi et al. 2020). Blockchain is widely used in the finance domain, including banking, smart financial contracts, cryptocurrencies, regulation compliance, and even crowdfunding. This technology can significantly improve security, transparency, and efficiency (Mukherjee et al. 2024).

Lakhchini et al. (2022) defines AI as a technology tool with the ability to perform complex operations that involve human intelligence. ML is considered an AI application focusing on creating models and systems that can automatically modify, learn, and improve the big data set and conduct predictive analysis. Nowadays, AI and ML are powerful data analytics tools that are extensively used in all sectors of finance, such as investment, risk management, price discovery, fraud detection, and compliance.

IoT is considered a powerful technology tool for data management and decision-making while increasing efficiency in productivity and operations in finance (Allioui and Mourdi 2023). IoT technology is an interconnected network of digital devices that requires

little human interaction. This technology is revolutionizing the financial industry by providing interconnected and smart systems using real-time data (Elias et al. 2024).

Robotics in finance is mainly employed by Robotic process automation (RPA). This software is designed to mimic human interaction with multiple applications in finance. This technology can be paired with other technologies, such as AI or blockchain, to make financial operations more efficient and tailored to customers' needs (Villar and Khan 2021).

5.2. Technologies and Risk Management of Green Projects

While economies worldwide are increasingly adopting green strategies, risk management remains a critical concern for the progress of trade and industry. Identifying the risks associated with green projects and implementing adequate controls are essential for safeguarding stakeholders' interests in long-term investments. AI-based technologies, when supported by regulations and assessed against sustainable development goals, have immense potential. The capital market has embraced the application of ML to manage and evaluate financial risks associated with underlying assets, as well as to integrate ESG-related intensive data into asset management. AI and ML-based models can revolutionize the economy by predicting trends and logic, thereby enhancing sustainability.

Chen and Zhao (2022) propose the creation of a shared central intelligence system to enhance the development and management of risks within the green industry of a given economy. Wang and Xue (2022) describe the sustainable development goals of the industry by comparing the historical improvements in the economy and suggest promoting intelligence-based optimization in financial risk assessment. Similarly, Berdiyeva et al. (2021) emphasize the importance of utilizing predictive models in both new and existing green projects to manage potential risks effectively. These technologies are designed to support economic sustainability, irrespective of product design or human activity. According to Lee (2021), AI can enhance social sustainability across various product designs, a concept that can be extended to financial products aligned with green finance. Organizations must consider the mechanisms and limitations related to sustainability to adopt these revolutionary technologies most effectively, thereby enhancing financial structures, regulations, and environmental policies (Liu et al. 2021; Wang et al. 2024).

ML, in particular, is highly effective in predicting the future value of financial instruments and establishing relationships between multiple variables based on historical data. The capital market has increasingly embraced ML for managing and assessing the financial risks associated with underlying assets and integrating ESG-related data into asset management practices (Nti et al. 2022; Raudha and Saeedi 2019).

Gan et al. (2020) argue that machine learning and deep learning offer fast, accurate, and reliable solutions for asset pricing, which are essential for investment managers and financial traders. This claim applies to various investment projects, including green initiatives. ML's broad applicability in predicting future risks, including potential biological and environmental risks, further solidifies its role in green finance.

As globalization and innovation continue to increase pressures on the financial system, organizations are increasingly vulnerable to the challenges of developing a green society. The adoption of technological advancements in green finance is crucial for significantly enhancing the efficiency of the financial ecosystem. Key stakeholders in this activity include government bodies, green enterprises, and financial service providers, all of which play pivotal roles in addressing green financial risks (Falcone et al. 2018).

5.3. Technologies and Innovation in Green Financing Products

The availability of green financing empowers individuals, corporations, and governments to invest in low-carbon operations (Huang et al. 2019). Such funding safeguards the environment (Wang and Zhi 2016) and propels sustainable trade and investment (Eyraud et al. 2013). However, developing low-risk green investment instruments remains challenging where technology emerges as a potent catalyst (Taghizadeh-Hesary and Yoshino 2019).

Digitalization has expanded financial avenues and fostered FinTech, with crowdfunding gaining prominence. A pivotal intersection of FinTech and sustainable finance, crowdfunding aggregates small investments from numerous individuals via online platforms. Green crowdfunding channels empower eco-friendly enterprises to access capital more efficiently (Macchiavello and Siri 2022). Crowdfunding has evolved into a potent tool for raising capital from a broad investor base, primarily through optimized online platforms.

