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Building an International Regulatory and Legal Framework for Green Digital Finance

Construindo um Quadro Regulatório e Legal Internacional para Finanças Digitais Verdes

Wahid Wachyu Adi WINARTO[1]
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ABSTRACT: This paper is to discuss the evolution of the concept of green digital finance and its relationship to achieving sustainable development goals. It aims to analyze the existing regulatory and policy framework related to green digital finance and explore legal and regulatory considerations for optimizing digitalization in supporting green finance. This study qualitatively examines the development and current status of green digital finance, emphasizing its alignment with sustainable development goals (SDGs). It explores the regulatory and policy frameworks shaping green digital finance, highlighting both the opportunities and challenges introduced by technologies like blockchain, AI, big data, and IoT. The analysis also investigates the efforts of regulators and financial institutions to adapt regulations, offering insights into legal and policy measures required to leverage digital innovations for advancing green finance. Sustainable development (SDGs) through technological innovation in the financial sector provided by technologies such as blockchain, AI, machine learning, big data, and IoT in enhancing green finance initiatives. While these technologies also present challenges related to data security, consumer protection, and regulatory adaptation.
KEYWORDS: Green digital finance, Climate change, Green finance, Sustainable development, Law, Regulation

RESUMO: Este artigo discute a evolução do conceito de finanças digitais verdes e sua relação com a obtenção de objetivos de desenvolvimento sustentável. Ele visa analisar estrutura regulatória e política existente relacionada às finanças digitais verdes e explorar considerações legais e regulatórias para otimizar a digitalização no suporte às finanças verdes. Este estudo examina qualitativamente o desenvolvimento e o status atual das finanças digitais verdes, enfatizando seu alinhamento com os objetivos de desenvolvimento sustentável (ODS). Ele explora as estruturas regulatórias e políticas que moldam as finanças digitais verdes, destacando as oportunidades e os desafios introduzidos por tecnologias Como blockchain, IA, big data e IoT. Também investiga os esforços de reguladores e instituições financeiras para adaptar regulamentações, oferecendo insights sobre medidas legais e políticas necessárias para alavancar inovações digitais para o avanço das finanças verdes. Desenvolvimento sustentável (ODS) por meio da inovação tecnológica no setor financeiro fornecida por tecnologias Como blockchain, IA, aprendizado de máquina, big data e IoT no aprimoramento de iniciativas de finanças verdes. Embora essas tecnologias também apresentem desafios relacionados à segurança de dados, proteção ao consumidor e adaptação regulatória.

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PALAVRAS-CHAVE: Finanças digitais verdes, Mudanças climáticas, Finanças verdes, Desenvolvimento sustentável, Lei, Regulamentação

1. INTRODUCTION

Green Digital Finance (GDF) is an emerging concept at the intersection of finance, technology, and environmental sustainability.[3] While there is no universally accepted definition, GDF broadly refers to the use of digital technologies such as blockchain, artificial intelligence (AI), big data, and the Internet of Things (IoT) to create financial solutions that support environmental sustainability and climate change mitigation (UNEP, 2020).[4] By bridging technological innovation, sustainability, and financial inclusion,[5] GDF aims to encourage green investments, reduce environmental impact, and facilitate the transition to a low carbon economy.[6]

The significance of GDF is increasingly evident in the rapid expansion of green finance markets.[7] According to the Climate Bonds Initiative (2023), the global green bond market surpassed $2.5 trillion in cumulative issuance, demonstrating a growing commitment to sustainable finance. Additionally, the World Bank (2022) highlights that climate related financial risks are escalating, necessitating the integration of advanced digital tools to enhance risk assessment and financial decision making. The intersection of digital finance and green investment is becoming crucial in addressing these challenges, particularly in emerging economies where financial inclusion and environmental sustainability are key priorities.[8]

However, the lack of a unified definition and regulatory framework poses significant challenges to the development and implementation of GDF. Terms such as green finance, climate finance, digital finance, and sustainable finance are often used interchangeably, yet they differ in scope and focus. Green finance typically refers to financing environmentally friendly projects, while climate finance focuses on mitigating

[3] ROEBEN, V, 2024. Synergy-as-principle in global climate regulation. *Global Policy*. Vol. 15, no. S5, pp. 53–63. http://doi.org/10.1111/1758-5899.13425
[4] GREEN, B A, 2012. The flood of US lawyers: Natural fluctuation or professional climate change? *International Journal of the Legal Profession*. Vol. 19, no. 2–3, pp. 193–207. http://doi.org/10.1080/09695958.2013.771122
[5] TSENG, C J and LIN, S Y, 2024. Role of artificial intelligence in carbon cost reduction of firms. *JOURNAL OF CLEANER PRODUCTION*. Vol. 447. http://doi.org/10.1016/j.jclepro.2024.141413
[6] XU, S, 2023. China's climate governance for carbon neutrality: regulatory gaps and the ways forward. *Humanities and Social Sciences Communications*. Vol. 10, no. 1. http://doi.org/10.1057/s41599-023-02381-8
[7] EDGEMAN, R, 2015. Wicked global challenges: sustainability in the enterprise crosshairs. *MEASURING BUSINESS EXCELLENCE*. Vol. 19, no. 1, pp. 13–23. DOI 10.1108/MBE-11-2014-0040
[8] WANG, Y et al., 2024. Financing the green transition: Mobilizing resources for efficient natural resource management. *Resources Policy*. Vol. 89. http://doi.org/10.1016/j.resourpol.2023.104522

and adapting to climate change.[9] Digital finance, on the other hand, emphasizes the transformation of the financial sector through technologies like blockchain and AI, which form the backbone of GDF.[10]

To fully grasp the concept of GDF, it is essential to break it down into three core components (Finance, Digital, Green).[11] Finance is encompasses a range of financial services and mechanisms, from investment to fund management, aimed at supporting sustainable projects.[12] Digital is leverages modern technologies such as blockchain, big data, and AI to enhance the efficiency, transparency, and accessibility of financial services. Green is Emphasizes sustainability, with a focus on mitigating climate change and creating a positive environmental impact.[13] By integrating these three elements, GDF has the potential to significantly contribute to achieving the Sustainable Development Goals (SDGs) and fostering a more inclusive, innovative, and environmentally friendly financial system.[14]

Despite its potential, the implementation of GDF faces significant challenges, particularly in the absence of a clear and unified regulatory and legal framework.[15] While various national and regional initiatives have been introduced, they remain fragmented and largely non binding, highlighting the need for a comprehensive international agreement.[16] This study focuses on the regulatory and legal aspects of GDF, with a particular emphasis on Indonesia as a case study. The research

