CAPITAL UNIVERSITY OF SCIENCE AND TECHNOLOGY, ISLAMABAD

The Impact of Financial Inclusion, Green Technology and Digitalization on Environmental Sustainability: Moderating Role of Green Finance on Financial Inclusion, Green Technology and Digitalization

by

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This research thesis is wholeheartedly dedicated to my parents whose support and continued encouragement have been my strength and source of inspiration in all of my endeavors.

CERTIFICATE OF APPROVAL

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Abstract

In the context of Sustainable Development Goals, this study explores the impact of financial inclusion, green technology and digitalization on environmental sustainability. The study identifies the moderating role of green finance on financial inclusion, green technology and digitalization. The study uses panel data in a large range from 2014-2023, for 58 developing countries. The econometric technique Generalized Method of Moments (GMM) is used for analysis of the data. The result confirms the positive impact of financial inclusion, green technology and digitalization on environmental sustainability. Financial inclusion has a major beneficial direct influence on environmental sustainability, emphasizing its role in promoting more environmentally friendly outcomes. It has been discovered that digitization and green technology both also have a major detrimental direct impact on environmental sustainability. This result raises the possibility of issues such as e-waste, rebound effects from green technology, or energy consumption from digital infrastructure, which calls for a critical examination of their environmental footprints. The result shows that green finance directly contributes to environmental sustainability in a favorable way, it also has a significant negative moderating influence on the link between environmental sustainability and financial inclusion, environmental sustainability and green technology and environmental sustainability and digitalization. The study is limited to macro-economic perspectives while ignoring the micro-level factors that may have different influence on different countries. The paper holds significance for policymakers and opens new avenues for future researchers by exploring the complex dynamic relationship of these variables. This paper is a novel contribution to finance literature by exploring the impact of financial inclusion, green technology and digitalization on environmental sustainability. and using green finance as moderator in this framework.

Keywords: Green Finance, Green Technology, Digitalization, Environmental Sustainability, Financial Inclusion, FDI

Contents

List of Figures

List of Tables

Abbreviations

DIG	Digitalization
ES	Environmental Sustainability
FDI	Foreign Direct Investment
FI	Financial Inclusion
GF	Green Finance
GT	Green Technology
IPCC	Intergovernmental Panel on Climate Change
IR	Inflation Rate
MDGs	Millennium Development Goals
SDGs	Sustainable Development Goals
UNCDF	United Nations Capital Development Fund
WIPO	World Intellectual Property Organization

Chapter 1

Introduction

1.1 Background of the Study

The United Nations (UN) has actively worked to address the issues facing the global environment. The Sustainable Development Goals (SDGs) provide a cohesive framework for sustainable development, with climate action, sustainable management of land and sea ecosystems, and sustainable resource management as vital components. Also, the UN Framework Convention on Climate Change (UNFCCC) COPs (Conference of Parties) serve as global forums for collaboration on climate change adaptation and mitigation efforts. Baku's COP29 focused on climate justice, accelerating climate action, innovation, technology, and improving climate change impact resilience. Pollution is dealt with immediately loss of biodiversity. They contain and capture the interrelation of these problems along with the need for international collaboration (H. Lee et al., 2023).

Heightened environmental issues, such as pollution, loss of biodiversity, and climate change, have sparked international initiatives for sustainable development in the 21st century. As a result, the concept of environmental sustainability (ES) gained prominence in both scholarly and policymaking circles. To ensure the planet can support life and human health in the long term, ES is defending the ecosystems and resources of the natural world while minimizing anthropogenic pressures (Purvis, Mao, & Robinson, 2019).

The problem of emissions threatens the existence of life on earth. The increasing number of emissions is causing global warming which has many adverse impacts on the ecosystem and also on humans (Calvin et al., 2023). With the increase in temperatures extreme weather conditions such as heatwaves, droughts and floods are happening more often and with increased intensity (Calvin et al., 2023). Ocean acidification is already impacting the survival and growth of marine species, and that could have consequences for fisheries and coastal communities (Hoegh-Guldberg et al., 2018).

The maintenance of ecological equilibrium and the ability of nature to support human well-being are two dimensions of the multifaceted concept of. It involves maintaining natural resources, maintaining ecosystem integrity, and mitigating the negative effects of human action on nature (Millennium Ecosystem Assessment (MEA), 2005). The long-term health of the planet and well-being of current and future generations are threatened by increasing anthropogenic pressures such as pollution, deforestation, and unsustainable consumption patterns, rendering the quest for ES urgent (Steffen et al., 2015). Technological advancements and digitalization (DIG) pose ES with both opportunities and challenges. Yet through enhanced efficiency and oversight, digital technology can enable sustainable practices (Acemoglu & Restrepo, 2018), yet in doing so, they also lead to greater energy consumption and electronic waste which can further complicate environmental issues (Bivens & Mishel, 2021). Hence understanding the nexus between DIG, technology development and environmental impacts is essential to formulate effective sustainable development strategies.

The access and utilization of formal financial services by all segments of society is referred to as financial inclusion (FI) and it is increasingly being recognized as a major driver of social and economic progress. FI can empower individuals and businesses facilitate economic growth and reduce poverty by providing them with access to savings, credit, payments, and insurance. For instance, a study from Sub-Saharan Africa indicates that FI exerts a strong positive impact on economic growth and highlights its importance in developing countries (Ifediora et al., 2022). It is important to know the broader implications of FI since the focus on these equitable and sustainable developments increases globally.

Academic interest in the interconnection among ES and FI is increasing. At the individual household and firm level greater provision of financial services can provide the finance needed to invest in sustainable practices and environmentally friendly technology. Additionally, e-financial inclusion coupled with new ideas and green finance (GF) initiatives could stabilize national banking systems and support environmentally conscious development in low-financially developed countries (Vuong, Barky, & Nguyen, 2025). It is necessary to study these relationships for the purposes of establishing the best option for an economically and environmentally inclusive future.

To improve the effectiveness and reach of FI in poor communities, DIG is needed. Studies on Indonesian Islamic boarding schools have shown that the digital economy and even digital FI are likely to interact in immature profound ways to impact socioeconomic transformation (Qizam, Berakon, & Ali, 2025). Furthermore, the impact of FI on ES is situated impact dependent and in emerging economies is heavily conditioned by trade openness and corruption control

As a response to the escalating worldwide concern regarding the environment, green technology (GT), that encompasses a broad array of products and practices designed to reduce environmental harm and promote ecological sustainability, has emerged. These technologies extend from pollution prevention, sustainable agriculture, energy efficiency, and ideally onto renewable energy. The approach that allows nations to achieve economic progress without causing environmental harm and provide a foundation for future economic growth is strongly believed to depend on the widespread adoption and application of GT (Canton, 2021).

FI along with the increasing trend of digitization are prime examples of supporting economic and technological factors that relate to the diffusion and impact of GT. Through FI, people and businesses can be provided with the necessary finances to invest in and implement green technologies. Simultaneously, DIG provides powerful instruments for optimizing resource consumption well as for monitoring the environment and implementing smart and sustainable systems across different fields of activities (Jin, Li, & Lei, 2024). Moreover, the trajectory of technical innovation in this area can be greatly shaped by the impact of intellectual property rights, namely patents, as discussed in (Hall & Ziedonis, 2022).

By considering the linked impacts of digitization and GT on ES this research hopes to contribute to the growing body of knowledge. Its particular focus is to analyze the manner in which these significant factors influence environmental outcomes while considering synergistic effects. Just as Lemley and Sampat (2023) underscore in artificial intelligence the enforcement and protection of patents on green technologies can similarly be to greater acceptance and environmental quality effects.

This study attempts to provide empirical evidence on the complex relationships between these key elements and their effects on ES using a tight analytical framework. Policymakers and actors interested in designing strategies that leverage DIG, FI and GT perhaps mitigated by GF to achieve a more economically and environmentally sustainable development path are expected to learn much from the research findings. In addition, in this regard GT development-oriented policies perhaps via patent protection regimes as explored by Chen, Huang, and Li (2024) are worth serious consideration.

Our planet is transforming rapidly because of DIG that is the groundbreaking embedding of digital technology within various aspects of life and the economy. This is both an opportunity and a challenge for ES. Production patterns, consumption patterns and governance systems are shifting because of our increasing dependence on digital infrastructure, data analysis and networked devices. While this digital revolution offers new prospects for resource efficiency, environmental surveillance, and the design of smart, sustainable solutions, its net impacts must be appraised with caution (Zaman, Vilkas, Zaman, & Jamil, 2025). With the way digital technologies are evolving and impacting a lot of industries it is necessary to thoroughly review how they enable or disable ES.

In pursuit of ES, it is increasingly evident how digitization and other key drivers such as FI and GT collaborate. Through greater access to financial services on digital platforms, digital financial inclusion can channel money into green investments and promote ecologically responsible behavior. In addition, the use of smart grids, precision agriculture, and advanced environmental monitoring systems is facilitated by DIG, which is one of the main enablers of most green technologies (Owusu & Acheampong, 2025).

However, digitization does not necessarily have a positive impact on the environment. The growth in demand for digital equipment, data center power consumption, and the growing problem of e-waste present serious ecological concerns, although it can lead to some areas of efficiency. Based on recent reports, DIG is associated with more comprehensive green transitions, and it contributes to supporting ES in key economies along with energy efficiency and green financing (Shen, Ridwan, Raimi, & Al-Faryan, 2025).

The objective of this research is to contribute towards a deeper understanding of the manner in which digitization and GT drive ES. It also examines if certain financial instruments for digital and green initiatives with environmental dividends could enhance their beneficial impacts and the moderating effect of GF for these complex relationships (Ijaz, Naz, & Sadiq, 2025).

GF has emerged as a powerful tool for ES. A range of ever more urgent environmental concerns have been brought sharply into focus following the relentless rush. The international community needs to actively seek out sustainable development pathways in the face of impending challenges from climate, change, loss of biodiversity, and rampant, pollution. The concept of ES has taken root amid such concerns attracting both researchers and policymakers.

ES is all about defending the natural environment of Earth keeping its intricately linked ecosystems intact and ensuring the supply of its vital resources. It is for the planet's ability to support all life including human health now and, in the generations, to come and it demands mitigation of the adverse impacts of human actions (Purvis et al., 2019).

The threat level is escalating, emissions are coming in at unprecedented levels, precisely for global warming purposes. As stated by Calvin et al. (2023), the phenomenon has dire consequences for the ecosystem and the society as a whole. Continuous rise in temperatures is causing degradation of environment which is reulting in frequent phenomena such as drought, heat waves, and floods (Calvin et al., 2023).

Sustaining human well-being as well as the ecological balance can be described as ES. It refers to conservation of natural resources, ecosystem integrity, mitigating hazardous human activities, and reduction and their impact on the environment (Millennium Ecosystem Assessment (MEA), 2005). Anthropogenic causes of pollution, deforestation, and over consumption contributions in the decline of eco system services are the leading concern for alienating contemporary society from nature (Steffen et al., 2015). All technological advancements as well as DIG pose both obstacles and opportunities for the ES.

As Acemoglu and Restrepo (2018) note, digital technologies have the potential to encourage sustainable habits by enhancing efficiency and surveillance. They can however rise energy demand and electronic waste which has the potential to enhance environmental challenges (Bivens & Mishel, 2021). To create effective sustainable development plans thus an understanding of how DIG, technology innovation, and ecological effects interact is imperative.