Emerging in 2007–2008 financial crisis, crowdfunding revolutionized entrepreneurial funding (Hommel and Bican 2020; Messeni Petruzzelli et al. 2019). By bypassing traditional intermediaries, crowdfunding democratizes access to capital (Rossolini et al. 2021). Common crowdfunding models include donation-based, reward-based, equity-based, and peer-to-peer financing (Rizwan and Mustafa 2022). Equity-based crowdfunding offers investors ownership stakes, with potential returns through dividends or capital appreciation (Brandl and Hornuf 2020; Wulandari et al. 2020). Peer-to-peer lending facilitates direct (Cumming et al. 2017) lending between individuals (Sangwan et al. 2020). Benefit-based crowdfunding rewards contributors with non-monetary incentives (Ali et al. 2020; Vrontis et al. 2021).

Financial services have undergone a transformative evolution due to advancements in telecommunications, information technology, and financial practices. This convergence of digitization and globalization has accelerated the growth of digital crowdfunding platforms.

An example is that digital technologies optimize solar energy project operations and management, driving down costs. Distributed ledger technology, integrated with crowdfunding, enables small investors to provide long-term, low-interest loans, enhancing project financing flexibility while accommodating investor risk profiles (Halden et al. 2021).

Several crowdfunding platforms have aligned with climate change mitigation goals, encompassing renewable energy, sustainable transportation, and resource conservation (Partoon et al. 2016). Additionally, they have included community-building and carbon capture projects (Cumming et al. 2017; Maehle et al. 2021). The burgeoning FinTech industry, characterized by technology-driven financial operations (Leong 2018), offers innovative tools, like crowdfunding platforms, to support the financing needs of environmentally focused organizations (Calic and Mosakowski 2016; Kim and Hall 2021; Messeni Petruzzelli et al. 2019). Crowdfunding is a significant area of alliance between FinTech and sustainable finance; people or businesses who work on green projects can receive a considerable amount of money from other users through an online crowdfunding platform. These platforms not only can assist sustainable businesses in obtaining capital and resources in a more timely and cost-effective manner, but also allow investors to participate in environmentally friendly projects (Kim and Hall 2021).

5.4. Technologies and Regulatory Compliance in Green Finance

A robust and secure financial system is essential for economic prosperity. Financial misconduct can have far-reaching consequences, prompting regulators worldwide to implement safeguards to maintain investor confidence. The financial industry has experienced periods of instability and fraud, which have eroded trust and impacted global economies (Hasan Eken et al. 2013). These events have heightened the complexity of risk management and compliance as regulatory responses often lag behind financial innovation.

The interconnectedness of finance and the environment has led central banks to prioritize sustainability. The Networking for Greening the Financial Services initiative, with a membership spanning from eight countries in 2017 to over ninety in 2020, underscores the global commitment to green finance. This network represents a significant portion of global GDP and greenhouse gas emissions (González 2021).

Central banks, traditionally focused on monetary policy, are evolving into “green central banks” to address climate and environmental risks (Dikau and Volz 2018). While the primary responsibility for sustainable finance lies with governments, central banks can play a catalytic role by incorporating environmental considerations into their policy frameworks. This includes developing clear guidelines for green financial products, promoting

awareness among stakeholders, and supporting the development of green finance markets (Zakari and Khan 2022).

To effectively navigate the evolving regulatory landscape, both regulators and financial institutions are increasingly relying on technology. RegTech, a subset of FinTech, offers solutions for automating compliance processes, detecting fraud, and analyzing data. By leveraging artificial intelligence and machine learning, RegTech can enhance efficiency and reduce risks for both regulators and regulated entities (Johansson et al. 2019; Nasir and Saeedi 2019). RegTech also helps regulators with supervision and communication with regulated institutions (Freij 2020). With the use of sophisticated technologies, such as big data and data analytics, both regulators and regulated organizations can save precious time while maintaining speed with accuracy (Arner et al. 2017).

Multiple climate-related decisions were made in the Paris Agreement; however, most of the regulations that deal with environmentally sustainable reporting and compliance are voluntary. At the international level, the idea of keeping the process not bound legally is to encourage developing countries to take steps for the environment (Clémentçon 2016). Most countries also do not have legally binding compliance requirements for companies in green finance. Furthermore, most countries have economic interests that are in conflict with the idea of completing the shift to sustainable finance. The importance of climate risk is well-accepted by most countries.

Xu et al. (2022) show that green finance has a positive impact on the regulations. It is not only the manufacturing industries, but also the other industries that contribute to the pollution, and there is a chance of the misallocation of funds in the name of green finance, and actual usage is different. It is also advised in the study that regulators must take appropriate measures for mandating the disclosure of information related to green projects and also perform real-time supervision. Regulatory measures must work in line with the legal framework, and all the stakeholders, like investors, regulated institutions, and regulators, should take responsibility for the supervision. Nenavath (2022) establishes that the association of FinTech and green finance will have a positive impact on the environment.

In many countries, significant importance has been placed on the disclosure of sustainability information; however, researchers have had conflicting views on its impact on sustainability performance. Few researchers have found a negative relationship between the two variables, while another set of researchers found a positive relationship. A study (Hummel and Schlick 2016) combined two theories and argued that sustainability performance depends on the quality of the disclosure. Low-quality disclosure has a negative relationship, while high-quality disclosure has a positive relationship with sustainability performance.