[9] QUITÉRIO RAMOS, C M, CASADO-MOLINA, A M and IGNÁCIO-PELÁEZ, J, 2019. An innovative management perspective for organizations through a reputation intelligence management model. *International Journal of Information Systems in the Service Sector*. Vol. 11, no. 4, pp. 1–20. http://doi.org/10.4018/IJISSS.2019100101

[10] KHARE, Anshuman and BABER, William W., 2023. Adopting and Adapting Innovation in Japan's Digital Transformation. *Asia Pacific Business Review*. Vol. 00, no. 00, p. 214. http://doi.org/10.1080/13602381.2024.2440032

[11] FATORACHIAN, H and KAZEMI, H, 2021. Impact of Industry 4.0 on supply chain performance. *Production Planning & Control*. Vol. 32, no. 1, pp. 63–81. http://doi.org/10.1080/09537287.2020.1712487

[12] SHI, J and LI, F, 2023. Aligning the BRI With Sustainable Development: A Regulatory Framework and Its Implementation. *Journal of World Trade*. Vol. 57, no. 6, pp. 933–956. http://doi.org/10.54648/trad2023039

[13] Petersmann, "The Future of the WTO: From Authoritarian 'Mercantilism' to Multilevel Governance for the Benefit of Citizens?"

[14] CHANG, A, LEE, T.-S. and LEE, H.-M., 2024. Applying sustainable development goals in financial forecasting using machine learning techniques. *Corporate Social Responsibility and Environmental Management*. Vol. 31, no. 3, pp. 2277–2289. http://doi.org/10.1002/csr.2694

[15] ZHANG, W Q and ZHAO, J L, 2023. Digital transformation, environmental disclosure, and environmental performance: An examination based on listed companies in heavy-pollution industries in China. *International Review Of Economics & Finance*. Vol. 87, pp. 505–518. http://doi.org/10.1016/j.iref.2023.06.001

[16] Truby, "Legality of Using Blockchain to Support INSTEX and Other Special Purpose Vehicles to Enable Humanitarian Trade with Sanctioned States."

addresses the following specific questions; (a) how do existing regulatory and legal frameworks support or hinder the development of GDF?, (b) what are the main regulatory and technological barriers to harmonizing GDF regulations at the international level?, (c) how can technologies such as blockchain, AI, and IoT be integrated into the regulatory framework for GDF?, (d) what roles do stakeholders governments, private sector actors, and civil society play in strengthening the regulatory framework for GDF?

This study narrows its focus to the regulatory and legal challenges of GDF in Indonesia, a country with significant potential for green finance due to its rich natural resources and growing digital economy. Indonesia's financial sector is witnessing a surge in sustainable investment, with the issuance of green sukuk bonds reaching $3.25 billion as of 2023 (Ministry of Finance Indonesia, 2023). However, regulatory inconsistencies and technological adoption gaps remain key barriers to the full realization of GDF's potential.[17] By concentrating on Indonesia, the analysis provides a detailed examination of how national regulations can align with international standards while addressing local challenges. Additionally, the study explores specific aspects of GDF, such as the role of blockchain in green crowdfunding and the integration of AI in environmental risk assessment.[18]

The advancement of technologies such as blockchain, AI, big data, and IoT offers significant opportunities for reforming green finance.[19] These technologies can enhance transparency, reduce transaction costs, and drive innovation in sustainability oriented financial services.[20] However, their implementation also presents challenges, including data security, consumer protection, and the need for regulatory adaptation. While blockchain can improve transparency in green bond issuance, its high energy consumption raises concerns about its environmental impact.[21] Similarly, AI driven

[17] LAUB, James Alan, 1999. Assessing the servant organization; Development of the Organizational Leadership Assessment (OLA) model. Dissertation Abstracts International.
[18] STEPHENS, J C, WILSON, E J and PETERSON, T R, 2008. Socio-Political Evaluation of Energy Deployment (SPEED): An integrated research framework analyzing energy technology deployment. *Technological Forecasting and Social Change*. Vol. 75, no. 8, pp. 1224–1246. http://doi.org/10.1016/j.techfore.2007.12.003
[19] LI, W J, WARIS, I and BHUTTO, M Y, 2024. Understanding the nexus among big data analytics capabilities, green dynamic capabilities, supply chain agility and green competitive advantage: the moderating effect of supply chain innovativeness. *JOURNAL OF MANUFACTURING TECHNOLOGY MANAGEMENT*. Vol. 35, no. 1, pp. 119–140. http://doi.org/10.1108/JMTM-07-2023-0263
[20] Kunhibava et al., "Ṣukūk on Blockchain: A Legal, Regulatory and Sharī'ah Review."
[21] TRUBY, "Legality of Using Blockchain to Support INSTEX and Other Special Purpose Vehicles to Enable Humanitarian Trade with Sanctioned States."

environmental risk assessment tools require robust data governance to ensure accuracy and accountability.

Harnessing the digital revolution to accelerate the achievement of the SDGs has become a key focus of international organizations, including the United Nations. The UN Development Programme (UNDP) has emphasized the potential of digital technologies to transform financial markets and drive sustainable development (UN Task Force on Digital Financing for SDGs, 2020). However, realizing this potential requires collaboration among public and private stakeholders, as well as technology transfer from developed to developing countries. In Indonesia, partnerships between the government, financial institutions, and technology providers are crucial for building a robust GDF ecosystem.[22]

This study adopts a descriptive and exploratory research approach, combining a systematic literature review with qualitative analysis. Given the relatively new and evolving nature of GDF, the available literature is limited and often fragmented across the fields of green finance and digital finance. By integrating these previously separate elements, this study aims to formulate a regulatory and legal framework that supports the development of GDF in Indonesia.[23]

The regulatory and legal framework is a critical component of any reform, as it provides legal validity, ensures coherence in application, and promotes best practices at both national and international levels.[24] This study contributes to the growing body of knowledge on GDF by offering a deeper understanding of the regulatory challenges and opportunities in digital finance. It also provides actionable insights for policymakers, regulators, and industry stakeholders to achieve a balance between technological innovation, consumer protection, and legal compliance. Ultimately, this research aims to inform the development of sustainable and adaptive regulations that can support the future of digital finance while advancing global sustainability goals.

2. LITERATURE REVIEW

[22] JIANG, L, GU, Y and DAI, J, 2023. Environmental, social, and governance taxonomy simplification: A hybrid text mining approach. *Journal of Emerging Technologies in Accounting*. Vol. 20, no. 1, pp. 305–325. http://doi.org/10.2308/JETA-2022-041

[23] WINARTO, Wahid Wachyu Adi, KURNIAWAN, Muhammad Arif and GUNAWAN, Ade, 2024. Behavioral Financial Fraud And Crime, Islamic Law Investigation In Using Financial Technology. *Revista Juridica*. Vol. 3, no. 80, pp. 1–27. http://doi.org/10.26668/revistajur.2316-753X.v3i80.6749

[24] LAUB, "Assessing the □ervant Organization; Development of the Organizational Leadership Assessment (OLA) Model."

