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EMERGING TECHNOLOGIES IN SUSTAINABLE FINANCE: AI AND DLT AS ENABLERS OF THE GREEN ECONOMY

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Abstract

This study aims to explore the role of emerging technologies in facilitating the global adoption of the sustainable finance agenda. It linked the carbon emission levels of several sectors and countries with technology-enabled sustainability practices to identify the individual contributions of technologies in the financing aspects. Despite challenges, an organisation's new performance benchmarks compel it to adapt technologies to several sectors, as technologies are seen as enablers of sustainability. A holistic study of the cautious applications of technologies is needed to assess their potential adverse effects and reap their benefits. Therefore, the study explores literature covering scholars' and practitioners' opinions and application experiences. Quantitative data on adaptation, emissions, and green product applications have been collected, tabulated, and analyzed to compare practices across sectors and countries. Findings indicate that technology applications are efficient enablers of sustainability. Also, there were differences in the utilization of green tech products, such as green bonds and climate tech, between sectors and countries. European countries have led the adaptation, while Asia has yet to adjust to the mismatch between emissions and green practices. A lack of a legal framework, standard reporting and measurement principles, and data security were leading causes of concern. The study will assist in careful future adaptation and policy formulation.

Keywords: Sustainable Finance, Green Economy, Blockchain, Artificial Intelligence, Machine Learning, Climate-tech, Carbon Emissions

1. Introduction

In 2015, the United Nations formulated the seventeen Sustainable Development Goals (SDGs) to end poverty, protect the planet, and tackle inequalities worldwide (United Nations, 2015). These 17 goals require sustainable development efforts worldwide to

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integrate social well-being, economic growth, and environmental protection. In line with this, the emergence of 'sustainable finance' can be traced to its intersection with the SDGs (Musleh Al-Sartawi et al., 2022). Strong links are proven between the sustainable finance model and social sustainability (SDG 1, 3, 4, 5, 10, 16), economic sustainability (SDG 8, 9, 17), and environmental sustainability (SDG 11, 12, 13, 15) (Ziolo et al., 2021).

The SDGs require funding for their implementation, which ensures a strong link between them and the sustainable finance model (Schoenmaker, 2017; Streimikiene et al., 2023). Global capital expenditures between USD 5 and 7 trillion are expected to be required annually to support these SDG-supporting projects (Lagoarde-Segot, 2020; Nedopil Wang et al., 2022).

In fact, the classical view of infinite economic growth has been proven undesirable at the cost of environmental degradation, assuming that development must be qualitative and long-lasting, which calls for sustainable finance (Streimikiene et al., 2023). According to Gu (2020), to maintain people's happiness and the earth's habitability, one needs to ensure that economic development is both sustainable and environmentally benign (Gu et al., 2020). It is proven that by employing the principles of sustainability, stability, and efficiency as their building blocks, an economic quality index can be built (Kong et al., 2021). Also, a three-tier index system to find the contributors to high-quality economic development confirmed ecological and social variables to be vital factors (T. Li et al., 2016).

This new economic development agenda prioritizing sustainable finance and environmental protections gives birth to the concept of the 'green economy'. It provides an alternative perspective to the present economic model that affects public health and the environment, exacerbates inequality, and increases waste (B. Li et al., 2023). The green economy promotes ecological preservation across all facets of economic development (Ilic & Mihajlovic, 2014). It is a progressive agenda, as it adopts a realistic and adaptable approach that may help achieve sustainable development in all aspects. Sustainable finance is just a side answer to these aspects (Ilic & Mihajlovic, 2014).

Sustainable finance is the integration of ESG (Environmental, Social, and Governance) criteria in business decisions for the longer-lasting benefits of individuals and society (WEF, 2020). However, there is a recommendation of having a broader exploration of the concept, not merely covering the ESG (McConnell, 2023; UBS, 2024). This study follows the proposition that '*sustainable finance should encompass all activities and factors that would make finance sustainable and contribute to sustainability*' (Kumar et al., 2022). This definition enables the incorporation of all technological adaptations that support sustainability.