The payout period of most green projects is more than that of the traditional projects, and hence it is logical for governments to provide tax subsidies to such projects so that investors of these projects have the incentive also to choose green projects over traditional projects. It is very important to make sure that funds allocated to green finance projects must be used for the allocated purpose only. Xu et al. (2022) discuss how, with the help of advanced technologies, green finance is allocated to the big companies or state-owned companies. The primary motive of these companies is to make a profit, and in most cases, the use of the funds is not as per the agreement.

The financial industry's history of rapid innovation, often outpacing regulatory frameworks, has necessitated a robust regulatory response. The Global Financial Crisis exemplified the need for increased oversight and the challenges of balancing financial stability with market efficiency. RegTech has emerged as a critical tool for addressing these challenges, enabling regulators to keep pace with industry developments while minimizing compliance burdens on financial institutions. Regulators must ensure that green funds are allocated as per the project type rather than the reputation of the companies. Financial institutions are using technology to reduce the cost of compliance by making automated processes, and regulators use technology for monitoring and supervision purposes.

6. Cryptocurrencies: Emerging Area of Research in the Domain of Technologies and Green Finance

The cryptocurrency industry faces significant challenges, primarily its substantial environmental impact. The energy-intensive mining process, often reliant on non-renewable sources, has raised concerns about its contribution to climate change (Wang and Xue 2022). While the potential benefits of cryptocurrency are undeniable, its environmental costs must be carefully considered (Gundaboina et al. 2022; Kabaklarlı 2022; Mohsin 2021; Yan et al. 2022). It is widely known that the biggest challenge of the use of cryptocurrency is that it needs to be more environmentally friendly; a very high cost and the mining process are involved in cryptocurrency while using electricity. If the mining process of cryptocurrency and the derivation of the capital out of the process is not adequately regulated, then it would have severe consequences (Tayebi and Amini 2024).

Advanced technologies are needed to support economic growth and reduce CO₂ emissions as cryptocurrency trading rises. These technologies must seek an eco-friendly environment with reduced CO₂-emitting energy sources. Individual nations are expected to support low-CO₂ technologies so that fiscal reforms are also environmentally friendly and beneficial to people (Mohsin et al. 2023).

To mitigate these concerns, a shift toward renewable energy sources for cryptocurrency mining is essential. Additionally, exploring alternative consensus mechanisms, such as Proof of Stake, could significantly reduce energy consumption (Islam et al. 2022). By decoupling cryptocurrency from fossil fuels, the industry can contribute to a more sustainable future.

However, addressing the environmental impact of cryptocurrency requires a multifaceted approach. Regulators must play a crucial role in promoting green energy adoption within the industry and establishing clear guidelines for sustainable cryptocurrency practices. Furthermore, research into the broader economic and social implications of cryptocurrency, including its impact on financial risk, human health, and security, is necessary to inform future policy and investment decisions (Al-Amri et al. 2019; Gundaboina et al. 2022).

The potential for cryptocurrency to drive investment in renewable energy is significant. By incentivizing the use of clean energy sources, the industry can contribute to a more sustainable future. However, it is essential to monitor the evolving landscape of cryptocurrency and its associated environmental impact to ensure that it aligns with broader sustainability goals.

7. Conclusions

This paper offers a comprehensive review of the literature exploring the pivotal role of technology in fostering green finance. Green finance refers to any financial transaction with any financial instrument that involves improving the environment and innovations and technology-driven tools significantly impact the intensity of this effect. In many cases, green technology and green finance have proven to promote environmental sustainability.

Our analysis identifies three core challenges impeding the growth of green finance: the effective management of green project risks, the development of innovative green financial instruments, and the complexities of regulatory compliance. To address these challenges, we explore the role of emerging technologies, including artificial intelligence, machine learning, big data, and robotics. Our findings suggest that these technologies can significantly enhance risk assessments, stimulate the creation of novel green financial products, and streamline regulatory processes through RegTech. Furthermore, we examine the environmental implications of cryptocurrencies as a rapidly evolving aspect of the technology–green finance intersection.

In this study, we provide a foundational framework to study the role of technology in the development of green finance. Our analysis of the literature indicates that research in this area is still scarce and lacks depth. We identify the following areas for future research.

One reason the existing research is not broad in scope is the lack of rich green finance and technology datasets. Because of this reason, the existing research largely uses indirect

or weak proxies of green finance and technology usage. This is a very strong area where future research may work. The development of new datasets can help to quantify the direct impact of specific technologies (e.g., AI, ML, and blockchain) on green finance metrics (e.g., green investment volume and green loan portfolios).

Future studies may also dig deeper and focus on the role of digital products in specific financial markets, such as debt or equities, in promoting green finance.

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