Theoretical Foundations

Institutional Theory and Diffusion of Innovations Theory (DIT) provide a framework for understanding Green Digital Finance (GDF). Institutional Theory explains how regulations, norms, and cultural expectations influence organizational behavior, shaping the adoption of green and digital financial practices.[25] A key challenge is the lack of harmonized international regulations, which may hinder GDF adoption, whereas strong institutional support can facilitate its growth.[26]

DIT explores how new technologies spread within societies, providing insights into the adoption of digital tools like blockchain and AI in the financial sector to support sustainability goals.[27] While some researchers argue that regulatory clarity accelerates technological adoption, others highlight risks such as cybersecurity threats and the digital divide, which may hinder equitable access to GDF solutions.[28]

Green Digital Finance Concept

Green Digital Finance (GDF) is an emerging concept at the intersection of finance, technology, and environmental sustainability.[29] While there is no universally accepted definition, GDF broadly refers to the use of digital technologies such as blockchain, artificial intelligence (AI), big data, and the Internet of Things (IoT) to create financial solutions that support environmental sustainability and climate change mitigation. By bridging technological innovation, sustainability, and financial inclusion, GDF aims to encourage green investments, reduce environmental impact, and facilitate the transition to a low carbon economy.[30]

The significance of GDF is increasingly evident in the rapid expansion of green finance markets.[31] According to the Climate Bonds Initiative (2023), the global green bond market surpassed $2.5 trillion in cumulative issuance, demonstrating a growing

[25] PETERS, B. Guy, 2022. Institutional theory. In : *Handbook on Theories of Governance*. ISBN 9781800371972. http://doi.org/10.5040/9781474274289.0014
[26] SUDDABY, “Challenges for Institutional Theory.”
[27] YU, Ping, 2022. Diffusion of Innovation theory. In : *Implementation Science: The Key Concepts*. ISBN 9781000583410. http://doi.org/10.4324/9781003109945-16
[28] GOVINDAN, Kannan, 2024. How Artificial Intelligence Drives Sustainable Frugal Innovation: A Multitheoretical Perspective. *IEEE Transactions on Engineering Management*. http://doi.org/10.1109/TEM.2021.3116187
[29] KUMAR, S et al., 2022. Past, present, and future of sustainable finance: insights from big data analytics through machine learning of scholarly research. *Annals of Operations Research*. http://doi.org/10.1007/s10479-021-04410-8
[30] HEITMANN, N and KHALILIAN, S, 2011. Accounting for carbon dioxide emissions from international shipping: Burden sharing under different UNFCCC allocation options and regime scenarios. *Marine Policy*. Vol. 35, no. 5, pp. 682–691. http://doi.org/10.1016/j.marpol.2011.02.009
[31] Asif et al., “Dark Side Whitewashes the Benefits of FinTech Innovations: A Bibliometric Overview.”

commitment to sustainable finance.[32] Additionally, the World Bank (2022) highlights that climate related financial risks are escalating, necessitating the integration of advanced digital tools to enhance risk assessment and financial decision making.[33] The intersection of digital finance and green investment is becoming crucial in addressing these challenges, particularly in emerging economies where financial inclusion and environmental sustainability are key priorities.[34]

Regulatory and Legal Challenges

The development of GDF is shaped by national and international regulatory frameworks.[35] In Indonesia, the Otoritas Jasa Keuangan (OJK) has introduced regulations such as the Green Bond Framework and the integration of environmental, social, and governance (ESG) principles into financial reporting. Globally, organizations like the Financial Stability Board (FSB) and the Task Force on Climate related Financial Disclosures (TCFD) provide guidelines for sustainable finance practices, ensuring financial systems remain resilient and transparent.[36]

However, challenges persist, including the lack of harmonized regulations across countries, complicating cross border transactions. Some scholars argue that strict regulations are necessary to mitigate risks, while others warn they may stifle innovation. Data privacy and cybersecurity concerns further complicate regulatory adaptation, requiring balance between security and accessibility.[37]

Digital technologies such as blockchain, AI, and IoT offer significant opportunities to enhance green finance by improving efficiency, transparency, and accessibility.[38] Blockchain ensures transparency in green bond issuance, AI optimizes environmental risk assessments, and IoT enables real time monitoring of energy

[32] ZHANG, Q et al., 2024. Synergistic Impact of Internet of Things and Big-Data-Driven Supply Chain on Sustainable Firm Performance. *Sustainability (Switzerland)* . Vol. 16, no. 13. http://doi.org/10.3390/su16135717

[33] FRECAUTAN, I and IVASHKOVSKAYA, I, 2024. Is corporate governance important for green bond performance in emerging capital markets? *Eurasian Economic Review*. Vol. 14, no. 1, pp. 175–212. http://doi.org/10.1007/s40822-023-00249-5

[34] Cumming et al., "ESG and Crowdfunding Platforms."

[35] Frecautan and Ivashkovskaya, "Is Corporate Governance Important for Green Bond Performance in Emerging Capital Markets?"

[36] WACHYU, Wahid and WINARTO, Adi, 2020. Peran Fintech dalam Usaha Mikro Kecil dan Menengah (UMKM). *Jurnal Ekonomi dan Ekonomi Syariah (JESYA)*. Vol. 3, no. 1, pp. 61–73. https://doi.org/10.36778/jesya.v3i1.132

[37] Winarto, Kurniawan, and Gunawan, "Behavioral Financial Fraud And Crime, Islamic Law Investigation In Using Financial Technology."

[38] ESKINDAROV, M A, MASLENNIKOV, V V and MASLENNIKOV, O V, 2019. Pros and cons of the digital economy in Russia. *Finance: Theory and Practice*. Vol. 23, no. 5, pp. 6–17. http://doi.org/10.26794/2587-5671-2019-23-5-6-17

consumption and emissions.[39] Nevertheless, barriers such as the high energy consumption of blockchain and the slow pace of regulatory adaptation hinder their full potential. Addressing these barriers requires a holistic approach integrating technology, finance, and sustainability.

Collaboration among governments, financial institutions, technology providers, and civil society is essential to developing harmonized regulations, enhancing data transparency, and ensuring responsible use of digital innovations.[40] Through such efforts, GDF can become a powerful tool for advancing global sustainability and addressing climate change and financial inclusion challenges.