Achieving this high goal necessitates an approach that utilizes various strategies and innovative solutions. Focusing on the moderating effect of GF this study tries to explore the interlinked functions of DIG, GT and FI towards achieving ES. To address these problems GF which seeks to encourage investment that is ecologically sustainable is increasingly becoming relevant. (Kates, Parris, & Leiserowitz, 2016).

The creation of green financial products is a component of GF. As a prominent example Flammer (2021) defines green bonds as "fixed-income instruments where proceeds are earmarked exclusively for projects with environmental benefits." The function of financial institutions is another.

Wang and Zhou (2020), banks may encourage green growth by declining to fund ecologically damaging projects in addition to offering green loans.Policies and legislation are also important. Cui et al. (2021) highlight that "government intervention plays a vital role in the development of GF." Being part of this involves coming up with clear definitions, standards and incentives.

In the context of ES, this research aims to lead in analyzing the connections between DIG, GT, FI, and green financing. This study seeks to develop understanding of the intricate systems in relation to sustainable activity and innovative solutions by looking at how these components may work together. FI role in encouraging individual and community motivation toward sustainable actions, the potential of GT to drive green innovation, the role of DIG in promoting sustainable actions and evidence-based decision making, and the capacity of GF to finance sustainable programs will be the main focus. From this analysis, the study will build actionable knowledge to support sustainable business and policy frameworks while identifying strategies to expedite achieving a sustainable future.

1.2 Research Gap

For the world to work in unison and promote ES, particularly for climate-vulnerable nations, collaborative efforts are crucial. This was further reiterated at COP 29. Considering Zhang (2024), it is necessary to evaluate green financing schemes to mobilize resources for sustainable development.

Although green financing is considered to be helpful in promoting eco-friendly projects, there is a knowledge gap pertaining to its effectiveness that needs to be bridged. Especially, the role of digitization and FI in promoting green innovation and business environmental performance is gaining attention (Mo, Chen, Wan, Liang, & Ma, 2025; Rehman et al., 2024). It is unclear how much collective impact these variables exert and the influence of green financing on that collective impact. Due to this research gap, addressing the impact of green financing on the relationships between DIG, ES, GT, and FI becomes crucial. To address this knowledge gap, this research will analyze the relationships among these variables and provide a comprehensive insight into how green financing can effectively promote ES (Banori, 2025).

1.3 Problem Statement

The soaring climate crisis and global environmental deterioration have increasingly required actionable strategies to promote ES. In this context, FI, GT, and DIG are acknowledged as impactful agents with considerable ability to foster sustainable development. At the same time GF has now also become one of the key financing instruments that has emerged to mobilize funds and encourage eco-friendly behaviors.

While much attention is being paid to these drivers in isolation, there is still a considerable gap in the literature regarding the specific question of how GF moderates the relationships between FI, GT, DIG and environmental outcomes. Such absence of scholarship is intriguing considering the several factors that intertwine to drive ES.

This study seeks to fill this gap by analyzing the direct impacts of FI, GT, and DIG on ES while paying particular attention to the moderating impact of GF on the relationships of FI, GT, and DIG. This paper remains relevant and as an answer to the information gap, especially for the policymakers, where FI and proper technological advancement can aid in achieving global environmental targets.

1.4 Theoretical Background

1.4.1 Stakeholder Theory

A particularly useful lens through which one may analyze the relationships between FI, technology innovations, and ES is stakeholder theory, which has been credited to R. Edward Freeman (Freeman, 2010). In the light of this theory, stakeholders which include shareholders, members of the community, government institutions, and the ecosystem itself needs to be taken into account for an organization's viability. This perspective appreciates that a wide range of stakeholders are affected by FI results, patents, and the processes of digitization, and hence need to be incorporated in the strategy aimed at achieving ES.

The use of the theory to address the research problem shows the intertwining relations of ES, digitization, patents, and FI. Technology FI and innovation can lead to the development of the economy, but there is also a possibility of creating risks to the environment. GF plays a moderating role by encouraging eco-friendly actions and reducing negative environmental externalities; thus, influencing the actions of financial institutions and other stakeholders. It recognizes the attempts being made to achieve the balance between economic growth and enhanced ecological wellbeing. Some recent studies emphasize the importance of stakeholder theory in the context of sustainable development.

As an example, scholars have studied the impact of stakeholders on the adoption and development of pro-ecological technology (Jones, Harrison & Felps, 2018). An examination about the role of financial institutions helps to explain why there is greater expectation of responsibility that comes with green financing tends to encourage eco-friendly practices Schaltegger, Hörisch & Freeman (2019). By using stakeholder theory, this research can provide valuable views concerning the advancement of ES alongside financial and technological progress.

1.4.2 Ecological Modernization

The relationship between concern for the environment and economic growth is examined under Ecological Modernization Theory (EMT), which Joseph Huber developed in 1980 (Huber, 2008). It makes the case that technical advancement, institutional changes and market-driven processes may all help capitalist economies become more ecologically sustainable. According to EMT, ecological problems may induce modernization ushering in a situation where both environmental and economic benefits are realized. This embraces the concept of adopting more environmentally friendly technologies and industrial processes, developing green economics, and accounting for the environment in business decisions.

Based on the application of EMT to the research problem at hand, digitization and technological patents alongside FI can foster ES. For instance, higher levels of FI could provide the necessary financial resources to support investments in GT. Additionally, patents can promote the creation and dissemination of green inventions. DIG may also prove to be very beneficial by increasing resource productivity, tracking environmental impacts, and enabling the creation of new sustainable business models. In this context, GF acts as a driving force as it helps direct investments towards sustainable projects and stimulates ecologically responsible actions.

The fundamental principles of EMT have received empirical validation from recent studies. For instance, research has looked at how DIG and technology innovation might reduce carbon emissions and encourage sustainable habits. In particular, (Hussain, Yang, Maqsood, & Zahid, 2024) looked into how corporate green innovation drives were affected by the deployment of artificial intelligence.

Furthermore, Banori (2025) examined how stakeholder management and sustainable leadership work together to improve project performance, showing how updating leadership techniques may balance ES with financial objectives. Through the use of EMT, this study can further knowledge of the circumstances in which digitization, patents, and FI can successfully advance ES, especially where green financing is involved.

1.5 Research Questions

The study tried to answer these questions:

Research Question 1

What is the impact of financial inclusion on environmental sustainability?

Research Question 2

What is the impact of green technology on environmental sustainability?

Research Question 3

What is the impact of digitalization on environmental sustainability?

Research Question 4

Do green finance moderates the relationship between financial inclusion and environmental sustainability?

Research Question 5

Do green finance moderates the relationship between green technology and environmental sustainability?

Research Question 6

Do green finance moderates the relationship between digitalization and environmental sustainability?

1.6 Research Objectives

The following are some objectives of this study:

Research Objective 1

To find the impact of financial inclusion on environmental sustainability.

Research Objective 2

To find the impact of green technology on environmental sustainability.

Research Objective 3

To find the impact of digitalization on environmental sustainability.

Research Objective 4

To find the moderating role of green finance between financial inclusion and environmental sustainability.

Research Objective 5

To find the moderating role of green finance between green technology and environmental sustainability.

Research Objective 6

To find the moderating role of green finance between digitalization and environmental sustainability.

1.7 Significance of the Study

The study, holds significance in the body of literature, as it is contributing uniquely. This research stands out from previous research in following way:

1. This study seeks to provide evidence showing how environmentally friendly technologies contribute to a more sustainable planet.

2. This study explores the impact of financial inclusion on environmental sustainability.

3. This study will delve into the various ways in which increasing digitalization impacts our environment.

4. This research will analyze whether and how green financial mechanisms alter the way financial inclusion affects environmental outcomes.

5. This study will assess how green finance influences the effectiveness and adoption of green technologies in promoting environmental sustainability.

6. This research aims to determine if and how green financial tools change the environmental impacts associated with increasing digitalization.

Chapter 2

Literature Review

This literature review seeks to synthesize the existing literature to induct valuable insight into our variables. The efforts of the past researchers, their findings and theoretical background related to this study are discussed.

2.1 Financial Inclusion and Environmental Sustainability

Recently, FI has become more relevant as a tool for alleviating poverty and stimulating economic development. FI, as explained by Aruwa, Mairafi, and Ngbede (2024), deals with the use and accessibility of financial services by people and businesses. Access and utilization covered basic accounts, credit, insurance, and even payment systems. Small businesses and individuals can participate in economically advantageous activities, improve their economic shock resilience, and enhance their money management skills through financial services (Demirgüç-Kunt, Klapper, Singer, & Ansar, 2022).

The development of digital financial services (DFS) has been one of the most important factors in advancing FI in many developing countries. Services such as mobile banking, digital wallets, and online payment systems make financial transactions cheaper and more accessible to previously unbanked populations (Mpofu, 2022).

In Kenya, mobile money services have been found to improve the financial access barrier and reduce poverty, especially among women (Suri & Jack, 2016). In addition, other studies have demonstrated that FI has the potential to increase access to resources and empower women, marginalized groups, and people living in rural areas (Gibson, Gazi, & Arner, 2024).

The growth of digital financial services has increased FI in most developing countries. Services such as mobile banking, electronic wallets, and internet payment systems have significantly reduced the cost of financial transactions and increased the accessibility of these services to the unbanked (Mpofu, 2022).

A study done in Kenya noted mobile money's positive impact on FI and increasing poverty levels, especially for women (Suri & Jack, 2016). Moreover, FI has shown to have a positive impact on women, rural dwellers, and marginalized communities by empowering them to have greater control over their economic resources (Gibson et al., 2024).

However, FI exists in varying levels from country to country and region to region. While some countries have made impressive leaps in deepening access to financial services others are still lagging behind especially in Sub-Saharan Africa and South Asia (Demirgüç-Kunt et al., 2022). It is worth noting that supply-side factors including the regulatory environment and financial infrastructure as well as demand-side factors such as financial literacy and trust play a significant role in fostering FI.

ES refers to the capacity to meet current needs without compromising the capacity of future generations to satisfy their own needs (World Commission on Environment and Development (WCED), 1987). Climate change, loss of biodiversity, deforestation, pollution, and depletion of resources are just some of the issues encompassed by this concept. Environmental degradation is a matter of serious concern to human well-being, economic security, and social justice.

One of the greatest environmental crises of our time is global warming which results from the emission of greenhouse gases due to human activities. Climate change affects vulnerable individuals disproportionately and the impacts of climate change are already being experienced worldwide and encompass increasing temperatures, sea level rise and weather extremes (Arias et al., 2021).

Enacted in 2015, the Paris Agreement aims to limit global warming to well below 2 degrees Celsius above pre-industrial levels. All countries are required to act urgently and ambitiously to achieve this goal (Change, 2015).

Along with climate change, other environmental challenges, including deforestation, and loss of biodiversity endanger the ecosystems of the planet and their services. Forests have millions of people depending on them to sustain their livelihoods maintain the climate and offer wildlife habitats.

Yet due to activities such as urbanization, forestry, and agriculture expansion, deforestation continues to occur at a shocking pace (Canton, 2021).

A multi-faceted strategy that involves behavioral changes, technical innovation, and regulation is required to solve these environmental problems. Implemented by the UN in 2015, the Sustainable Development Goals (SDGs) provide a paradigm for achieving ES with social and economic development in a harmonized manner (B. X. Lee et al., 2016).