Worldwide, financial institutions are utilising technologies such as Big Data, Distributed Ledger Technology (DLT), particularly Blockchain, Artificial Intelligence (AI), Machine Learning (ML), and the Internet of Things (IoT) as tools to integrate with Financial Technology (FinTech). This integration aims to improve sustainable financial

development on a global scale by uniting green finance with it (He et al., 2020). The specialists firmly believe that a sustainable business model can be developed by acknowledging the effects of ESG risks, ethical considerations of AI, and FinTech (Musleh Al-Sartawi et al., 2022). Riding on the tools of AI, Blockchain, and big data analytics, corporations are achieving enhanced efficiency, transparency, and automated corrections of processes without human intervention (Alijanova, 2020).

By allocating more funds towards intelligent and environmentally friendly technology, such as renewable energy, electric vehicles, energy-efficient buildings, and sustainable infrastructure, and divesting from carbon-intensive assets like fossil fuels, carbon emissions can be decreased (Anders Quitzau, 2021). In the opinion of the World Economic Forum (WEF), when technology meets sustainable finance, it enables better data analysis, empowers prudent investment decisions, and creates jobs in low-carbon economic sectors (WEF, 2020). Sustainable practice within firms that use sustainable technologies scores 4% higher in ESG metrics performance than those that do not adopt it (Arabesque, 2024).

However, the technological adaptation process is not simple. The software system is an integral part of firms' sustainability practices. The software itself does not produce any harmful discharge or consume energy, but it works on hardware that is responsible for carbon emissions in machines and devices with the uptick of software (Podder et al., 2020). Training an AI robot will produce carbon emissions to the extent of five cars' emissions in their lifetime (Hao, 2019).

Despite these challenges, an organization's new performance benchmarks compel it to adapt technologies to several sectors of the economy. A holistic study of the cautious applications of technologies is needed to assess their potential adverse effects and reap their benefits. Considering the above aspects, this study aims to explore the role of emerging technologies in facilitating the global adoption of the sustainable finance agenda. It links the carbon emission levels of several sectors and countries with technology-enabled sustainability practices to identify the individual contributions of technologies in the financing aspects. The study covered scholars' and practitioners' views on the technological contributions to sustainable finance. The following sections of the chapter have been segmented to provide an overview of sustainable finance, explore the contributions of technologies to sustainability practices, and examine the challenges that all applications face. This study will contribute to the existing body of knowledge by examining the role of the most prominent technological tools in achieving sustainable finance practices and promoting a green economy.

2. Sustainable Finance

Unlike traditional finance, sustainable finance broadens the emphasis from ‘economic’ to the new ‘economic, societal, and environmental’ dimension of finance (Schoenmaker, 2017). The most impactful definition of sustainable finance can be attributed to the European Commission's observation. It defines sustainable financing as the

consideration of environmental, social, and governance (ESG) at the time of investment into financial sectors (European Commission, 2021). In practical terms, the inclusion of ESG data into investment management can be called sustainable finance (Berg et al., 2020). A systematic review of the research works from 1986 to 2021 on sustainable finance shows seven vital themes: climate financing, carbon financing, impact investing, energy financing, green financing, socially responsible investing, and governance of sustainable financing and investing (Kumar et al., 2022).

Each theme of sustainable finance includes an agenda to reduce the adverse effects of the individual domain. For example, in climate financing, efforts were made to reduce environmental degradation. Carbon financing focuses on reducing carbon emissions from high-emission sectoral activities. Researchers concentrated on renewable and alternative energy sources in the energy financing domain. Social problems are targeted to be solved in socially responsible and impact financing, which will bring out impactful positive evidence to society (Kumar et al., 2022). In the governance domain, the timely detection of violations of stability tendencies is studied. By adopting technological transformations, the task has been achieved, and this simultaneously contributes to the improved corporate governance system of a firm (Alijanova, 2020). However, the theme that dominates most of the literature is green finance. Although sometimes used interchangeably with sustainable finance, green finance encompasses and overlaps many of the previously mentioned themes of sustainable financing.

The phrase ‘green finance’ refers to the provision of financial assistance to environmentally friendly initiatives (Akomea-Frimpong et al., 2021). To effectively implement these procedures, issues such as deforestation, carbon emissions, pollution from industrial and transportation sources, water sanitation, energy conservation, and using renewable energy must be addressed (Gu et al., 2020). To determine the degree to which policies successfully mobilize private capital, it was found that green financing can improve the performance of various businesses (D’Orazio & Popoyan, 2019). Additionally, Green finance has significantly increased environmentally conscious investment and consumption, which is closely associated with rising incomes (Jin & Han, 2018).