3. METHOD

This study employs a critical review analysis to examine the regulatory and legal frameworks governing Green Digital Finance (GDF), focusing on constructing an international regulatory and legal framework.[41] The research integrates normative legal research methods, including systematization, analysis, and synthesis, to evaluate theoretical issues, global regulatory policies, and their applications across jurisdictions.[42] Indonesia is chosen as a case study to provide a detailed examination of national regulations and their alignment with international standards.

A comparative law analysis is conducted to assess regulatory frameworks in various countries, offering insights for harmonizing international policies and developing a cohesive global framework for GDF. The study employs a systematic literature review, analyzing articles published in Scopus indexed journals between 2017 and 2024. The inclusion criteria for article selection include; (a) Relevance to GDF, covering topics such as green finance, digital finance, sustainability, and international regulatory frameworks, (b) Peer reviewed journal articles with empirical or theoretical contributions, (c) Publications in English to ensure accessibility and comparability, (d) Articles must address at least one of the main aspects of green digital

[39] PERDANA, Arif et al., 2021. Distributed ledger technology: Its evolutionary path and the road ahead. *Information and Management*. Vol. 58, no. 3, p. 103316. http://doi.org/10.1016/j.im.2020.103316
[40] OSOKIN, N A, NIKITUSHKINA, Y V and ZOLOTOVA, I.Yu., 2022. Green Finance instruments as a Factor of increasing industrial Waste Utilization in Russia. *Finance: Theory and Practice*. Vol. 26, no. 6, pp. 17–31. http://doi.org/10.26794/2587-5671-2022-26-6-17-31
[41] DEMETRACOPOULOU, Vassiliki et al., 2024. *A critical review and analysis of decision-support processes and tools for project delivery method selection*. Engineering, Construction and Architectural Management. http://doi.org/10.1108/ECAM-05-2022-0455
[42] NEGARA, Tunggul Ansari Setia, 2023. Normative Legal Research in Indonesia: Its Originis and Approaches. *Audito Comparative Law Journal (ACLJ)*. http://doi.org/10.22219/aclj.v4i1.24855

finance (regulation, policy, technology, or legal aspects). Exclusion criteria include; (a) Articles lacking a direct focus on financial regulations or digital sustainability, (b) Publications that do not provide substantial legal or regulatory insights, (c) Duplicates or non peer reviewed sources.

The research process consists of multiple stage; (a) Data collection, articles are retrieved from Scopus using predefined keywords related to GDF and regulatory frameworks; (b) Screening and filtering, titles, abstracts, and keywords are reviewed to ensure relevance based on inclusion and exclusion criteria; (c) Thematic analysis, key patterns, trends, and gaps in international regulations are identified; (d) Synthesis of findings, comparative insights are drawn from different jurisdictions to propose recommendations for regulatory harmonization, (e) Comparative analysis, regulatory frameworks across selected countries are examined to identify best practices and challenges.

4. RESULT AND DISCUSSION

We conducted a literature study by searching for published article data in the Scopus database with the search string "*Green digital finance" OR "Climate change" OR "Green finance" AND legal AND regulatory.* We found 754 articles and after we conducted a review and filter that were relevant to the discussion of this problem, we collected 72 articles that were used as critical review materials. The growth of the discussion that we have analyzed has an increase in publications that raise the theme of green digital finance from 2017 to 2024.

Based on the results of our analysis by applying the critical review method, we discuss the areas of green digital finance by providing a framework for the theme which is discussed in depth and by paying attention to the supervision, regulation and law aspects applied in building the green digital finance framework (Figure 1).

4.1 Green Digital Finance Regulation and Policy Framework

The development of GDF hinges on the establishment of robust regulatory and policy frameworks that integrate digital innovation with sustainability goals. While digital finance strategies in countries like Indonesia emphasize the adoption of technologies such as Distributed Ledger Technology (DLT) and crypto assets, these efforts often operate within fragmented policy frameworks. The European Union's Green Deal highlights the harmonization of policies to achieve climate neutrality, yet a significant gap remains between digital finance and sustainable finance agendas. This

disconnect undermines the potential of digital technologies to fully support green finance initiatives.[43]