The links between FI and ES are complicated, as certain studies show both positive and negative impacts. In another study, it was shown that greater FI is associated with greater environmental degradation because the provision of financial services may lead to higher levels of consumption, energy consumption, and carbon dioxide emissions (Gyamfi et al., 2023).

Studies from developing countries show that increased access to credit enables households to purchase electricity used appliances, which result in greater electricity consumption and carbon emissions (Usman & Elsalih, 2024).

Furthermore, it has been established that FI accelerates pollution in the economies of ASEAN countries and increases carbon emissions in African countries (Ali, Gyamfi, Bekun, Ozturk, & Nketiah, 2023; Ahmad, Khan, & Magda, 2022). But some academic works indicate important contributions of FI in encouraging active ES. (Karlan & Zinman, 2010) suggest that FI will allow individuals and businesses to invest in green technologies like sustainable farming and renewable energy. Access to credit, for example, allows farmers to adopt climate-resilient agricultural practices such as growing drought-resistant crops and utilizing low carbon emission-efficient irrigation systems that enhance productivity while reducing greenhouse gas emissions (Paroda, 2011).

Furthermore, breakthroughs in digital financial services could reduce the amount of paper used and help funnel money towards sustainable environmental projects (Mas & Radcliffe, 2010). Egypt's green economy research showed that investment in green technologies could be facilitated through digital financing, thereby reducing carbon emissions (Salman & Ismael, 2023).

In addition, FI can contribute an important role in promoting the uptake of renewable energy technologies. Access to credit and other financial instruments can assist households and enterprises in bridging the initial investment costs of availing themselves of solar panels, wind turbines and other renewable energy systems (Nikolina, 2016). Also, FI can aid in the establishment of green financial markets which can direct funds to environmentally friendly projects and firms (Feridun & Talay, 2024).

The effect of FI on the ES is determined by various contextual determinants such as the degree of economic development, regulatory environments, governance and innovation. Where there are high environmental regulations and good governance, FI tends to favor ES by stimulating green investments and deterring environmentally degrading behavior. On the other hand, where environmental laws are poor and there is high corruption, FI could worsen environmental degradation through supporting unsustainable consumption and production patterns (Trabelsi & Fhima, 2025). A complex route to a brighter future is shown by the close connection between environmental sustainability and financial inclusivity. Expanding financial access has the potential to be a tremendous stimulus for positive change, but it can also have unanticipated environmental effects due to increasing consumption. Financial inclusion may have a direct impact on environmental well-being by giving people and companies the money and services they need to invest in clean technology, embrace sustainable farming methods, and construct infrastructure that is climate resilient. This study has brought attention to the necessity of a focused, policy-driven strategy that guarantees financial inclusion programs are purposefully created to direct funding toward environmentally beneficial projects. In the long run, developing an inclusive financial system is crucial for protecting the environment globally and goes beyond simple economic fairness.

Table 2.1: Latest Studies to Explore FI and ES

AUTHORS	COUNTRIES	ECONOMETRIC TECHNIQUE	FINDINGS
Adeneye, Musah, Gyamfi, and Agozie (2023)	15 West African nations	Co-integration test, Panel corrected standard errors (PCSE), and Common Correlated Effects Mean Group (CCEMG).	Financial inclusion positively impacts environmental sustainability in West Africa, with depositors having a significant negative effect on greenhouse gas emissions, while commercial bank branches have an insignificant impact.
Ahmad et al. (2022)	Nine ASEAN countries	PMG-ARDL	Financial inclusion, energy use, economic growth, and urbanization significantly contribute to environmental degradation in the ASEAN region. Specifically, a 1% increase in financial inclusion leads to a 0.15% rise in environmental degradation in the short run and a 0.42% increase in the long run.
Ali et al. (2023)	African economies	Two-step, difference Generalized Method of Moments (GMM)	Economic growth is a significant contributor to environmental pollution in Africa. While agricultural production and labor help decrease pollution, capital and foreign direct investment show mixed effects, often promoting pollution or decreasing agricultural output.

Table 2.1: Latest Studies to Explore FI and ES (continued from previos page)

AUTHORS	**COUNTRIES**	**ECONOMETRIC TECHNIQUE**	**FINDINGS**
Aruwa et al. (2024)	Nigeria	Error, Correction Model (ECM) and Fully Modified Ordinary Least Square (FMOLS)	Financial, inclusion, specifically through increased commercial bank branches, demand deposits, and loans to rural areas, significantly and positively impacts sustainable development (IHDI) in Nigeria in both the short and long run.
Feridun and Talay (2024)	European countries	empirical analysis	European countries with a higher share of wholesale banks adhering to Principles of Responsible Banking show more advanced progress towards Sustainable Development Goals, a trend not observed for retail banks
Salman and Ismael (2023)	Egypt	Autoregressive Distributed Lag (ARDL) model	Digital financial services reduce carbon emissions in the long run for Egypt, but not in the short run. Increased investment in renewable energy also significantly improves environmental quality in the long term.

2.2 Green Technology and Environmental Sustainability

GT or clean technology is concerned with the creation and use of things like equipment and systems which save the natural world as well as human resources reduce the negative impacts of human behavior while encouraging human wellbeing (Chen et al., 2024). This encompasses the generation of renewable energy, pollution and waste management, green buildings, as well as sustainable farming (Li, Chen, & Wu, 2023). The concern of environmental issues, stricter enforcement of environmental regulations, and rising fossil fuel prices are some GT adoption drivers (Zhang, Yu, & Zhang, 2022). Wang, Qu, Wang, Wang, and Yang (2019) describes how policies to promote GT, offering subsidies and tax credits, and carbon pricing policies are used worldwide. There are also international treaties such as the Paris Agreement which fosters GT adoption (United Nations, 2015).

Guo, Nowakowska-Grunt, Gorbanyov, and Egorova (2020) identifies the reduction of greenhouse gas emissions, improving air and water quality, and enhancing energy security as benefits of GT. The use of Solar and wind energy in place of fossil fuels is quite effective in avoiding the impacts of climate change (International Renewable Energy Agency (IRENA), 2021). The use of advanced technologies in wastewater treatment plays a significant role in removing water pollutants which protects the aquatic environment and humans (Singh, Kumar, & Das, 2023). In addition to the above, GT fosters economic growth and job creation. According to the OECD, the GT sector is expanding its boundaries very quickly as it is creating new opportunities in areas such as the renewable energy sector, energy efficiency, and green construction (Organisation for Economic Co-operation and Development (OECD), 2022). Other researchers have argued that investments in GT lead to greater productivity, innovation and overall competitiveness. (Acemoglu, Aghion, Bursztyn, & Hemous, 2012). Regardless of the advantages of adopting GT, its implementation faces numerous obstacles.

One of the main challenges is the high initial cost of most green technologies which proves to be a major hindrance for businesses and households especially in developing nations (World Bank, 2023). Moreover, poor awareness and technical skills may be a hindrance to the usage of GT (UNDP, 2020). The infrastructural and institutional structures in place may not be very supportive of efficient implementation of green technologies (International Energy Agency (IEA), 2024). To bridge these gaps governments and global institutions are considering new financing instruments including green bonds and public-private partnerships to alleviate the cost burden on adopters and spur investment in GT.

ES is the ability to sustain the natural world and its varied biological systems over long periods. One of the fundamental principles is ensuring current needs are met without weakening the capacity of future generations to meet their own needs (World Commission on Environment and Development (WCED), 1987). The idea highlights the value of not depleting natural capital which includes things such as air, water, land and biodiversity necessary to sustain human welfare and economic activity (Costanza et al., 2014).

Climate Change Mitigation and Adaptation is about decreasing greenhouse gas emissions and proactive steps for adaptation to the inevitable effects of climate change like sea level rise and extreme weather events (Intergovernmental Panel on Climate Change (IPCC), 2021). This involves shifting towards renewable energy sources increasing energy efficiency and adopting sustainable transport systems. Adaptation responses could include the creation of drought-resistant crops, seawall construction and enhancing disaster preparedness. Biodiversity Conservation preservation of the diversity of life on our planet, plants, animals, and microbes is essential as it ensures the integrity of ecosystems and their services like pollination and water purification (CBD, 2018). Biodiversity loss can have ripple effects on food security, human health, and economic, stability.

Resource Management entails the sustainable harvesting of renewable resources such as forests and fisheries as well as the effective use and recycling of non-renewable resources such as minerals and fossil fuels (United Nations Environment Programme (UNEP), 2019). This entails activities such as sustainable forestry, sustainable fishing and the creation of a circular economy. Pollution, Prevention and Control reducing the emission of toxic substances into the environment is important for safeguarding the quality of air, water and soil which are for human and ecosystem health (World Health Organization (WHO), 2021).

The quest for ES is motivated by the awareness that environmental degradation presents major threats to human societies and economies. For instance, climate change can impair agricultural output result in extensive damage due to extreme weather conditions and bring about social instability (Stern, 2007). Loss of biodiversity can impair the resilience of ecosystems and lessen the access to vital resources (Millennium Ecosystem Assessment (MEA), 2005). Pollution can cause health issues, lower productivity and lower the overall standard of life (Landrigan et al., 2018). These environmental issues not only endanger human well-being but also compromise the long-term sustainability of economic systems and social frameworks.

ES calls for joint efforts at local, national, and global levels. Governments have an important role in setting environmental policies, implementing rules and investing in sustainable infrastructure (Organisation for Economic Co-operation and Development (OECD), 2018). This involves establishing emission standards, conserving nature reserves and advocating for sustainable development. Companies can also play their part by embracing sustainable practices, minimizing their footprint on the environment and creating green technologies (World Business Council for Sustainable Development (WBCSD), 2017). This includes steps such as conserving energy, minimizing waste generation and adopting environmentally friendly manufacturing processes. People can also make a difference by altering consumption patterns, buying sustainable products and voicing support for conservation (World Wildlife Fund (WWF), 2020). This entails measures such as lowering their carbon footprint, water conservation, and supporting policies that foster sustainability.

The Sustainable Development Goals (SDGs), which the United Nations adopted in 2015 have established a global blueprint for attaining ES while fostering social and economic growth. A number of SDGs directly target environmental concerns such as SDG 6 (Clean Water and Sanitation), SDG 7 (Affordable and Clean Energy), SDG 13 (Climate Action), SDG 14 (Life Below Water), and SDG, 15 (Life on Land) (United Nations, 2015). They focus on the interrelatedness of the environmental, social, and economic aspects of sustainable development and underscore the necessity for an integrated approach towards resolving these issues. GT has an important role in promoting ES. Through its innovative solutions for addressing and adapting to environmental problems the technologies have a major contribution in conserving resources, reducing pollution and the advancement of a more sustainable future (Norton, Olewiler, & Woodward, 2022). GT development and deployment are important for breaking economic growth from causing environmental degradation so that societies can prosper without harming the health of the planet.