3. Technologies for Sustainable Financing

The holistic application of technologies into sustainability practice can be traced in Accenture's survey. Accenture, a global service company serving 40 industries in more than 120 countries with 699,000 employees, surveyed executives' motives for adopting sustainability practices. This survey, conducted by 300 researchers, over 560 companies from 20 countries, showed the output in Table 1:

Table 1: Technological Adaptations for Sustainability Practices

Target Criteria	Percentage of companies that use the following technologies				
	AI	Blockchain	Cloud	Data Analytics	IOT
Renewable Energy	62%	50%	58%	56%	44%
Waste Management	61%	49%	64%	57%	42%
Supply Chain	63%	53%	63%	57%	47%
Production and Operation	70%	47%	69%	51%	55%
Data Organization and Disclosure	75%	52%	75%	63%	61%
Building Customer Perception	60%	54%	62%	53%	53

Source: Data are extracted and tabulated by the authors (Daugherty P et al., 2022)

In Table 1, companies are increasingly adopting technologies for sustainability, especially in Production and Data Disclosure, where adoption rates are high. IoT is also prominent in Waste Management and Supply Chain, while Renewable Energy adoption is relatively lower at 44%. This survey also found that applying digital twin technology to track plastic uses and adopting blockchain to trace real-time ECG data ensures sustainability practices in firms. Firms depend on machine-learning-enabled ESG data sets like Arabesque S-Ray's in data organization and disclosure. These metrics guide CEOs to identify challenging sustainable areas like circular business models, decarbonization, human rights, and workforce transformations (Daugherty P et al., 2022).

Choosing Germany as a test case for identifying fintech solutions to sustainability showed that fintech startups are the main contributors to sustainable solutions rather than commercial banks. These startups mainly depend on cloud financing to invest in renewable energy and energy savings. Among Germany's 36 fintech firms, 30% concentrate on AI-based robo advisors to relocate capital to sustainable assets. Also, DLT has been a common enabler in carbon accounting, e-mobility, smart grid, and tokenized energy investments. Besides, Paytech and mobile banking contribute to sustainable impact donations in Germany (Alliance, 2020). The individual applications of technologies are discussed in the following sections.

3.1 DLT for Sustainable Financing

DLT is a decentralized network of ledger entries that share immutable data with vast stakeholders (Haynes & Yeoh, 2020). DLT systems, especially blockchain, have revolutionized data storage and allow parties with a history of mutual distrust to conduct transactions directly with each other while ensuring the visibility and integrity of the stored data (Conti et al., 2018). Blockchain is defined as a system that enables trustworthy, transparent, reliable, fast, and effective automated peer-to-peer transactions (Mihaylov et al., 2018). It functions similarly to a conventional public ledger and is composed of interconnected blocks that, when added together, include an exhaustive record of all transactions. A "blockchain" is a methodological name for how it

is organized, a series of interconnected blocks. A record of transactions can be stored in a data structure called a block (Zia & Ali, 2019).

The blockchain market positively affects green financing within firms, and green finance is the central orchestrator of the carbon neutrality agenda. So, blockchain has a positive effect on sustainability practices (Qin et al., 2023). Blockchain directly contributes to climate management, smart energy management, the development of sustainable products, reduced production costs, and improved waste management (Calandra et al., 2023; Sultana & Alam, 2024). Blockchain technology can significantly improve the efficiency, accountability, and openness of financial transactions, making it an ideal tool for environmentally sustainable project fundraising (Hui & Loang, 2023).

Blockchain's distributed ledger, smart contracts, and inherent transparency might improve data sharing, automate compliance checks to reduce risks, and increase participation from micro and small firms in green financing (Zhuang, 2023). It is crucial in enhancing the efficiency and transparency of green finance systems, such as green bonds and sustainability-linked credit. Green finance solutions, such as green bonds, green development funds, and green insurance, are crucial in providing financial support for promoting sustainability (Kaur & Aadheesh, 2023). It is evident that climate technology, accessibility of financial institutions, and the utilization of green bonds effectively decrease carbon emissions (Q. Li et al., 2022). From 2008 onwards, the World Bank has issued almost USD 19 billion worth of Green Bonds to support projects aimed at reducing climate vulnerability (World Bank, 2024).

Green bonds, instruments designed to raise capital for environmentally friendly initiatives, must have their spending habits thoroughly tracked to guarantee they are being used for their intended purpose. Here, efficiency is achieved by providing unchangeable, transparent, and secure transaction records that promotes confidence among various parties (Zhao, 2022). It also tackles long-standing obstacles green finance encounters, such as a lack of clarity and expensive transactions (Ezekiel Onyekachukwu Udeh et al., 2024).