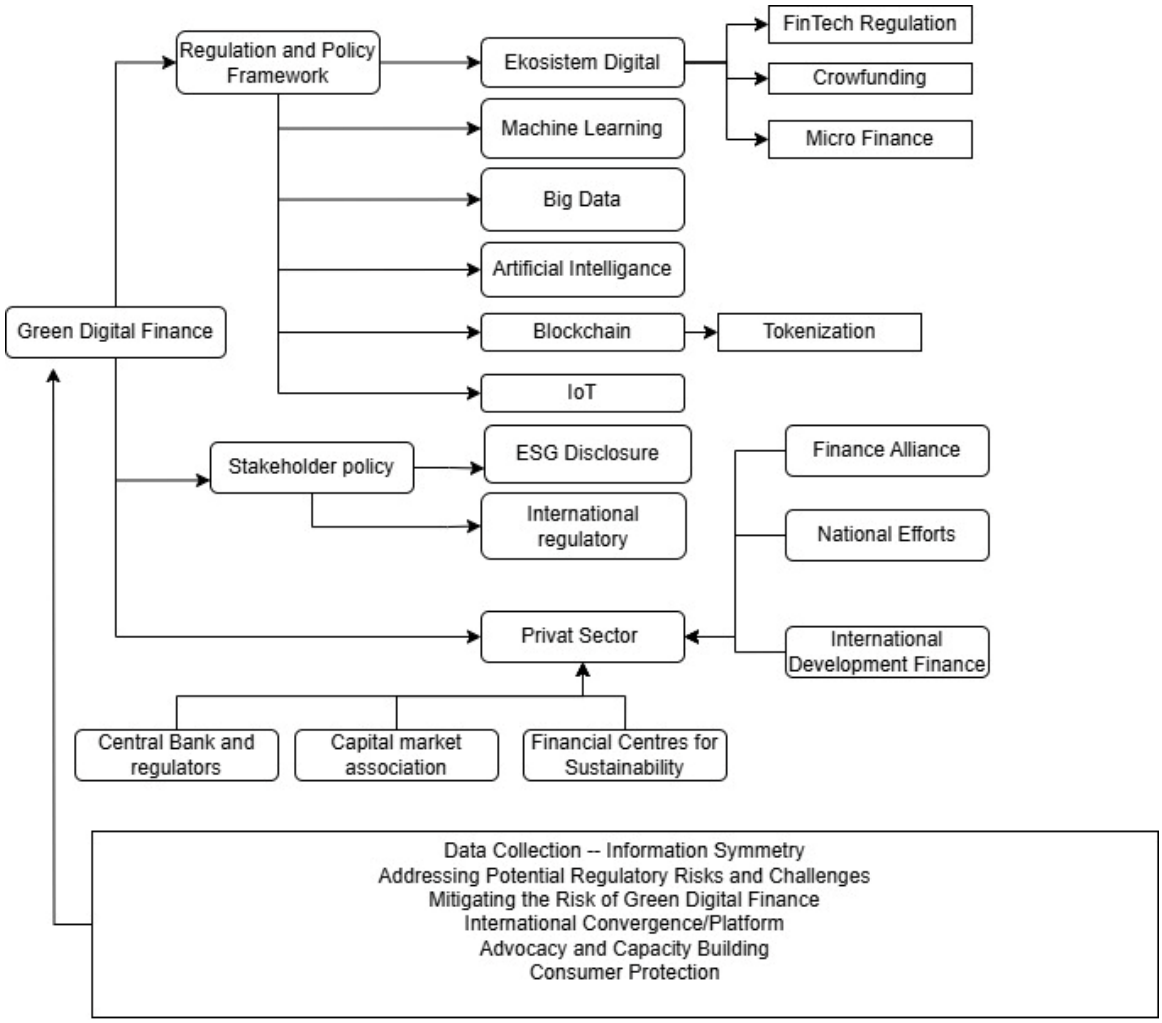

Figure 1. Green Digital Finance Framework

Existing regulatory frameworks both support and hinder GDF development. On one hand, initiatives like the EU's Green Deal and Indonesia's Green Bond Framework provide a foundation for integrating digital technologies into green finance.[44] On the other hand, the lack of harmonized international regulations creates barriers. Differing standards for green bonds in the EU and Asia complicate cross border investments, while the rapid evolution of digital technologies often outpaces regulatory

[43] RINGBOM, H and JOAS, M, 2018. Concluding article: The changing regulatory landscape of the Baltic Sea – An analysis. *Marine Policy*. Vol. 98, pp. 317–324. http://doi.org/10.1016/j.marpol.2018.09.029
[44] SCHERER, M, BRUCE, S and RESCHKE, J, 2021. Environmental Counterclaims in Investment Treaty Arbitration. *ICSID Review*. Vol. 36, no. 2, pp. 413–440. http://doi.org/10.1093/icsidreview/siab006

developments, leading to gaps in oversight and increased risks such as data breaches and cyberattacks.[45]

The main challenges in harmonizing GDF regulations include regulatory fragmentation, differing national priorities, and the absence of a unified taxonomy for green finance.[46] While the EU has stringent ESG reporting requirements, other regions lag behind, creating inconsistencies in global markets.[47] Additionally, the energy intensive nature of technologies like blockchain raises concerns about their compatibility with sustainability goals unless powered by renewable energy.[48]

Digital finance and sustainable finance are inherently complementary, as digital tools like blockchain and AI can enhance transparency, reduce costs, and improve access to green investments.[49] Blockchain's ability to track carbon credits in real time can significantly boost the credibility of green finance projects.[50]

However, the lack of a unified international governance framework poses challenges. Without harmonized regulations, cross border green finance initiatives face legal and operational hurdles. Differing standards for green bonds in the EU and Asia complicate international investments. Moreover, the rapid evolution of digital technologies often outpaces regulatory developments, creating gaps in oversight and increasing risks such as data breaches and cyberattacks.[51]

The regulatory and policy GDF plays a crucial role in integrating digital technologies such as Machine Learning (ML) and Artificial Intelligence (AI) for environmental risk analysis and more accurate decision-making, Big Data for providing structured and transparent data in assessing green projects, Blockchain to enhance

[45] SHARIFI, A et al., 2024. Smart cities and sustainable development goals (SDGs): A systematic literature review of co-benefits and trade-offs. *Cities*. Vol. 146. http://doi.org/10.1016/j.cities.2023.104659

[46] OSOKIN, N A, NIKITUSHKINA, Y V and ZOLOTOVA, I.Yu., 2022. Green Finance instruments as a Factor of increasing industrial Waste Utilization in Russia. *Finance: Theory and Practice*. Vol. 26, no. 6, pp. 17–31. http://doi.org/10.26794/2587-5671-2022-26-6-17-31

[47] HARASCHUK, V et al., 2020. Administrative and legal support challenges of environmental safety under globalization. *European Journal of Sustainable Development*. Vol. 9, no. 2, pp. 20–30. http://doi.org/10.14207/ejsd.2020.v9n2p20

[48] WANG, Y et al., 2024. Financing the green transition: Mobilizing resources for efficient natural resource management. *Resources Policy*. Vol. 89. http://doi.org/10.1016/j.resourpol.2023.104522

[49] COTULA, L, 2023. International Investment Law and Climate Change: Reframing the ISDS Reform Agenda. *Journal of World Investment and Trade*. Vol. 24, no. 4–5, pp. 766–791. http://doi.org/10.1163/22119000-12340310

[50] Wang et al., "Financing the Green Transition: Mobilizing Resources for Efficient Natural Resource Management."

[51] BAKER, H et al., 2023. Impact of Financial Technology on Improvement of Banks' Financial Performance. *Journal of Risk and Financial Management*. Vol. 16, no. 4. http://doi.org/10.3390/jrfm16040230

transparency and security in green bond issuance or carbon credit tracking, and Internet of Things (IoT) for real-time monitoring of environmental impacts.

4.1.1 Digital Ecosystem

The digital ecosystem in finance has evolved from traditional banking to include innovative models like crowdfunding and peer to peer (P2P) lending.[52] While these models promote financial inclusion and support green projects, they also introduce regulatory challenges. P2P platforms like Greenvesting and Windcentrale enable funding for renewable energy projects but operate in a regulatory gray area, with varying levels of oversight across jurisdictions.[53]

Technologies like blockchain, AI, and IoT can be integrated into GDF regulatory frameworks by establishing clear guidelines for their use.[54] Blockchain's ability to track carbon credits in real time can enhance transparency, while AI can optimize environmental risk assessments. IoT devices, such as smart meters, can provide real time data on energy usage, enabling more informed investment decisions. However, regulatory frameworks must address challenges such as data privacy, cybersecurity, and energy consumption to ensure these technologies align with sustainability goals.[55] Crowdfunding and P2P lending democratize access to green investments, allowing individuals and small businesses to participate in sustainability initiatives. These platforms can mobilize capital more efficiently than traditional banking systems.

The lack of standardized regulations for crowdfunding raises concerns about investor protection and platform accountability. In some countries, the absence of clear guidelines has led to fraudulent schemes, undermining trust in green finance. Additionally, the energy intensive nature of blockchain, often used in these platforms, contradicts sustainability goals unless powered by renewable energy.