One of the most significant effects of GT is climate change mitigation. Green energy technologies including solar, wind and hydropower are key technologies for mitigating our dependence on fossil fuels which are the main causes of greenhouse gas emissions. The widespread use of these technologies has resulted in substantial decreases in carbon dioxide emissions and has been an integral part of global efforts to contain temperature rises and their resultant implications (Intergovernmental Panel on Climate Change (IPCC), 2021). Energy-efficient technology also plays an important role in this through the reduction of energy consumption in different sectors such as buildings, transport and industry (International Energy Agency (IEA), 2023). For instance, it has been established through research that enhanced building insulation and the production of more efficient vehicles have seen tremendous energy consumption and associated emissions declines (Ürge-Vorsatz et al., 2018). In addition, technologies for capturing and storing carbon present promising solutions for reducing emissions from current fossil fuel infrastructure offering a transition to a carbon-neutral world.

GT also greatly improves pollution control and waste management. Advanced filtration technologies such as systems can successfully eliminate pollutants from industrial emissions and wastewater making air and water cleaner (Singh et al., 2023). Sustainable waste management methods including recycling and composting contribute significantly to minimizing the percentage of waste deposited in landfills thus reducing methane emissions and saving precious resources (United Nations Environment Programme (UNEP), 2019).

Green chemistry is aimed at designing chemical processes and products that eliminate or minimize the use and generation of hazardous substances as well as pollution at its source (Anastas & Warner, 1998). In addition, bioremediation technologies involve the use of microorganisms to degrade pollutants offering a natural and low-cost method of environmental cleanup.

GT has an important role in maintaining biodiversity conservation through encouraging sustainable land-use patterns and minimizing the harmful effects of human activities on the environment. Precision agriculture deploys technology to enhance the utilization of water, fertilizers, and pesticides hence lessening their detrimental effects on ecosystems (Robertson, Paul, & Swinton, 2014). Green buildings which are engineered and built to reduce energy and resource use also help lower habitat loss and enhance biodiversity (U.S. Green Building Council (USGBC), 2020). Remote sensing and ecological monitoring technologies further assist in monitoring and conserving threatened species and habitats (Jetz, McPherson, & Guralnick, 2018). New technologies like synthetic biology can potentially generate sustainable materials and reduce pressure on natural ecosystems.

The transition to a green economy led by GT creates many opportunities for economic growth, sustainable and job creation. Investments in renewable energy, energy efficiency, energy and sustainable transportation can drive innovation, improve competitiveness, and generate new industries and employment opportunities (Organisation for Economic Co-operation and Development (OECD), 2022). This shift has the potential to cause long-term cost savings through the minimization of our reliance on fossil fuels and the lessening of the health and environmental costs of pollution (World Bank, 2023). Research has shown that for every dollar spent on renewable energy several dollars are saved in decreased healthcare costs and damages to the environment (Hsu, Bernstein, Lubarsky, & Hayes, 2020). The expansion of green industries is also creating new skills and expertise, leading to a more sustainable and resilient workforce.

Using GT though requires overcoming some challenges. Steep initial costs linked to most green technologies are a major obstacle in many developing economies. In order to respond to this policy support in the form of subsidies, tax incentives and carbon pricing is essential for creating a level playing field and promoting the uptake of green solutions (Sterner, 2012).

Moreover, continued technological innovation and strong research and development (R&D) are pivotal in enhancing the performance and cost-competitiveness of green

TABLE 2.2: Latest Studies to Explore Green Technology and Environmental Sustainability

Authors	**Year**	**Countires**	**Econometric Technique**	**Findings**
Zhang et al. (2022)	2022	Egypt	Autoregressive Distributed Lag (ARDL) model	Digital financial services reduce carbon emissions in the long run for Egypt, but not in the short run. Increased investment in renewable energy also significantly improves environmental quality in the long term.
Norton et al. (2022)	2022	Okanagan Basin	Random Forest probabilistic model	A random forest model successfully predicted and mapped wetland classes in the Okanagan Basin with 84.8% accuracy, identifying 313.9 km^2 of wetlands, predominantly marshes and swamps. Key predictors included topography, proximity to streams, and vegetation metrics.

technologies making them more accessible and desirable to a larger range of users (Rennkamp, Kindermann, & Marquard, 2021).

In addition, international cooperation and knowledge sharing is to speeding the global spread of green technologies. Joint action can enable the transfer of technology from developed to developing countries, capacity building and the implementation of best practices (United Nations Framework Convention on Climate Change (UNFCCC), 2025). Public education and awareness are pivotal to creating a sustainability culture and inspiring demand for green goods and services and thus a cycle of innovation and adoption (United Nations Educational, Scientific and Cultural Organization (UNESCO), 2017). International agreements and partnerships are indispensable in marshaling financial capital and technical capability required to implement green technologies efficiently and fairly.

2.3 Digitalization and Environmental Sustainability

DIG defined by the large-scale adoption and embedding of digital technologies in all aspects of society and economy has arisen as a transformative force with deep ramifications for ES. This includes technologies like Artificial Intelligence (AI), the Internet of Things (IoT), big data analytics, blockchain and cloud computing which are essentially transforming industries, governance and everyday life. ES by contrast is the prudent engagement with the world in order to prevent depletion or deterioration of natural resources and maintain long-term environmental quality. The interface between these two foundational areas is intricate and multifaceted and offers both enormous opportunities for dealing with environmental issues and possibilities for risk that must be carefully assessed (United Nations Conference on Trade and Development (UNCTAD), 2024; Salehzadeh, Javani, & Esmailian, 2024).

DIG is a ubiquitous and continuous societal shift profoundly reshaping the creation, processing, transmission and use of information. It is more than just digitization (the process of converting analogue information into digital) but includes embedding digital technologies into every facet of life creating new business models, processes and social processes (Pagoropoulos, Pigosso, & McAloone, 2017). Fundamentally, DIG uses a set of linked technologies to improve efficiency, promote innovation and enable data-driven decision-making in many fields like Artificial Intelligence (AI) and Machine Learning (ML): These include algorithms that allow machines to learn from data, find patterns, make predictions, and carry out complex tasks. Applications of AI range from maximizing energy use in smart buildings to predictive maintenance in manufacturing, and advanced climate modeling (Miller et al., 2025; Hussain et al., 2024). Internet of Things (IoT): An assembly of physical objects containing sensors, software and other technologies for connecting and sharing data with other devices and systems via the internet. IoT allows real-time monitoring and control of environmental parameters, utilization of resources and performance of assets essential for smart cities and precision agriculture (Biswas & Podder, 2024).

Big Data Analytics: The technique of analyzing large and diverse data sets to find hidden patterns unknown correlations, market trends, customer preferences and other valuable information. Environmentally, big data enables the analysis of massive environmental datasets for pollution detection, resource optimization and climate change studies (United Nations Conference on Trade and Development (UNCTAD), 2024).

Blockchain Technology: A distributed, decentralized ledger system recording, transactions on numerous computers, guaranteeing data integrity and transparency. Blockchain is applicable for open supply chains, carbon credit tracking and authentication of sustainable practices, increasing accountability (Luo, Leng, & Bai, 2022).

Cloud Computing: The provision of on-demand computing services from applications to storage and processing power via the internet. Cloud platforms offer scalable infrastructure for big data processing, AI applications and digital twins supporting many sustainability initiatives (Rehman et al., 2024).

Digital Twins and Cyber-Physical Systems: Digital twins, virtual copies of physical objects, processes or systems, can be employed for simulation, analysis and optimization. Cyber-physical systems combine computing and physical processes, usually applied in smart manufacturing to boost efficiency and minimize waste (Pislaru, Herghiligiu, & Robu, 2019).

This integrated approach of digital technologies makes economies more agile, responsive and resilient and fundamentally transforms industries and conceivably redefines strategies for green development (ResearchGate, 2024b).

DIG is a very effective toolbox for promoting ES by raising efficiency, facilitating green technologies and enhancing monitoring functions. One of the main mechanisms is dematerialization in economic processes where digital services substitute for physical products and processes, thus lowering resource utilization and waste. E-commerce has the potential to decrease the demand for physical stores and hence the energy spent thereon and digital documents sharply minimize the usage of paper. This dematerialization of the economy directly helps in conserving resources (United Nations Framework Convention on Climate Change (UNFCCC), 2015). In addition to dematerialization, DIG promotes innovation in environmental technologies, speeding up the creation and application of solutions imperative to protecting the environment. Empirical studies show that digital transformation highly increases companies' green innovation capacities through enhanced information flow and efficiency in resource use (Chen et al., 2024).

In addition, DIG has a vital role to play in maximizing resource management and operational efficiency across industries. IoT-enabled smart grids can maximize energy distribution, minimize transmission losses and incorporate renewable energy sources better resulting in reduced carbon emissions (Miller et al., 2025). In farming precision agriculture methods use sensors, drones and data analytics to maximize water and fertilizer application, reducing waste and environmental footprint while maximizing yields (Biswas & Podder, 2024). Likewise, intelligent logistics and transport systems take advantage of real-time data, to plan optimal routes, lower fuel, consumption, and lower vehicular emissions. Such uses illustrate how digital technologies can bring large efficiency gains, translating into a lower environmental footprint (Wang et al., 2019).

The improved data collection, analysis and openness enabled by DIG also enable improved environmental governance and decision-making. Big data analytics are able to handle enormous amounts of environmental data, enabling pollution monitoring more accurately earlier detection of environmental degradation and better climate modeling. This real-time insight enables adaptive management approaches and quicker reactions to environmental catastrophes. Additionally, blockchain technology can help increase supply chain transparency so that consumers and regulators can monitor products from the point of origin to use ensuring accountability for sustainable operations and preventing deforestation or inhumane sourcing (Luo et al., 2022). These digital technologies offer the information infrastructure to ensure successful environmental policy enforcement and corporate sustainability disclosure. Even with its environmental promise DIG does come with considerable environmental challenges mainly from the rising energy demand of digital infrastructure and the rising issue of electronic waste (e-waste). The swiftly growing digital economy calls for colossal energy usage for data centers, telecommunications networks and manufacturing and running end-user devices. For instance, data centers which operate 24/7 are highly energy-intensive, with their power demand projected to grow substantially by 2030 (Gidigbi, 2021). This escalating energy demand if primarily met by fossil fuels directly contributes to increased greenhouse gas emissions potentially offsetting any efficiency gains achieved elsewhere through DIG (Santarius et al., 2023; United Nations Conference on Trade and Development (UNCTAD), 2024).

Another environmental concern associated with DIG is the accelerating generation of electronic waste. A considerable volume of e-waste arises from the rapid obsolescence of electronic devices triggered by consumer demand for newer models and technical enhancements. Such waste has harmful chemicals such as lead, mercury and cadmium that have the potential to pollute land and water and create serious health risks if not disposed of correctly. Additionally, the production of rare earth metals and other raw materials used to make digital devices has its own substantial environmental impact including the destruction of ecosystems and pollution (Ouyang, Ye, & Li, 2023). The Estimated compound annual growth rate of e-waste from large language AI models alone gives an indication of the magnitude of the fast-growing challenge in question (Gidigbi, 2021). Additionally, the rebound effect is also an important factor when evaluating the net environmental impact of DIG. Although digital technologies do make things more efficient (e.g., more efficient transport, better production) this added efficiency sometimes is actually accompanied by increased overall consumption of resources or energy thus negating the original environmental benefits. For instance, more efficient e-commerce may encourage consumers to buy more products or quicker processing of data may stimulate the creation of more data-hungry applications. Comprehending and preventing these rebound effects is key to ensuring DIG actually delivers net environmental benefits instead of causing them to merely shift or intensify consumption habits (Miller et al., 2025). This effect means although there may be efficiency gains in individual digital solutions overall digital growth can still result in greater resource consumption and emissions, necessitating thorough policy design for actual environmental benefits. Economic sustainability has now become a priority world concern, leading to large-scale inquiry into mechanisms that can create a balance between economic growth and the protection of nature.