In 2024, Standard & Poor's (S&P) published its outlook for the green, social, sustainability, and sustainability-linked bond (GSSSB) markets. Social bonds are used as a financing tool to raise funds that aim to address a specific social issue or achieve a social outcome, such as education or food security. On the other hand, the sustainability bond serves both social and environmental causes. The sustainability-linked bond does not fall into the green category, but supports its environmental transition (Cochelin et al., 2024). In Table 2, we can see the percentage growth of the issuance of GSSSB bonds from 2019 to 2023. With its overwhelming increase in 2021 and 2020, we can see a sharp drop in the issuance, which increased again in 2023. The already issued tremendous value of bonds requires the efficient practice of credit management, which could be facilitated by the adaptation of blockchain to the entire system.

Table 2: GSSSB Issuance Volume and Growth from 2019 to 2023

Types of GSSSB	Issuance of each type of GSSSB bond in billion-dollar				
	2019	2020	2021	2022	2023
Green bond	265	308 (16.23%)	570 (85%)	523 (-9%)	575 (9.94%)
Social bond	19	170 (794%)	221 (30%)	175 (-20%)	181 (3.43%)
Sustainability bond	53	137 (2%)	200 (46%)	151 (-24%)	159 (5.30%)
Sustainability-linked and Transition bond	5	12 (1.4%)	101 (741%)	81(-20%)	69 (-15%)

Source: Data were extracted and tabulated, and the authors calculated percentage growths (Cochelin et al., 2024).

In Table 3, the carbon emissions data for each region are represented in millions of metric tons of carbon dioxide (CO_2). GSSSB data is presented as the proportion of issuance worldwide. The difference between carbon emissions and GSSSB issuance percentages is presented in the table and is denoted as D*. We found that the issuance of GSSSB bonds in Asia, which is the number one regional economy in the world (Worldometer, 2024), was the minimum, representing the highest difference in D* (28%) in 2022. In contrast, North America and Europe are the frontrunners in issuing GSSSB compared to their emission contributions.

Table 3: A Comparative Picture of Carbon Emissions and GSSSB Issuance in Different Regions from 2019 to 2022

	2019			**2020**			**2021**			**2022**		
Region	CO_2	GSSSB	D*	CO_2	GSSSB	D*	CO_2	GSSSB	D*	CO_2	GSSSB	D*
Middle East and Africa	10% (3411)	1%	9%	10% (3264)	1%	9%	10% (3407)	1%	9%	10% (3507)	1%	9%
Latin America	4% (1244)	2%	2%	7% (1109)	3%	4%	4% (1248)	5%	-1%	4% (1258)	4%	0%
Asia/Pacific	50% (17199)	21%	29%	51% (16924)	12%	39%	52% (17682)	18%	34%	52% (17955)	24%	28%
Europe	12% (4078)	45%	-33%	10% (3621)	41%	-31%	11% (3845)	45%	-34%	11% (3770)	44%	-33%
North America	18% (6020)	22%	-4%	16% (5381)	16%	0%	17% (5728)	16%	1%	17% (5851)	15%	2%
Commonwealth Independent States	6% (2092)	-	-	6% (1986)	-	-	6% (2142)	-	-	6% (2033)	-	-
Supranational	-	9%	-	-	27%	-	-	15%	-	-	12%	-
Total	100% (34044)	100%	-	100% (32285)	100 %	-	100% (34052)	100%	-	100% (34374)	100%	-

Source: CO_2 data (Statista, 2024) and GSSB data (Cochelin et al., 2024) are extracted, tabulated, and differences are calculated by the authors.

The success of Europe in issuing GSSSB depends significantly on the adoption of blockchain technology. It is evident that the European Union (EU) market uses blockchain technology as a decentralized, tamper-proof platform that ensures green

growth instead of creating greenwashing (Christodoulou et al., 2023). Greenwashing is the misrepresentation of data about environmentally friendly projects (Katten, 2021). To combat greenwashing, blockchain technology might verify that funds are going to projects with a genuine commitment to sustainability, cutting down on the possibility of misleading advertising. This inclusion of blockchain boosts the legitimacy of green finance instruments by drawing in more investors who care about ESG issues (Malamas et al., 2023; Zhuang, 2023). There is also evidence that the adoption of blockchain into green bonds reduces association costs, allowing the issuer to publish impact reports to all stakeholders that help the verifier to grant ratings (Darwish et al., 2023; Katten, 2021). However, it was also of the opinion that different countries must customize their practices of blockchain in green bond management, considering different socio-economic aspects (Misra et al., 2023).