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[52] FRECAUTAN, I and IVASHKOVSKAYA, I, 2024. Is corporate governance important for green bond performance in emerging capital markets? *Eurasian Economic Review*. Vol. 14, no. 1, pp. 175–212. http://doi.org/10.1007/s40822-023-00249-5

[53] MILIAN, Eduardo Z., SPINOLA, Mauro de M. and CARVALHO, Marly M.de, 2019. Fintechs: A literature review and research agenda. *Electronic Commerce Research and Applications*. Vol. 34, no. January. http://doi.org/10.1016/j.elerap.2019.100833

[54] MOUTI, Samar et al., 2022. Cyber Security Risk management with attack detection frameworks using multi connect variational auto-encoder with probabilistic Bayesian networks. *Computers and Electrical Engineering*. Vol. 103, no. August, p. 108308. http://doi.org/10.1016/j.compeleceng.2022.108308

[55] SHARIFI, A et al., 2024. Smart cities and sustainable development goals (SDGs): A systematic literature review of co-benefits and trade-offs. *Cities*. Vol. 146. DOI 10.1016/j.cities.2023.104659

4.1.2 Machine Learning and Artificial Intelligence

Artificial intelligence (AI) and machine learning (ML) hold immense potential for advancing GDF by enabling data driven decision making and predictive analytics. AI can optimize environmental risk assessments, helping financial institutions identify and mitigate climate related risks.[56] AI and ML can be integrated into GDF frameworks by developing policies that address algorithmic bias and ensure data privacy. Regulators could mandate transparency in AI algorithms to prevent discriminatory practices. Additionally, energy efficient AI systems should be promoted to minimize their environmental impact. AI driven tools can enhance the accuracy and efficiency of green finance by analyzing vast datasets to uncover patterns and predict outcomes. This capability is crucial for aligning investments with the Sustainable Development Goals (SDGs).[57]

However, AI systems are not without flaws. Issues such as algorithmic bias, data privacy concerns, and high energy consumption pose significant challenges. Biased algorithms may disproportionately exclude certain communities from green financing opportunities, exacerbating social inequalities. Furthermore, the environmental impact of AI's energy intensive computations must be addressed to ensure its alignment with sustainability principles.

4.1.3 Big Data

Big data plays a pivotal role in green finance by providing insights into environmental risks and investment opportunities. However, the lack of standardized metrics for environmental data complicates the assessment of green projects. To leverage big data in GDF, regulators should establish standardized metrics for environmental data. This would enhance comparability and transparency, reducing the risk of greenwashing. Additionally, energy efficient data processing technologies, such as cloud computing, should be encouraged to minimize the carbon footprint of big data applications.[58]

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[56] HUNG, Dau Hoang et al., 2023. Financial reporting quality and its determinants: A machine learning approach. *International Journal of Applied Economics, Finance and Accounting*. Vol. 16, no. 1, pp. 1–9. http://doi.org/10.33094/ijaefa.v16i1.863

[57] YIN, H et al., 2024. Predicting the climate impact of healthcare facilities using gradient boosting machines. *Cleaner Environmental Systems*. Vol. 12. http://doi.org/10.1016/j.cesys.2023.100155

[58] SHARMA, R et al., 2020. A systematic literature review on machine learning applications for sustainable agriculture supply chain performance. *Computers and Operations Research*. Vol. 119. http://doi.org/10.1016/j.cor.2020.104926

Access to high quality, standardized data can drive sustainable investments by enabling investors to evaluate the environmental impact of their portfolios. [59] The absence of a unified data taxonomy hampers comparability and transparency. Without agreed benchmarks, greenwashing where companies falsely claim environmental benefits becomes a significant risk. Moreover, the energy consumption associated with processing large datasets, particularly in data centers, raises concerns about the carbon footprint of big data technologies.

4.1.4 Blockchain Technology

Blockchain technology offers transformative potential for GDF by enhancing transparency and reducing transaction costs. Applications such as peer to peer renewable energy trading and carbon credit tracking demonstrate its ability to support sustainability goals. Blockchain can be integrated into GDF frameworks by developing energy efficient protocols and providing clear regulatory guidelines. Regulators could mandate the use of renewable energy for blockchain operations and establish standards for carbon credit tracking. [60]

Blockchain's decentralized nature eliminates the need for intermediaries, reducing costs and increasing efficiency. Its immutable ledger ensures transparency, making it an ideal tool for tracking green investments and preventing fraud. [61] Despite its benefits, blockchain's energy consumption is a major drawback. Bitcoin mining consumes more energy than some countries, raising questions about its compatibility with green finance. Additionally, the lack of regulatory clarity in many jurisdictions creates uncertainty, hindering widespread adoption. To address the regulatory limitations related to blockchain's energy consumption and lack of clarity, several steps can be taken, establishing international standards for sustainable blockchain use, incentivizing renewable energy adoption, creating adaptive and progressive regulations, enforcing transparency and reporting requirements, promoting education and awareness, and fostering international collaboration. By developing clear

[59] WACHYU, Wahid and WINARTO, Adi, 2020. Peran Fintech dalam Usaha Mikro Kecil dan Menengah (UMKM). *Jurnal Ekonomi dan Ekonomi Syariah (JESYA)*. Vol. 3, no. 1, pp. 61–73. http://doi.org/10.36778/jesya.v3i1.132

[60] SETHIBE, T and MALINGA, S, 2021. Blockchain technology innovation: An investigation of the accounting and auditing use-cases. In : F., Matos et al. (eds.), *Proceedings of the European Conference on Innovation and Entrepreneurship, ECIE*, pp. 892–900. Agriculture Research Council, Pretoria, South Africa : Academic Conferences and Publishing International Limited. 2021. ISBN 20491050 (I□□N); 978-191458715-3 (ISBN). http://doi.org/10.34190/EIE.21.001

[61] IRWIN, A S M and TURNER, A B, 2018. Illicit Bitcoin transactions: challenges in getting to the who, what, when and where. *Journal of Money Laundering Control*. Vol. 21, no. 3, pp. 297–313. http://doi.org/10.1108/JMLC-07-2017-0031

guidelines, encouraging the use of energy-efficient protocols like Proof of Stake (PoS), and ensuring accountability through transparent reporting, regulators can mitigate blockchain's environmental impact while supporting its integration into green finance.