Table 2.3: Latest Studies to Explore Digitalization and Environmental Sustainability

Authors	**Countires**	**Econometric Technique**	**Findings**
Rehman et al. (2024)	Pakistan	SEM (Structural Equation Modeling) enhanced with Artificial Neural Network (ANN) approach.	Fintech adoption and digital transformation (DT) directly impact bank sustainable performance. Green finance and competitiveness mediate this relationship, while DT further moderates the links between Fintech adoption, green finance, and competitiveness.
Ouyang et al. (2023)	China	ARDL, GMM	Digital investment improves environmental performance in Chinese pollution-intensive firms, with both production efficiency and green innovation acting as partial mediators. This effect is more pronounced in state-owned and heavy industrial firms.
Wang et al. (2019)	China	Comprehensive analysis method	China made significant progress in green technology innovation from 2000-2015, particularly in water treatment, solar PV, and electric vehicles, driven by environmental

In this context GF has appeared as a driving force and a key moderator. GF consists of financial products, services and investments that support environmental ends including reducing climate change, pollution management, biodiversity, conservation and resource efficiency (Mu, Chen, & Zhang, 2025). Its purpose is not only to deliver capital for green initiatives but also to shape the relationship between different economic and technological drivers and their eventual effect on environmental outcomes.

2.4 Moderating Role of Green Finance

GF acts as an enabler and catalyst towards ES by committing financial resources to sustainable initiatives while deterring destructive activities. Its moderating function entails the transformation of incentives, mitigating risk and supporting investments in activities that enhance ecological health. Through integrating environmental aspects into financial choices GF instruments green bonds, green loans and carbon finance mechanisms elicit more sustainable business practices from economic actors (ResearchGate, 2024a). For instance, a study by Karlilar, Balcilar, and Emir (2023) points out the important roles played by GF, DIG, green innovation, and renewable energy in ES in OECD countries. This suggests that the positive environmental impacts of these variables can be strengthened when complemented with good green financial systems.

In addition, GF has a key role in reducing the financial risks, implicated in environmental projects and thereby making them attractive to investors. It organizes financial flows in a way that internalizes environmental externalities and penalizes polluters while rewarding sustainable behavior. Such financial realignment is conducive to a larger transformation towards a sustainable economic paradigm (Mu et al., 2025). GF as an effective moderator also stems from its capacity for promoting greater transparency and accountability in environmental performance, commonly through standardized reporting and disclosure requirements. Such practices steer investors and policymakers towards more sustainable decisions (Clarity AI, 2025).

FI as the access to and use of useful and affordable financial products and services is increasingly seen as a central driver of sustainable development. Yet its direct contribution to ES is sometimes unclear; although it enables individuals and small enterprises to invest in cleaner technologies, it may also promote consumption which can lead to growing environmental pressures. In this case, GF has an important moderating function in that it ensures, that increased financial access is channeled into environmentally positive activities. If GF guidelines are incorporated into financial inclusion policies, they can channel newly available capital into sustainable business e.g., small-scale renewable energy enterprises, green agriculture or green entrepreneurship (AFI Global, 2024).

Abubakar and Handayani (2019) study the application of principles of responsible banking a foundational aspect of GF in order to reach Indonesian bank Sustainable Development Goals.

As it is not an explicit moderation study but will suggest that if financial institutions practice green financial services expansion (FI) by such financial institutions will be more congruent with the environment.

In the absence of the balancing role of GF higher FI might translate into greater carbon footprint or depleting resources particularly in emerging economies where environmental policy might be less binding. Therefore, GF is a key mechanism directing the virtuous effects of FI towards a greener economy and countering the adverse effects on environmental quality.

GT which comprises innovations meant to minimize human intervention on the environment is central to ES. This includes renewable energy, waste management, sustainable, agriculture, and pollution control technologies.

Although green technologies have vast potential their mainstream application frequently faces huge cost hurdles for example, high initial costs and perceived risks (Kwilinski, Lyulyov, & Pimonenko, 2025). GF is an influential moderating force in this respect by decreasing these financial barriers and encouraging investments in green technological innovation and deployment.

GF offers required capital via specialized tools, enhancing GT projects viability and scalability.

Studies show that GF measures can hugely catalyze industrial cluster-level innovation particularly in industries such as new energy vehicles (Kwilinski et al., 2025). This implies that GF is not only financing but also promoting the transition to new green technologies thus speeding up the transition to a greener economy.

In addition, GF can increase the environmental performance of companies by encouraging them to invest in green technological improvements and industrial evolution (MDPI, 2024). In contrast, without GF, the transition to a greener economy would probably be significantly slower.

Table 2.4: Latest Studies to Explore Dig. and ES

Authors	Year	Countries	Econometric Technique	Findings
Abubakar and Handayani (2019)	2019	Indonesia	Descriptive analytical and Normative juridical approach	The implementation of responsible banking principles in Indonesia, including CSR and environmental fund management, has not been optimal due to fragmented regulations and insufficient oversight.
Karlilar et al. (2023) & Emir	2023	36 OECD countries	System Generalized Method of Moments (SYS-GMM)	Digitalization, ,green innovation, ,renewable energy, and financial development significantly promote environmental sustainability. Their positive interactions further enhance digitalization's capacity to reduce the ecological footprint.
Guo et al. (2020)	2020	20 countries from the Sustainable Development Goals Index (SGDI) ranking	Methodological approach	Intensive brown industries lead to significant carbon dioxide emissions in countries like UAE and Russia, impacting their sustainable development scores. The gap between Normalized Sustainable Development Index (NSDI) and Averaging Sustainable Development Index (ASDI) values suggests unfavorable conditions for greentech adoption in most developing countries

Table 2.4: Latest Studies to Explore Dig. and ES (continued from previous page

Authors	Year	Countries	Econometric Technique	Findings
Kwilinski et al. (2025)	2025	European Union (EU) countries	Spatial Durbin Model (SDM) and Entropy methods	Green finance initiatives significantly drive positive environmental outcomes within EU countries' ESG performance. By channeling financial resources to eco-friendly projects, green finance facilitates the transition to a low-carbon and resource-efficient economy, contributing to emission reduction and resource conservation.
Mu et al. (2025)	2025	Shanghai and Shenzhen	Robustness tests, Baseline regression	Digital transformation significantly enhances green innovation in manufacturing firms via "risk" and "reputation" effects. This positive impact is more pronounced in state-owned enterprises within regions of advanced digital financial development, and digital transformation also improves green innovation efficiency
El Awady, Salman, and Eltayb (2025)	2025	63 countries with middle or high incomes	Two-way fixed effects model	Digital Transformation (DT) has an immediate and constant positive impact on Sustainable Development Goals (SDGs), primarily driven by its technology dimension, with no dynamic relationship or lasting effect from past technological advances. The knowledge and future readiness aspects of DT do not influence SDGs.

2.5 Hypothesis Statement

H1: Financial inclusion has negative impact on environmental sustainability.

H2: Green technology has positive impact on environmental sustainability.

H3: Digitalization has positive impact on environmental sustainability.

H4: Green Finance positively moderates the relationship between financial inclusion and environmental sustainability.

H5: Green finance positively moderates the relationship between green technology and environmental sustainability.

H6: Green finance positively moderates the relationship between digitalization and environmental sustainability.

2.6 Theoretical Framework

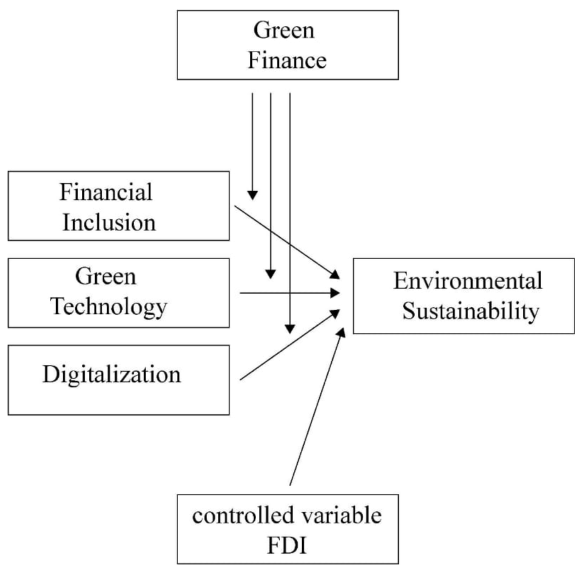

FIGURE 2.1: Theoretical Framework of Research

This theoretical framework presents an in-depth exploration of the determinants of ES. It specifically focuses on, the impact of GF, FI, Green, Technology and DIG on ES. One of the main emphases of this framework is the examination of the moderating function of GF i.e., how it moderates the links between FI and ES, GT and ES, and DIG and ES. Finally, the framework should forecast ES by assessing both the standalone contributions and the interactive joint effects of GF, FI, GT and DIG

Chapter 3

Research Methodology

This section of the research depends on the data collection and methodology integrated. The data type, data source, and data range are addressed in this section. In addition, this section gives the proxies of variables, econometric methods applied in the study and modeling data. The variables within this research are Environmental sustainability (DV), Financial Inclusion (IV), Green Technology (IV), Digitalization (IV), Green Finance(moderator). FDI is the control variable.

3.1 Data Description and Methodology

This section of the research depends on the data collection and methodology integrated. The data type, data source, and data range are addressed in this section. In addition, this section gives the proxies of variables, econometric methods applied in the study and modeling data. The variables within this research are Environmental sustainability (DV), Financial Inclusion (IV), Green Technology (IV), Digitalization (IV), Green Finance(moderator). FDI is the control variable.

3.1.1 Sample

Initially, the data was extracted for 80 developing countries for year 2000 to 2021. Then the data was sorted according to the number of countries that have accurate data available for each of the variables for the desired years. Due to the data availability, we opt for a data range of 2014 to 2023, for 58 countries. In order to maintain consistency, the overall data range for all variables is 2014-2023.

3.1.2 Sources of Data

This study used the panel data collected from 4 sources our worldindata.org, world bank, OECD and World Bank Indicator (WDI).

3.2 Variable Measurement

3.2.1 Dependent Variable

3.2.1.1 Environmental Sustainability

Environmental sustainability is quantified in terms of CO_2 emissions and data derived from the World Development Indicators (WDI) database.

This metric indicates the volume of carbon, dioxide released per individual in a nation; through the evaluation of carbon dioxide CO_2 emissions (total) excluding LULUCF (% change from 1990), this research explores the environmental sustainability performance of developing nations (Ansari et al., 2024).

3.2.2 Independent Variable

3.2.2.1 Financial Inclusion

WDI data on the number of ATMs, per 100,000 adults was utilized as an indicator to measure financial inclusion.

Another standard used measure of financial inclusion in the study is the number of ATMs per 100,000 adults, a nation will be said to have a high degree of financial inclusion if it possesses a high number, of ATMs for every 100,000 people as they facilitate greater ease in accessing the funds of people's deposit accounts (Nuta et al., 2024).