3.2 AI for Sustainable Financing

Artificial intelligence (AI) was first introduced at the Dartmouth Conference in 1956, marking the beginning of AI research, which states that creating smart machines, especially computer programs, is the heart of AI (Moor, 2006). Presently, two main categorizations of AI exist: Narrow Artificial intelligence (NAI) and Artificial General Intelligence (AGI). AI has three primary advantages. Firstly, AI enables automating essential but onerous and frequently performed tasks, freeing human beings to concentrate on more valuable activities. The second advantage is that artificial intelligence helps discover patterns in enormous amounts of unstructured data, which would have been impossible for humans to manage and analyze without this technology. Lastly, the third advantage of artificial intelligence is that it may syndicate the resources of hundreds of computers to confront problematic issues (Makridakis, 2017).

AI is a recognized powerful tool that can significantly contribute to achieving global sustainability objectives. The main reason for its extensive use is its ability to gather and scrutinize vast amounts of data related to the environment. The application of artificial intelligence to issues about sustainability is continually evolving. AI can optimize processes, perform predictive analytics, and achieve economies of scale. These tasks are complex and require large-scale efforts (Munoz, 2017). The incorporation of AI into green finance can transform the process of evaluating risk and making investment decisions (Hui & Loang, 2023).

A practical application of AI in sustainability survey was conducted in February 2024, which is highlighted in Table 4. In this survey, the tech-leader Intel Corporation has surveyed 2000 C-suite leaders of 11 sectors in 22 countries to search for organizational efforts to apply AI to carbon reduction goals. The survey samples are divided into three categories: Visionaries (G1), who have efficient plans and structures to introduce sustainability-related AI; Advancers (G2), who are making headway to apply AI tools to sustainability solutions; and the Followers (G3), who are falling behind in the entire system. For AI to drive sustainability, three key tech trilemmas (Knowledge, Investment, and Innovation) have been explored. The expectations of the adaptation are greater

energy efficiency, improved carbon footprint tracking, optimized resource allocation, optimized supply chain management, and improved renewable energy integration (Intel, 2024).

Table 4: Sustainable Intelligent Index 2024

Key Sectors	Percentage of Firms that Fall under Each Category								
	Knowledge Knowledge of AI, Training, and Scope to reduce the carbon footprint			**Investment** Investment in AI and Use Cases			**Innovation** Patents of AI tools and Solutions		
	G1	G2	G3	G1	G2	G3	G1	G2	G3
Financial services	53%	42%	5%	23%*	61%	16%	31%	59%	9%*
Government & public sector	27%	62%*	11%	9%*	65%	26%	16%*	69%*	15%
Healthcare & life sciences	29%	61%	10%	19%	62%	20%	24%	60%	16%
Manufacturing	44%	50%	6%	19%	61%	20%	27%	59%	14%
Professional services	24%	69%	8%	11%	61%	28%	20%	65%	15%
Retail	8%*	60%	32%*	10%	67%	23%	21%	65%	14%
Technology, media & telecommunications (TMT)	62%*	34%*	3%*	20%	69%*	11%*	34%*	58%*	9%*
Transportation & Automotive	38%	53%	9%	23%*	61%	16%	19%	67%	14%
Travel & Hospitality	39%	55%	6%	18%	61%	21%	20%	70%	10%
Education	27%	60%	12%	10%	57%*	33%*	17%	63%	20%*
Engineering, energy, & Infrastructure	44%	51%	5%	19%	61%	20%	21%	70%	9%*

Source: Data are extracted and tabulated by the authors (Intel, 2024)

Table 4 shows that advancers dominate each tech dimension, indicating firms' ongoing efforts to adopt AI that creates sustainability. The table symbolizes (*) the highest and lowest contributors, and it finds that Technology, media, and telecommunications are the sectors where most advancement happens. The high values of the G3 group in the education domain indicate a low level of AI-enabled sustainability investment and innovation in educational sectors, whereas the retail sector must build knowledge of sustainability practices. However, compatible results were found in all three tech trilemmas that ensure that knowledge, investment, and innovation are on the agenda of market players.