4.1.5 Internet of Things

IoT enables real time monitoring of environmental impacts, such as energy consumption and emissions, making it a valuable tool for green finance. However, its application in this field remains underexplored.[62] IoT can be integrated into GDF frameworks by promoting its use in environmental monitoring and establishing cybersecurity standards to protect sensitive data. Regulators could incentivize the adoption of IoT devices for energy efficiency projects while ensuring robust data protection measures.

IoT can enhance the accuracy of environmental data, enabling more informed investment decisions. The integration of IoT into green finance faces challenges such as high infrastructure costs and data security risks. Without robust cybersecurity measures, IoT devices are vulnerable to hacking, which could compromise sensitive financial and environmental data.

4.2 Stockholders and regulation

The complexity of climate related risks necessitates collaboration among governments, the private sector, and civil society. The Green Finance Platform's "5R" framework capital raising, risk management, responsibility, reporting, and reset provides a comprehensive approach to sustainable finance. However, the lack of international consensus on regulatory standards remains a significant barrier. [63]

Governments play a crucial role in developing and enforcing regulations, while private sector actors drive innovation through initiatives like green bonds and sustainable investment platforms. Civil society organizations advocate for transparency and accountability, ensuring that GDF initiatives align with sustainability goals.[64] Collaboration among these stakeholders is essential to address regulatory fragmentation and promote harmonized standards.

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[62] TROTTA, A, RANIA, F and STRANO, E, 2024. Exploring the linkages between FinTech and ESG: A bibliometric perspective. *Research in International Business and Finance*. Vol. 69. http://doi.org/10.1016/j.ribaf.2023.102200

[63] PARK, S K and BISHARA, N D, 2023. Climate Change and a Just Transition to the Future of Work. *American Business Law Journal*. Vol. 60, no. 4, pp. 701–748. http://doi.org/10.1111/ablj.12235

[64] AHMED, K and LONG, W, 2013. Climate change and trade policy: From legal complications to time factor. *Journal of International Trade Law and Policy*. Vol. 12, no. 3, pp. 258–271. http://doi.org/10.1108/JITLP-02-2013-0003

International bodies like the G20 and the Financial Stability Board (FSB) have made strides in promoting sustainable finance. The FSB's Task Force on Climate related Financial Disclosures (TCFD) has developed standards for climate risk reporting, enhancing transparency and accountability.

Despite these efforts, regulatory fragmentation persists. While the EU has adopted stringent ESG reporting requirements, other regions lag behind, creating inconsistencies in global markets. This fragmentation undermines the effectiveness of international green finance initiatives.

4.2.1 Private Sector and ESG Reporting

Private companies are pivotal in advancing GDF by integrating sustainability into their operations and leveraging digital technologies to promote environmental goals. The adoption of Environmental, Social, and Governance (ESG) reporting has become a global practice, linking corporate activities to the Sustainable Development Goals (SDGs).[65] Frameworks such as the Climate Disclosure Standards Board (CDSB), Global Reporting Initiative (GRI), and International Financial Reporting Standards (IFRS) provide structured guidelines for companies to disclose their sustainability efforts. These frameworks enhance transparency and accountability, enabling investors and stakeholders to assess the environmental impact of businesses.

Despite the progress made through ESG reporting, significant gaps remain in addressing the digital aspects of sustainability. While existing frameworks like CDSB and GRI cover environmental issues, they often lack specific guidelines on how digital technologies can be integrated into sustainability strategies. This omission limits the ability of companies to leverage digital tools, such as blockchain, AI, and IoT, to enhance their green finance initiatives.

Moreover, the absence of standardized ESG reporting creates inconsistencies in how companies disclose their sustainability efforts. While some companies may highlight their use of digital technologies for carbon credit tracking, others may not report on digital initiatives at all. This inconsistency undermines the credibility of ESG disclosures and makes it difficult for investors to compare and evaluate companies' sustainability performance.

[65] AVERSA, D, 2024. Disclosures Of Banks' Sustainability Reports, Climate Change And Central Banks: An Empirical Analysis With Unstructured Data. *Risk Governance and Control: Financial Markets and Institutions*. Vol. 14, no. 1, pp. 76–102. http://doi.org/10.22495/rgcv14i1p6

4.2.2 International Framework and Response

The literature review on "green digital finance" reveals a lack of international consensus on a unified regulatory framework, which poses a significant challenge to the global adoption of GDF. However, various international and regional bodies, such as the G20, Financial Stability Board (FSB), and OECD, have outlined broad policy directions to address this gap. The G20's Green Finance Study Group (GFSG), established in 2016 and later restructured into the Sustainable Finance Study Group (SFSG) in 2021, aims to coordinate international efforts to mobilize sustainable finance and align financial systems with the Paris Agreement and Sustainable Development Goals (SDGs). These initiatives demonstrate a growing recognition of the need for harmonized policies to support green finance.[66]

The efforts of international bodies like the G20 and FSB highlight the potential for global cooperation in advancing GDF. The FSB's Task Force on Climate related Financial Disclosures (TCFD) has made significant strides in promoting transparency and accountability in climate related financial reporting. Similarly, the OECD's Green Finance and Investment Center and Blockchain Policy Centre provide platforms for addressing financial, environmental, and digital challenges. These initiatives underscore the importance of international collaboration in developing regulatory frameworks that support sustainable finance.[67]

Despite these efforts, the lack of specific guidelines on "green digital finance" remains a critical barrier. While frameworks like the TCFD focus on climate related risks, they often fail to address the unique challenges and opportunities presented by digital technologies, such as blockchain, AI, and IoT.[68] Energy consumption of blockchain technology raises concerns about its compatibility with sustainability goals, yet there are no clear international standards to address this issue. Additionally, the absence of a unified taxonomy for green finance creates inconsistencies in how digital

[66] Lowitt, "How to Survive Climate Change and Still Run a Thriving Business: Checklists for Smart Leaders."
[67] OSOKIN, N A, NIKITUSHKINA, Y V and ZOLOTOVA, I.Yu., 2022. Green Finance instruments as a Factor of increasing industrial Waste Utilization in Russia. *Finance: Theory and Practice*. Vol. 26, no. 6, pp. 17–31. http://doi.org/10.26794/2587-5671-2022-26-6-17-31
[68] CHIU, Y.-L.A., 2015. Towards sustainable enterprises: the impact factor of climate change for corporate responsibility and performance. *European Journal of Law and Economics*. Vol. 40, no. 2, pp. 341–365. http://doi.org/10.1007/s10657-012-9364-x

technologies are integrated into sustainability strategies, leading to fragmented regulatory approaches across jurisdictions.

Furthermore, while initiatives like the Sustainable Stock Exchanges (SSE) program and the International Organization of Securities Commissions (IOSCO) rules promote transparency and prevent greenwashing, their focus remains largely on traditional sustainability reporting rather than digital innovation. The Non Financial Reporting Directive in Indonesia, which mandates "digital tagging" of information, is a step in the right direction but is limited in scope and application.