3.2.2.2 Green Technology

Green technology measures Technologies pertaining to the environment A nation's inventive activity in environmental technologies is reflected in its patents, which are sourced from the OECD. It indicates their dedication to sustainable development by quantifying the quantity and complexity of patents pertaining to green solutions. Research on the worldwide landscape of green innovation has made considerable use of this metric (Kirikkaleli & Ali, 2023).

3.2.2.3 Digitalization

The percentage of the population that uses the Internet and information from the World Development Indicators (WDI) database are used to measure digitalization. A population's percentage of internet users reflects access, equity and the potential for social and economic growth in 58 developing nations, indicating the degree of digital inclusion (Zulfiqar, Tahir, Ullah, & Ghafoor, 2023).

3.2.3 Moderating Variable

3.2.3.1 Green Finance

Chan, Saqib, and Nuzula (2024) used International, financial flows, to developing countries in support of clean energy R&D and renewable energy production, including the hybrid, systems (US$ millions at constant value) to proxy green finance. The data source of green finance is Our World in Data.

3.2.4 Control Variable

3.2.4.1 FDI

Foreign Direct Investment (FDI) that is defined as net inflows of capital to acquire a long-term managerial interest . This indicator is often utilized to assess a country's economic potential participation in the world economy and attractiveness as an investment site. The inflation rate has also been utilized in existing studies as a vital indicator influencing FDI flows (Nuta et al., 2024).

TABLE 3.1: List of Variables

Variable Type	**Symbol**	**Indicator**	**Source**	**References**
Dependent variable ES	ES	Corbon Dioxide Co_2 Emissions (total) excluding LULUCF (% change from 1990)	WDI	Ansari et al. (2024)
Independent variable Financial Inclusion	FI	Number of ATMs per 100,000 adults	WDI	Abbas et al. (2024)
Independent variable Green technology	GT	Environment-related technologies patents	OECD	Kirikkaleli and Ali (2023)
Independent variable Digitalization	DIG	Individuals using Internet (percentage of population)	WDI	Zulfiqar et al. (2023)
Moderator Green Finance	GF	International, financial flows to developing countries in support of clean energy research and development and renewable energy production, including in hybrid systems (millions of constant 2020 United States dollars)	Our World in Data	Chan et al. (2024)
Control variables FDI	FDI	FDI(%GDP)	World Bank	Nuta et al. (2024)

3.3 Data Analysis

3.3.1 Descriptive Statistics

Descriptive, statistics are employed in order to capture the statistics behavior of the data. It is the method employed in the summarizing, organization, and simplifying of data. Descriptive statistics consist of mean which provides the average of the data, median which splits the data set into two halves. In a data set, the mode refers to the value with the highest frequency and the median refers to the middle value when the values are ordered in ascending or descending order. Standard deviation or the square root of variance reports the extent to which the values spread out from the mean.

The mean and standard deviation should be applied simultaneously; otherwise, they are useless. Measurement of the asymmetry of the data distribution is known as skewness. It measures both the positive and negative data spread. High and low kurtosis measures if the curve of the distribution is flat or not. Kurtosis is a measurement of the "tailedness" of the curve of the distribution.

It emphasizes the extremes or outliers in a distribution how pointed or broad the peak and how heavy or light the tails are relative to a normal distribution compared to. If the distribution is more than 3 ($kurtosis > 3$), then it is referred to as leptokurtic distribution curve, that is, there are numerous outliers or extreme values in the data.

If the distribution is equal to 3 (kurtosis = 3), it is referred to as mesokurtic, which means normal distribution. And the distribution less than 3 ($kurtosis < 3$), it is referred to as platykurtic, which indicates that there are fewer outliers.

3.3.1.1 Correlation Analysis

Correlation analysis is a statistical measure that describes the strength, and direction among variables. It indicates how the change in one variable is associated with the change in another variable. Correlation analysis among variables demonstrates positive and negative connections among distinct variables. Its range is between -1 and +1. The value that is close to the -1 means that the connection between the variable is perfectly negative.

The values that are close to the +1 means that the connection between the variable is perfectly positive. The value that is 0 or close to 0 are showing that the connection between the variable is weak or no connection between them. The likelihood of multicollinearity is lower when there is low correlation between two variables and higher when there is significant correlation between two variables.

3.3.1.2 Panel Unit Root Test

It is probable to be having unit root in the panel data since there are vast number of observations in the data set. It might lead to biased results and can lead to spurious regression and therefore Panel Unit Root tests are performed to test the stationarity of the variable. For the measurement of the unit root in the data, this research uses a range of unit root measurements. Levin, Lin, and Chu (2002) and Im, Pesran, and Shin (2003) have been used. The two considerations used by the method in making its decision are p value and t statistics.

3.3.1.3 Econometric Models

The relationship between ES, FI, GT, DIG, GF is the main focus of this study. In order to look deep at the link between the variables the following model has been created.

Model 1: Impact of FI, GT and DIG on ES

$$ES_{i,t} = \beta_1 ES_{i,t-1} + \beta_2 FI_{i,t} + \beta_3 GT_{i,t} + \beta_4 DIG_{i,t} + \beta_5 FDI_{i,t} + \varepsilon_{i,t} \qquad (3.1)$$

Where:

- ES is Environmental Sustainability
- FI is Financial Inclusion
- GT is Green Technology

- DIG is Digitalization
- FDI is Foreign District Investment
- β_1 is the is the coefficient for Environmental Sustainability
- β_2 is the coefficient for Financial Inclusion
- β_3 is the coefficient for green technology
- β_4 is the coefficient for Digitalization
- β_5 is the coefficient for Foreign District Investment
- i is cross section
- t is time period

Model 2: Moderating role of GF on FI and ES

$$ES_{i,t} = \beta_1 ES_{i,t-1} + \beta_2 FI_{i,t} + \beta_3 GF_{i,t} + \beta_4 (GF \times FI)_{i,t} + \beta_5 FDI_{i,t} + \varepsilon_{i,t} \quad (3.2)$$

Where:

- ES is Environmental Sustainability
- FI is Financial Inclusion
- GF is Green Finance
- FDI is Foreign District Investment
- β_1 is the is the coefficient for Environmental Sustainability.
- β_2 is the coefficient for Financial Inclusion
- β_3 is the coefficient for Green Finance
- β_4 is the coefficient for the interaction term between Green, Finance and Financial Inclusion

- β_5 is the coefficient for Foreign District Investment
- i is cross section
- t is time period

Model 3: Moderating role of GF on GT and ES

$$ES_{i,t} = \beta_1 ES_{i,t-1} + \beta_2 GT_{i,t} + \beta_3 GF_{i,t} + \beta_4 (GF \times GT)_{i,t} + \beta_5 FDI_{i,t} + \varepsilon_{i,t} \quad (3.3)$$

Where:

- ES is Environmental Sustainability
- GT is Green Technology
- GF is Green Finance
- FDI is Foreign District Investment
- β_1 is the is the coefficient for Environmental Sustainability.
- β_2 is the coefficient for green technology
- β_3 is the coefficient for Green Finance
- β_4 is the coefficient for the interaction term between Green, Finance and Green technology
- β_5 is the coefficient for Foreign District Investment
- i is cross section
- t is time period

Model 4: Moderating role of GF on DIG and ES

$$ES_{i,t} = \beta_1 ES_{i,t-1} + \beta_2 DIG_{i,t} + \beta_3 GF_{i,t} + \beta_4 (GF \times DIG)_{i,t} + \beta_5 FDI_{i,t} + \varepsilon_{i,t} \quad (3.4)$$

Where:

- ES is Environmental Sustainability
- DIG is Digitalization
- GF is Green Finance
- FDI is Foreign District Investment
- β_1 is the is the coefficient for Environmental Sustainability.
- β_2 is the coefficient for Financial Inclusion
- β_3 is the coefficient for Green Finance
- β_4 is the coefficient for the interaction term between Green, Finance and Digitalization
- β_5 is the coefficient for Foreign District Investment
- i is cross section
- t is time period

3.3.1.4 Dynamic Panel Analysis

The panel data set includes both cross-sectional and time-varying data. A balancing panel is one in which each cross-section of a variable has the same series of time observations. A dynamic panel model is an econometric model used to analyze data that varies across both time and cross-sections. The dynamic panel model uses the lagged dependent variables as a regressor. It means that previous values of the dependent variable are used to predict the current values. These models can capture the dynamic nature of the relationships being studied.

(a) Generalized Method of Moments (GMM)

A key challenge in the dynamic panel model is endogeneity which arises when lagged dependent variables correlate with error terms. This correlation can bias the results of estimations. This issue can be resolved by using Generalized Method of Moments (GMM) which uses instruments to provide consistent results. These instruments are those variables that have a correlation with the endogenous regressor but not with the error term.

Chapter 4

Result and Analysis

4.1 Descriptive Statistics

The study's descriptive statistics for the variables are presented in Table 4.1, based on 580 observations. For ES the mean value is 2.1760, with a standard deviation of 2.2696 and a median of 1.4054. Its values range from a minimum of 0.0320 to a maximum of 9.6151. The positive skewness of 1.5607 indicates a right-skewed distribution, and a kurtosis of 4.5919, which is greater than 3, suggests a leptokurtic curve. Regarding FI, the mean is 30.9926, the standard deviation is 27.2868, and the median is 25.2900. Its values span from a minimum of 0.7500 to a maximum of 126.7100. FI also exhibits positive skewness at 1.1564 and a leptokurtic distribution with a kurtosis of 3. 9913.For GT, the mean value is 2.4378, with a standard deviation of 2.5070 and a median of 1.2390. The range is from a minimum of 0.1077 to a maximum of 9.0999. GT's skewness is 1.5024 (positive), and its kurtosis is 3.9847, indicating a leptokurtic distribution. DIG shows a mean of 43.0192, a standard deviation of 21.5946, and a median of 41.0000. Its values range from 1.2487 to 89.5550. The skewness is a slight positive 0.1464 and the kurtosis value of 1.9858, which is less than 3, signifies a platykurtic curve.GF has a mean value of 1.56E+08 and a standard deviation of 3.22E+08, with a median of 21,690,000. The maximum value reaches 2.4E+09, while the minimum is 10,000. GF is highly positively skewed at 3.3279 and demonstrates a highly leptokurtic distribution with a kurtosis of 15. 7096.Finally, for FDI, the mean is 2.7560, the standard deviation is 3.9822, and the median is 2.0059. Its range is from a minimum of -37.1727 to a maximum of 32.7649. FDI exhibits positive skewness at 0.6147 and a very high kurtosis of 31.4400, indicating an extremely leptokurtic distribution.