It is expected that, riding on the power of new startups, the existing business players are scaling new approaches and technologies to transform sectors into a zero-carbon economy (Herweijer et al., 2020). In line with this, the average global warming has been set to 1.5^{o}c by 2040, above which there is the prediction of having a dangerous impact on human beings (IPCC, 2018). Market players believe that applying AI to some crucial sectors of the economy can reduce carbon emissions by 2.4 gigatons in 2030, which is 4.4 to 8.0% of the total emissions (Joppa et al., 2019). Also, a responsible target

accuracy of AI use by ensuring a trade-off between efficiency and accuracy of AI models could reduce carbon emissions by 80% (Daugherty P et al., 2022).

Clean Technology, also called clean tech, is the technology-related entrepreneurial initiatives that reduce adverse environmental effects (Eilperin, 2012). With its extension, the new term climate-tech encompasses sectors that serve the cause of decarbonization and net-zero emissions by 2050 (Herweijer et al., 2020). In Table 5, the state of climate tech over the last four years is tabulated. Most of the technologies adopted in these were AI-driven.

Table 5: State of Climate-tech over Four Years

a) Criteria	**2020**	**2021**	**2022**	**2023**
Climate-tech Investment Growth	7.22%	8.41%	9.16%	10.02%
Cumulative number of climate-tech startups	1200+	3000+	4000+	8000+
Number of climate-tech deals	4188	4918	4491	2216
Cumulative number of investors in climate-tech	15,410	19,358	23,133	25,244
b) Challenging sectors with a percentage of emissions based on 2019 data	**Sector-wise climate-tech financing**			
	2020	**2021**	**2022**	**2023**
Energy (12%)	8.2%	9.36%	27%	29%
Mobility and transport (15%)	63%	66.22%	48%	45%
Food-Agriculture-Land (22%)	13.6%	9.36%	12%	8%
Heavy Industries (34%)	6.4%	7.30%	9%	14%
Built environment (17%)	6.2%	1.59%	4%	5%
Others	2.6%	2.72%	-	-
c) Region-wise Climate-Tech Investments	**2020**	**2021**	**2022**	**2023 (Until Q3)**
North America	26.64B	69.19B	39.83B	18.26B
Europe	11.12B	25.81B	21.3B	11.75B
China	18.43B	19.98B	22.53B	7.24B
Asia Pacific	4.12B	6.68B	6.88B	7.09B

Source: Data are extracted and tabulated by the authors (Cox et al., 2022, 2023; Herweijer et al., 2020; Johnson & Cox, 2021)

In Table 5, section b, climate-tech financing is lower in the food and agriculture, heavy industries, and building environment sectors compared to their respective emission percentages. Besides, in section c, we can see that between 2020 and 2021, there was a significant change in climate change investment. Developed economies, such as those in North America and Europe, reduce their investments, while developing economies, including China and those in the Asia Pacific, increase their investments. Therefore, the untapped capacity of Asia and China can be further explored. This finding is in line with the recommendation that developing countries are in a better position to identify and utilize technologies in the field of green finance (Kaur & Aadheesh, 2023). Although climate change affects every individual, developing countries are expected to be disproportionately impacted by it. The possible impacts on temperatures, patterns of rainfall, sea levels, and weather-related disasters in developing countries pose hazards for agricultural, food, and water sources (WorldBank, 2024). This survey also indicated

that the cost curve has decreased with the adoption of AI, blockchain, cloud, and advanced sensors (Herweijer et al., 2020).

4. Key Insights and Current Challenges

Exploring literature on technology for sustainability and the growing challenges in technological adaptation found several key findings and challenges, which are listed below:

- Blockchain technology's decentralized, unchangeable, transparent, and better visible recording nature ensures efficiency, accountability, and transparency within a system that is beneficial for several sustainable practices, including supply chain management, sustainable investment, sustainability project fundraising, and sustainability-linked credit management. The management of GSSSB bonds, which are the prominent growing products of sustainable financing, should explore these pressing advantages.

- In GSSSB issuance, Asia should exploit the benefits of adopting technology, as its circulation volumes of GSSSB are still lower than those of North America and Europe in terms of carbon emissions. In this regard, technologies, especially blockchain, could combat greenwashing, reduce financing and associated costs, and trace genuine commitments to sustainability efforts. However, Blockchain still faces a lack of guidelines and laws regarding disputes that arise (Hui & Loang, 2023; Nassiry, 2019).