4.3 Private Sector Initiatives and Frameworks

Private sector initiatives, such as the Green Digital Finance Alliance (GDFA) and the Network of Central Banks and Supervisors for Greening the Financial System (NGFS), play a crucial role in advancing GDF. However, their impact is limited by the absence of a unified global framework Private sector actors contribute to GDF by developing innovative financial products and technologies.[69] However, their efforts require regulatory support to ensure consistency and prevent greenwashing. Governments and civil society must work together to create an enabling environment that fosters private sector innovation while safeguarding sustainability goals.

Private sector innovation drives the development of green finance solutions, such as green bonds and sustainable investment platforms. These initiatives demonstrate the potential of market driven approaches to achieve sustainability goals.[70] Without regulatory support, private sector efforts risk being fragmented and inconsistent, the lack of standardized ESG reporting frameworks allows companies to engage in greenwashing, eroding trust in green finance.

4.4 Policy Direction

To address the challenges facing GDF, policymakers must prioritize conceptual clarity, data standardization, and regulatory harmonization.[71] Key actions include; (a) Developing a Unified Taxonomy, establishing clear definitions and standards for green

[69] SHI, J and LI, F, 2023. Aligning the BRI With Sustainable Development: A Regulatory Framework and Its Implementation. *Journal of World Trade*. Vol. 57, no. 6, pp. 933–956. http://doi.org/10.54648/trad2023039

[70] CHOWDHURY, M A A et al., 2023. Demystifying the Role of Stakeholder Pressure and Competitive Advantage on Environmental Performance of Readymade Garments Industries in Bangladesh. *Journal of Environmental Accounting and Management*. Vol. 11, no. 2, pp. 115–138. http://doi.org/10.5890/JEAM.2023.06.001

[71] KLIMAS, E, 2020. Sustainable development and urban planning regulations in the context of climate change management measures. *Entrepreneurship and Sustainability Issues*. Vol. 8, no. 1, pp. 24–37. http://doi.org/10.9770/jesi.2020.8.1(2)

finance to prevent greenwashing and ensure consistency; (b) Enhancing Data Transparency, creating international platforms for sharing high quality environmental data to support informed decision making; (c) Enhancing Data Transparency, creating international platforms for sharing high quality environmental data to support informed decision making. [72]

Achieving global consensus on GDF regulations is challenging due to differing national priorities and regulatory capacities. Developing countries may lack the resources to implement stringent ESG reporting requirements, creating disparities in global markets. A coordinated global approach is needed to unlock the full potential of GDF and ensure its alignment with the Sustainable Development Goals (SDGs). A coordinated global approach can unlock the full potential of GDF, enabling the financial sector to play a transformative role in achieving the SDGs.

Achieving global consensus is challenging due to differing national priorities and regulatory capacities. Developing countries may lack the resources to implement stringent ESG reporting requirements, creating disparities in global markets.

To address the lack of resources and regulatory challenges in developing countries within the framework of Green Digital Finance (GDF), a regulatory and legal approach can be implemented as follows; Policymakers should prioritize conceptual clarity, data standardization, and regulatory harmonization by developing a unified taxonomy with clear definitions and standards for green finance to prevent greenwashing and ensure consistency. Additionally, international platforms for sharing high-quality environmental data should be established to enhance transparency and support informed decision-making. To bridge the resource gap, capacity-building initiatives and technical assistance should be provided to developing countries, enabling them to adopt and implement ESG reporting requirements effectively. By fostering a coordinated global approach, the financial sector can play a transformative role in achieving the Sustainable Development Goals (SDGs), ensuring that no country is left behind in the transition to sustainable finance.

5. CONCLUSIONS

[72] CHOWDHURY, M A A et al., 2023. Demystifying the Role of Stakeholder Pressure and Competitive Advantage on Environmental Performance of Readymade Garments Industries in Bangladesh. *Journal of Environmental Accounting and Management*. Vol. 11, no. 2, pp. 115–138. http://doi.org/10.5890/JEAM.2023.06.001

Green Digital Finance (GDF) represents a transformative intersection of finance, technology, and environmental sustainability, offering significant potential to drive green investments, reduce environmental impact, and support the transition to a low carbon economy. However, the development and implementation of GDF face substantial challenges, particularly due to the lack of a unified regulatory framework and harmonized international standards. While digital technologies such as blockchain, artificial intelligence (AI), big data, and the Internet of Things (IoT) provide innovative solutions to enhance transparency, efficiency, and accessibility in green finance, their full potential remains untapped due to regulatory gaps, technological barriers, and inconsistent policy approaches.

The analysis highlights that digital finance and sustainable finance agendas are often managed separately, creating disconnect that limits the integration of digital innovation with sustainability goals. This gap is particularly evident in emerging economies like Indonesia, where regulatory inconsistencies and technological adoption challenges hinder the full realization of GDF's potential. Despite these challenges, Indonesia has made strides in green finance, such as the issuance of green sukuk bonds, but further efforts are needed to align national regulations with international standards and address local barriers.

Key challenges in GDF include the lack of a unified taxonomy for green finance, regulatory fragmentation, data privacy concerns, and the environmental impact of energy intensive technologies like blockchain. To address these issues, policymakers must prioritize conceptual clarity, data standardization, and regulatory harmonization. International collaboration among governments, private sector actors, and civil society is essential to develop a cohesive global framework that supports GDF while ensuring consumer protection, financial stability, and environmental sustainability.

The integration of digital technologies into GDF regulatory frameworks offers opportunities to enhance transparency, reduce transaction costs, and improve risk assessment. However, this requires robust policies to address challenges such as algorithmic bias, cybersecurity risks, and the digital divide. Additionally, the role of private sector initiatives, such as green bonds and sustainable investment platforms, must be supported by clear regulatory guidelines to prevent greenwashing and ensure accountability.

In conclusion, GDF has the potential to significantly contribute to achieving the Sustainable Development Goals (SDGs) by fostering a more inclusive, innovative, and

environmentally friendly financial system. However, realizing this potential requires a coordinated global approach that balances technological innovation with regulatory adaptation, ensuring that GDF aligns with sustainability principles and addresses the unique challenges of the digital era. For Indonesia, adaptive regulations, strict supervision, and collaboration among stakeholders are critical to building a robust GDF ecosystem that supports both economic growth and environmental sustainability. This study provides actionable insights for policymakers, regulators, and industry stakeholders to develop sustainable and adaptive regulations that can unlock the full potential of GDF while advancing global sustainability goals.

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