Table 4.1: Descriptive Statistics

	ES	**FI**	**GT**	**DIG**	**GF**	**FDI**
Mean	2.1760	30.9926	2.4378	43.0192	1.56E+08	2.7560
Median	1.4054	25.2900	1.2390	41.0000	21690000	2.0059
Maximum	9.6151	126.7100	9.0999	89.5550	2.4E+09	32.7649
Minimum	0.0320	0.7500	0.1077	1.2487	10000	-37.1727
Std. Dev.	2.2696	27.2868	2.5070	21.5946	3.22E+08	3.9822
Skewness	1.5607	1.1564	1.5024	0.1464	3.3279	0.6147
Kurtosis	4.5919	3.9913	3.9847	1.9858	15.7096	31.4400
Jarque-Bera	296.6986	153.0178	241.6314	26.9295	4974.2834	19583.384
Probability	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Sum	1262.101	17975.68	1413.895	24951.15	9.03E+10	1598.4898
Sum Sq. Dev.	2982.514	431105.29	3638.927	270003.8	6.00E+19	9181.7589
Observations	580	580	580	580	580	580

4.2 Correlation Matrix Analysis

The table 4.2 displays the correlation coefficients among the variables showing their linear relationships. The correlation between GF and FI is 0.138653 which indicates a weak positive relationship not a strong negative one. For GF and GT, the correlation is -0.20813 suggesting a weak negative association. GF has a positive weak correlation with ES at 0. 071713. FI shows a moderate positive correlation with ES at 0.50261. FI also has a moderate positive correlation with DIG at 0. 621703. GT has a weak negative correlation with ES at -0.292 and a weak negative correlation with FI at -0.33072. It also shows a weak negative correlation with DIG at-0. 32474. DIG is moderately positively correlated with ES at 0.484333. It has a weak positive correlation with GF at 0.008348. FDI generally shows very weak correlations with other variables, including ES (-0.04186), FI (0.013679), GT (0.063167), DIG (0.027879), and GF (-0.0802).

Table 4.2: Correlation Matrix

	ES	**FI**	**GT**	**DIG**	**GF**	**FDI**
ES	1.0000					
FI	0.5026	1.0000				
GT	-0.2920	-0.3307	1.0000			
DIG	0.4843	0.6217	-0.3247	1.0000		
GF	0.0717	0.1387	-0.2081	0.0083	1.0000	
FDI	-0.0419	0.0137	0.0632	0.0279	-0.0802	1.0000

4.3 Panel Unit Root Test

Table 4.3 presents the results of the panel unit root test at 1st difference for several series. Results indicates that GF at both the Levin, Lin & Chu test and the Im, Pesaran & Shin W-stats show a p-value of 0.0000. Since these p-values are less than typical significance levels (e.g., 0.05), it indicates that GF is stationary at 1st difference. FI at the Levin, Lin & Chu test for FI yields a p-value of 0.0000, suggesting stationarity. The Im, Pesaran & Shin W-stats for FI show a p-value of 0.0000, also indicating stationarity.

GT at the Levin, Lin & Chu test for FI yields a p-value of 0.0000, suggesting stationarity. The Im, Pesaran & Shin W-stats for GT show a p-value of 0.0000, also indicating stationarity. DIG shows Both the Levin, Lin & Chu test and the Im, Pesaran & Shin W-stats report a p-value of 0.0000 for DIG, indicating that DIG is stationary at the level.

ES shows Both the Levin, Lin & Chu test and the Im, Pesaran & Shin W-stats report a p-value of 0.0000 for ES, indicating that ES is stationary at 1st difference. For FDI the Levin, Lin & Chu test reports a p-value of 0.0000, implying stationarity. The Im, Pesaran & Shin W-stats show a p-value of 0.0000. Since it is less than 0.05, the Im, Pesaran & Shin test also indicates that FDI is stationary at 1st difference.

TABLE 4.3: Pannel Unit Root Test at 1st difference

	Levin, Lin&Chu		**Im, Pesaran& Shin W-stats**	
Variables	**Statistic**	**Prob.**	**Statistic**	**Prob.**
ES	-12.7664	0.0000	-4.27580	0.0000
FI	-39.6654	0.0000	-7.40162	0.0000
GT	-9.67703	0.0000	-4.55503	0.0000
DIG	-41371.2	0.0000	-3179.57	0.0000
GF	-191.832	0.0000	-27.4612	0.0000
FDI	-15.4888	0.0000	-6.68210	0.0000

4.4 Results of GMM Estimation

The study uses FI, DIG, GT as a key variable to explain ES along with the moderating effect of GF on FI, DIG and GT.

4.4.1 Impact of Financial Inclusion, Green Technology and Digitalization on Environmental Sustainability

Table 4.4 presents the econometric findings from the panel GMM model (orthogonal deviations transformation) demonstrate the impact of FI, GT and DIG on ES. The dependent variable which is LNES (a logarithm of environmental sustainability), with its lagged value, LNFI (a logarithm of financial inclusion), LNGT (a logarithm of green technology), LNDIG (a logarithm of digitalization) and FDI as explanatory variables. The results indicate that the LNES has a statistically significant positive impact, with a coefficient of 0.0547 ($p < 0.01$). This suggests that past environmental sustainability positively influences current environmental sustainability. LNFI shows a statistically significant effect on ES, with a coefficient of 0.4651 (p $<$ 0.01). This implies that a 1% increase in FI is associated with a 0.4651% increase CO_2 emissions which means there is decrease in ES. This shows FI has negative impact on ES. LNGT shows a significant positive effect on ES, with a coefficient of-0.0468 (p=0.0105). This implies that a 1% increase in GT is associated with a 0.0468% decrease in the CO_2 emissions which shows increase in ES. LNDIG also demonstrates a statistically significant positive impact on ES, with a coefficient of-0.0015 ($p < 0.01$). This suggests that increased DIG is associated with a decrease in CO_2 emissions which shows increase in ES. FDI exhibits a statistically significant positive effect on ES, with a coefficient of 0.0153 ($p < 0.01$). This indicates that a 1% increase in FDI leads to a 0.0153% increase in CO_2 emissions which shows decrease in ES.

The model diagnostics confirm its validity. The J-statistic p-value of 0.1604 is greater than the typical 0.05 significance level, indicating that the null hypothesis of valid over-identifying restrictions cannot be rejected. This suggests that the instruments used in the GMM model are appropriately specified. These findings collectively offer insights into the complex relationships between FI, GT, DIG, FDI, and ES with a persistent effect observed from past environmental sustainability levels.

TABLE 4.4: Impact of Financial Inclusion, Green Technology, Digitalization on Environmental Sustainability

Variables	**Co efficient**	**Std. Error**	**t-Statistic**	**Prob.**
LNES (-1)	0.0547	0.0056	9.8137	0.0000
LNFI	0.4651	0.0482	9.6498	0.0000
LNGT	-0.0468	0.0062	-7.5143	0.0000
LNDIG	-0.0015	0.0007	-2.0821	0.0418
FDI	0.0153	0.0007	20.5121	0.0000

Effects Specification

Cross-sectional fixed (Orthogonal deviations)

Mean dependent var	-0.0239	S.D dependent var	0.2558
S.E. of regression	0.2549	Sum squared resid	29.7580
J-statistic	38.7231	Instrument rank	36
Prob(J-statistic)	0.1604		

4.4.2 The Moderating Role of Green Finance on Financial Inclusion and Environmental sustainability

Table 4.5 presents the econometric findings from the panel GMM model (orthogonal deviations transformation), investigating the moderating role of GF on FI and ES. The dependent variable is ES and the explanatory variables include the lagged value of LNES, LNGF, LNFI, FDI, and an interaction term between GF and FI (LNGF*LNFI) to capture the moderating effect. The results indicate that the LNES has a statistically significant positive impact, with a coefficient of 0.1459 ($p < 0.01$). This suggests that past environmental sustainability levels positively influence current environmental sustainability. LNGF shows a statistically significant negative effect on ES, with a coefficient of 0.1034 (p < 0.01). This implies that a 1% increase in GF is associated with a 0.1034% increase in CO_2 emissions which shows decrease in ES.

LNFI demonstrate a statistically significant negative impact on ES, with a coefficient of 1.0625 (p < 0.01). This shows that 1% increase in FI leads to a substantial 1.0625% increase in CO_2 emissions and shows decrease in ES.FDI also exhibits a statistically significant negative effect on ES, with a coefficient of 0.0110 (p < 0.01). This indicates that increased FDI contributes negatively to ES. The interaction term (LNGF*LNFI) has a statistically significant negative coefficient of-0.0289 (p < 0.01). This negative coefficient for the interaction term indicates that GF positively moderates the relationship between FI and ES in a way that, as GF increases, the positive impact of FI on ES diminishes or becomes less pronounced.This suggests a more complex interplay where the benefits of FI for ES might be dampened when combined with higher levels of GF, or perhaps it signifies a saturation point or a shift in the nature of their combined impact. The model diagnostics confirm its validity, with a J-statistic p-value of 0.273450. Since this p-value is greater than the typical 0.05 significance level, it suggests that the hypothesis of valid over-identifying restrictions cannot be rejected, indicating that the instruments used in the GMM model are appropriately specified. These findings collectively highlight the individual positive contributions of GF, FI and FDI to ES, while also revealing a significant moderating role of GF on the effect of FI.

Table 4.5: Moderating role of GF on FI and ES

Variables	**Co efficient**	**Std. Error**	**t-Statistic**	**Prob.**
LNES (-1)	0.1459	0.0106	13.7191	0.0000
LNGF	0.1034	0.0103	9.9965	0.0000
LNFI	1.0625	0.0726	14.6364	0.0000
FDI	0.0110	0.0011	9.7987	0.0000
LNGF*LNFI	-0.0289	0.0030	-9.7333	0.0000
		Effects Specification		
Cross-sectional fixed (Orthogonal deviations)				
Mean dependent var	-0.023881	S.D dependent var	0.255845	
S.E. of regression	0.249791	Sum squared resid	28.57709	
J-statistic	35.264203	Instrument rank	36	
Prob(J-statistic)	0.273450			

4.4.3 The Moderating Role of Green Finance on Green Technology and Environmental sustainability

Table 4.6 presents the econometric findings from the panel GMM model (orthogonal deviations transformation), investigating the moderating role of GF on GT and ES. The dependent variable is ES, and the explanatory variables include the lagged value of LNES, the LNGT, LNGF, FDI, and an interaction term between GF and GT (LNGF*LNGT) to capture the moderating effect. The results indicate that the LNES has a statistically significant positive impact, with a coefficient of 0.5159 ($p < 0.01$). This suggests that past environmental sustainability levels positively influence current environmental sustainability. LNGT shows a statistically significant negative effect on ES, with a coefficient of 0.0278. This implies that an increase in GT is associated with an increase in CO_2 emissions which leads to decrease in ES. LNGF does shows a statistically significant negative impact on ES when considered individually, as its coefficient is 0.0274. FDI exhibits a statistically significant negative effect on ES, with a coefficient of 0.0227. This indicates that increased FDI contributes negatively to ES. The interaction term (LNGF*GT) has a coefficient of-0.0017. This indicates that there is statistically significant positive moderating role of GF on the relationship between GT and ES in this model. In other words, the impact of GT on ES significantly changes with varying levels of GF.

The model diagnostics confirm its validity, with a J-statistic p-value of 0.1420. Since this p-value is less than the typical 0.05 significance level, it suggests that the hypothesis of valid over-identifying restrictions cannot be rejected, indicating that the instruments used in the GMM model are appropriately specified. These findings collectively highlight the individual contributions of GT and FDI to ES, while suggesting that GF, when acting as a moderator, significantly alter the relationship between GT and ES in this specific model.