- Organizational efforts to apply AI to sustainability goals showed greater energy efficiency, improved carbon footprint tracking, optimized resource allocation and supply chain management, and enhanced renewable and energy integration. It also performs predictive analytics and achieves economies of scale. However, ethical considerations, trust, and acceptance from individuals and communities are essential for AI adoption, considering data privacy, algorithmic bias, and societal perceptions of automation (Watson et al., 2012).

- ML has been extensively used in AI solutions for sustainability, using historical data to make future predictions (Belkin et al., 2019). Additionally, ML-enabled ESG data sets help CEOs identify sustainable areas, such as circular business models, decarbonization, human rights, and workforce transformations. However, if this reliance is biased, inadequate, or incomplete, the recommendations can lead to incorrect predictions and neglect of sustainability efforts (Watson et al., 2012).

- Digital twin technology and blockchain are being used to track plastic usage and real-time ECG data, ensuring sustainability practices. The overall technology and blockchain adaptation contribute to circular economy management, climate

management, smart energy management, sustainable products, and waste management (Daugherty P et al., 2022).

- Firms in the technology, media, and telecommunications sectors dominate the adoption of AI for sustainability efforts. However, there is a low level of AI-enabled sustainability investment and innovation in education, as the retail industry needs to build knowledge of sustainability practices (Intel, 2024).

- Between 2020 and 2021, climate change investment in developed countries like North America and Europe decreased, while developing economies like China and the Asia Pacific increased (Cox et al., 2022, 2023; Herweijer et al., 2020; Johnson & Cox, 2021). This suggests that developing countries are better positioned to identify and utilize green finance technologies. In this regard, the adoption of AI, blockchain, cloud, and advanced sensors has decreased the cost curve and assisted in risk evaluation and investment decisions, making it more critical to explore untapped capacity in green finance.

- Blended financing, combining public and private financial systems, is crucial for sustainable financing, contributing to SDGs and technological adaptation in these areas (Nedopil Wang et al., 2022; Streimikiene et al., 2023). The private sector is already in a better position in the ICT sector, where the government can provide better policy support for long-term financial system solutions (Alijanova, 2020).

- Socially sustainable goals must encompass environmentally sustainable objectives and utilize legal frameworks, with specific sustainable goals linked to finance dimensions (Streimikiene et al., 2023). A precise selection of industries for financing and investment in SDG attainment is essential, and unique monitoring indicators and reporting standards are needed (Nedopil Wang et al., 2022; Streimikiene et al., 2023).

- The development of all technological systems requires substantial computational resources and investment, which can increase energy consumption and carbon emissions and affect an economy's sustainability goals. It also creates enormous amounts of electronic waste. Besides, AI still leads to concerns about job losses and economic displacement (Kern et al., 2018; United Nations, 2024).

- Due to their vast amount of data, AI systems are vulnerable to cyberattacks, making data security crucial for maintaining their integrity. Malicious actors can manipulate AI models, leading to incorrect predictions and potential harm (Watson et al., 2012).

- Finally, unevenly distributed technological innovation from 1980 to 2024 by the top 10 countries primarily contributes to technological innovation and is expected to

continue because of patent rights, which is creating a centralised growth (United Nations, 2024).

5. Conclusion

Technologies and sustainable finance are two of the most talked-about agendas worldwide. It is a fact that the ongoing fourth industrial revolution creates a path to adopt long-lasting, sustainable development with efficient utilization of technologies. Blockchain and AI technologies have the most potential to ensure suitable financing practices. Among various sustainable financing themes, green finance has been taken for its vast application of evidence. Blockchain was an efficient tool for credit management tasks for green bonds and other potential areas. AI has proven its strong footing in optimising processes, performing predictive analytics, and achieving economies of scale. Besides, Europe has proven to be a frontrunner in practising the green agenda, whereas Asia has shown substantial untapped potential in adopting green finance practices.

Future studies could explore how these technologies can be tailored to meet the specific needs of diverse markets, particularly in developing economies where there is evidence of untapped capacity. Another critical area for further research is the regulatory landscape surrounding the use of these technologies in sustainable finance. Future research could also focus on developing frameworks that balance innovation with security, privacy, and ethical considerations. Lastly, further studies could investigate how AI and DLT technologies can be integrated into more extensive systemic approaches to sustainability and how they can be leveraged to achieve measurable reductions in environmental impact over time.

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