Table 4.6: Moderating role of GF on GT and ES

Variables	**Co efficient**	**Std. Error**	**t-Statistic**	**Prob.**
LNES (-1)	0.5159	0.0056	92.4556	0.0000
LNGT	0.0278	0.0108	2.5678	0.0129
LNGF	0.0274	0.0017	16.4392	0.0000
FDI	0.0227	0.0007	33.6105	0.0000
LNGF*LNGT	-0.0017	0.0008	-2.0723	0.0428

Effects Specification

Cross-sectional fixed (Orthogonal deviations)

Mean dependent var	-0.0239	S.D dependent var	0.2558
S.E. of regression	0.2041	Sum squared resid	19.0860
J-statistic	42.8500	Instrument rank	39
Prob(J-statistic)	0.1420		

4.4.4 The Moderating, Role of Green Finance on Digitalization and Environmental sustainability

Table 4.7 presents the econometric findings from the panel GMM model (orthogonal deviations transformation), examining the moderating role of GF on DIG and ES. The dependent variable is LNES and the explanatory variables include the lagged value of ES, LNDIG, LNGF, FDI, and an interaction term between GF and DIG (LNGF*LNDIG) to capture the moderating effect. The results indicate that the LNES has a statistically significant positive impact, with a coefficient of 0.1139 ($p < 0.01$). This suggests that past environmental sustainability levels positively influence current environmental sustainability. LNDIG shows a statistically significant negative effect on ES, with a coefficient of 0.0060. This implies that an increase in DIG is associated with an increase in CO_2 emissions which leads to decrease in ES. LNGF also demonstrates a statistically significant negative impact on ES, with a coefficient of 0.0167. This suggests that 1% increase in GF leads to increase in CO_2 emissions which contributes negatively to ES. FDI exhibits a statistically significant negative effect on ES, with a coefficient of 0.0123. This indicates that 1% increased FDI leads to increase in CO_2 emissions which contributes negatively to ES. The interaction term (LNGF*DIG) has a statistically significant negative co efficient of-0.0003. This negative coefficient for the interaction term indicates that GF positively moderates the relationship between DIG and ES in a way that, as GF increases, the positive impact of DIG on ES. This suggests that while both DIG and GF individually promote ES, their combined effect shows a decreasing marginal benefit or a more complex interplay where higher levels of GF might re duce the additional positive impact of DIG on ES.

The model diagnostics confirm its validity, with a J-statistic p-value of 0.154432. Since this p-value is greater than the typical 0.05 significance level, it suggests that the null hypothesis of valid over-identifying restrictions cannot be rejected, indicating that the instruments used in the GMM model are appropriately specified. These findings collectively highlight the individual positive contributions of DIG, GF and FDI to ES, while also revealing a significant moderating role of GF that somewhat dampens the positive impact of DIG on ES.

Table 4.7: Moderating role of GF on DIG and ES

Variables	**Co efficient**	**Std. Error**	**t-Statistic**	**Prob.**
LNES (-1)	0.1139	0.0069	16.5306	0.0000
LNDIG	0.0060	0.0012	4.9343	0.0000
LNGF	0.0167	0.0035	4.7751	0.0000
FDI	0.0123	0.0008	15.7085	0.0000
LNGF*LNDIG	-0.0003	0.0001	-4.2007	0.0001
		Effects Specification		
Cross-sectional fixed (Orthogonal deviations)				
Mean dependent var	-0.023881	S.D dependent var	0.255845	
S.E. of regression	0.233215	Sum squared resid	24.91036	
J-statistic	38.951446	Instrument rank	36	
Prob(J-statistic)	0.154432			

Chapter 5

Conclusions

5.1 Conclusion

This research explored the multifaceted impact of FI, GT and DIG on ES, specifically focusing on the moderating role of GF in relation to FI, GT and DIG across 58 developing countries from 2014 to 2023. To analyze these complex interactions among variables, the study employed a GMM estimation approach.

One important study finding is the remarkable persistence of ES, which highlights the significance of consistent efforts by showing that historical levels have a considerable and beneficial effect on current levels. However, the study found that DIG and GT both had statistically significant positive effects on ES. This result implies that, in the context of developing nations, the growth of DIG and GT may be linked to enhanced resource efficiency, the promotion of sustainable practices through innovation, or improved environmental monitoring and management. The introduction of cleaner technology and the implementation of more stringent environmental regulations, on the other hand, are perhaps the reasons why foreign direct investment has continuously shown itself to be a beneficial and noteworthy contributor to ES.

Dynamics were exposed by GF moderating influence. FI and GF each had a negative and statistically significant interaction term, despite their unique favorable direct effects on ES. This suggests a complicated reallocation of resources or declining returns when these two factors are coupled, since GF beneficial moderating influence on FI may decrease or become less than additive as it grows. Similarly, the beneficial impact of DIG on ES was shown to be considerably and negatively moderated by GF. This suggests that when these two factors are combined, GF may reduce or reroute the beneficial environmental effects of DIG, leading to a less noticeable overall improvement in ES.

It was shown that the beneficial impact of GT on ES was considerably and negatively moderated by GF. This suggests that when these two factors are combined, GF may reduce or reroute the beneficial environmental effects of DIG, leading to a less noticeable overall improvement in ES. In conclusion, DIG, FI, and GF may all support ES, but their combined benefits are complex and not necessarily directly additive. The unanticipated drawbacks of DIG and GT underscore the necessity for a more thorough comprehension of the practical implementation difficulties encountered in developing nations.

5.2 Policy Implications

From the empirical analysis, this paper offers policymakers various aspects to consider in promoting ES in developing countries. The results, obtained from the effect of FI, GT and DIG on ES, and the role of GF as a moderator on FI, GT, and DIG, are instrumental in crafting sound green growth policies.

The study reemphasizes the significance of long-term dedication and ongoing policy initiatives in environmental policy. Environmental gain is not realized through one-off efforts but through incremental development and the creation of strong, long-standing structures. Governments are urged to value continuing consistent environmental policies over the years in order to see that previous gains leave a strong foundation for future gains. This requires integrating sustainability targets deeply into national development plans and the budgeting process, turning them into integral policy ambitions as opposed to add-on considerations.

The surprising statistically significant direct effects of both DIG and GT on ES call for prompt attention. This seemingly counterintuitive result implies that mere diffusion or adoption of green technologies and digital tools, in the absence of supportive policies, will not necessarily assure intended environmental outcomes in developing environments. Policymakers must thus aim at the strategic deployment of actually environment-friendly green technologies accompanied by regulation that guarantees their sustainable production, deployment, and disposal. At the same time, advancing "green digitalization" by promoting the use of renewable energy sources for data centers, designing energy-efficient digital infrastructure, and adopting extensive e-waste management and recycling schemes. Policies must enable environmental benefits of DIG to truly exceed environmental costs.

The persistent and statistically significant positive impact of FDI on ES is extremely encouraging. This implies that FDI has the potential to act as a lifeblood for cleaner production practices, superior environmental management systems, and the diffusion of environmentally friendly technologies. Policymakers ought to strategically court environmentally friendly FDI by creating investment promotion schemes that particularly address green industries and sustainable sectors. At the same time, it is necessary to reinforce environmental due diligence in order to guarantee that effective environmental impact assessments and strong regulatory controls cover all the incoming FDI in order to avoid "pollution haven" effects and respect high environmental standards.

The moderating function of GF on FI and ES is one of the most important insights. While GF and FI, separately, contribute to ES in a positive manner, the negative moderating effect shows that an increase in GF can reduce the supplementary environmental benefits gained from FI. These intricate interactions call for policies that link sustainability with FI by urging financial institutions to incorporate environment-consciousness into lending and investment activities for financially included consumers. In addition, regulatory authorities and central banks ought to create specific GF products that can make green financial instruments widely available in a way that suits the environmentally friendly projects at all levels of the economy, particularly for marginalized communities. The emphasis should be placed on channeling funds into low-carbon activities instead of merely boosting overall financial flow, which is for prevention of a situation where broader FI could end up creating more resource use without environmental protection. It is important to integrate sustainability into FI initiatives to guarantee that environmental quality is not sacrificed in the face of economic growth.

GF does not have a statistically significant moderating effect on GT and ES; this does not undermine the significance of both factors. Policy makers ought to keep supporting GT uptake by encouraging the development, research, and extensive use of green technologies.

It is equally to bring finance and technology into alignment through ensuring financial instruments, including GF, are accessible to leverage up the rolling out of established green technologies, financing gaps for renewable energy schemes, sustainable transport solutions, and waste management facilities.

The moderating function of GF on DIG and ES, which also manifests in a negative dampening effect, calls for a complex policy response.

While both GF and DIG on their own encourage environmental sustainability, their compound effect indicates marginal diminishing returns.

Policy makers need to develop green digital ecosystems by adopting policies that encourage the creation of inherently green digital infrastructure and services.

Additionally, acknowledging that merely investing more GF in DIG may not proportionally increase its green value, the policies should aim to spend strategically in DIG that specifically addresses environmental issues, maximizing the environmental benefits and avoiding being negated by the mechanism of the finance.

Finally, becoming environmentally sustainable in developing nations is a dynamic, intricate process, and hence it calls for an extensively integrated policy structure. There is a need to go beyond the siloed thinking, with policymaker's keen on developing an enabling environment where GF strategically steers resources, FI encourages sustainable behavior, GT is responsibly adopted, and DIG adds to, not detracts from, the quality of the environment.

This requires cross-border partnerships to facilitate fair access to GF and technology, together with sound domestic regulatory frameworks that enhance effective policy implementation and enforcement.

By striking the correct balance between these variables and unleashing their synergy potential, developing nations can advance notably towards their sustainable development goals and address climate change in unison.

5.3 Limitations of the Study

Although this study contributes uniquely in the literature, there are still some limitations. The study has limited time period from 2014 to 2023. The reason to use this time period is the limited availability of data for most of the countries. The study focused on the macro perspectives while ignoring the micro level aspect, to ensure proper focus on specific perspectives. The study is only limited to developing countries, thus ignoring the cross-country analysis to make generalized perspective.

5.4 Future Directions

Due to the limitations stated in the study, this study presents new windows of opportunity for future researchers to explore. The comparative analysis by region, in relation to these variables (GT, DIG, ES, GF, and FI) can aid in delving deeper into this study. In addition, there needs to be a specific emphasis on a micro-level approach in subsequent research, examining firm-level or household-level effects in order to generate finer insights.

The utilization of multiple moderator's models within the subject of environmental finance is currently relatively new, so subsequent researchers may utilize this advanced modeling method in numerous potential ways to study intricate relationships in finance and environmental research. Alternative methodologies, aside from the GMM, may also be employed to further confirm the results of this study and undertake additional robustness tests.

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Appendix A

Appendix A

S.no	Name	S.no	Name	S.no	Name	S.no	Name
1	Afghanistan	16	Dominican Republic	31	Iran	45	Mongolia
2	Algeria	17	Ecuador	32	Iraq	46	Morocco
3	Bangladesh	18	Egypt	33	Jamaica	47	Myanmar
4	Belize	19	El Salvador	34	Jordan	48	Namibia
5	Bhutan	20	Eswatini	35	Kenya	49	Nepal
6	Botswana	21	Fiji	36	Lebanon	50	Niger
7	Brazil	22	Gambia	37	Lesotho	51	Nigeria
8	Burkina Faso	23	Ghana	38	Libya	52	Pakistan
9	Cambodia	24	Guatemala	39	Madagascar	53	Paraguay
10	Cameroon	25	Guinea	40	Malaysia	54	Peru
11	China	26	Guyana	41	Mali	55	Philippines
12	Colombia	27	Haiti	42	Mauritania	56	South Africa
13	Congo	28	Honduras	43	Mauritius	57	Sri Lanka
14	Costa Rica	29	India	44	Mexico	58	Türkiye
15	Djibouti	30	Indonesia				