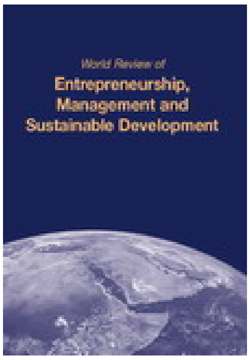

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Sustainable finance and social development: do institutional quality and ICT infrastructure matter?

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Abstract: The link between social sustainability and sustainable finance has drawn considerable scholarly attention due to its significance in advancing the Sustainable Development Goals (SDGs). Among the critical enablers for achieving these goals are strong institutional frameworks and robust ICT infrastructure. This study examines the effectiveness of sustainable finance in promoting social sustainability, with particular emphasis on the moderating roles of institutional quality and ICT infrastructure. Using the PMG-ARDL model, the study analyses panel data from G20 and non-G20 countries spanning 2000–2020. Findings reveal that both green and social finance are key drivers of social sustainability. However, the interaction between ICT and the social finance–social sustainability nexus diminishes its effectiveness in both G20 and non-G20 contexts, as disadvantaged groups often face barriers to accessing digital financial services, limiting the benefits of social finance. Institutional quality amplifies the positive impact of social finance on social sustainability across all countries studied.

Keywords: sustainability; green finance; social development; technology; developed countries.

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1 Introduction

Given the escalating environmental concerns and the pressing need for sustainable development, the convergence of finance, institutional quality, ICT infrastructure and social sustainability has emerged as a topic of study and policy debate (Zhang et al., 2023). Green and social finance are at the heart of this convergence. Green finance is a systematic allocation of financial resources to projects and initiatives that promote environmental sustainability while also driving economic sustainability (Dziejarski et al., 2023). Social finance is the application of financial resources to enhance the environment and societal development. Understanding the mechanics of green and social funding, and their relationship to social sustainability, is crucial to attaining sustainable development (Rizwan-Ul-Hassan, 2017).

The primary objectives of social sustainability are to create societies that are equal, inclusive and resilient. As nations throughout the world attempt to construct resilient societies and meet the United Nations' Sustainable Development Goals (SDGs), the role of sustainable finance in aiding this change becomes increasingly important (Alharbi and Hashim, 2024; Altamar et al., 2025). However, the efficacy of these programs is dependent on several factors, including the quality of institutions (Hossin et al., 2024;

Sharma et al., 2022) and the availability of ICT infrastructure. Institutional quality, which includes governance structures, regulatory frameworks and legislation, affects the enabling environment for sustainable financing (Zhao et al., 2024) and influences investor confidence and sustainable company practices. Because of the relevance of sustainable finance in sustainable development, previous studies have investigated the relationship between green and social finance and sustainable development. However, there is a significant gap in understanding the roles of institutional quality and ICT infrastructure in this relationship. Existing research has primarily concentrated on the direct benefits of green and social finance on environmental outcomes and economic development (Agboola and Tunay, 2023; Udemba et al., 2024), ignoring that the interaction of institutional variables and ICT may influence the sustainable finance and development nexus. Also, Rao et al. (2023) and Wang et al. (2022a) did an analogous investigation in China on the nexus of sustainable finance and environmental sustainability. Xie (2024) examined the moderating impact of institutional quality on the link between financial development and environmental quality in South Asia. Wang et al. (2023), among others, conducted the same analysis using a sample of advanced and developing nations but did not examine institutional quality. Consequently, there is a scarcity of empirical proof and theoretical frameworks that explain the moderating impact of these variables on the relationship between sustainable finance and social sustainability.

The inspiration for this research derives from an understanding of the crucial role that green and social funding play in furthering sustainable development goals in both emerging and developed countries (Amuah et al., 2024). In emerging economies, where ecological challenges frequently interact with socioeconomic weaknesses, green and social funding provide a chance to address serious environmental concerns while fostering inclusive growth and poverty reduction. Similarly, in advanced nations, sustainable development is vital, especially when sustainable practices are integrated into corporate strategy, and green and social funding drives sustainability outcomes.

The objectives of this study are twofold. First, it assesses the direct effects of green finance and social finance on social sustainability outcomes. Second, it explores the moderating role of institutional quality and ICT infrastructure in shaping the relationship between these financing mechanisms and social sustainability across G20 and non-G20 countries. This involves analysing the combined influence of global governance dimensions – namely, control of corruption, regulatory quality, political stability, government effectiveness, voice and accountability and rule of law – alongside ICT infrastructure, on the effectiveness of green and social finance systems in both economic groups.

This work aims to make several significant contributions. The study offers practical proof and theoretical insights into the effects of green and social finance on social sustainability. It also seeks to determine the moderating effects of institutional quality and ICT infrastructure on the sustainable finance – social sustainability nexus. The study improves understanding of the intricate interplay of financial mechanisms, governance structures and information and Communication Technology (ICT) in driving sustainable development. Furthermore, the current study provides policy suggestions for policymakers, financial institutions and other players to capitalise on the synergies between green finance, social finance, institutional quality and ICT for sustainable development. The rest of the paper is structured as follows. Section 2 includes the literature review; Section 3 presents the data and model estimation; Section 4 presents the results and discussion and Section 5 presents the Conclusion, implications and limitations.

2 Literature review

Social sustainability is one of the three fundamental tenets of sustainability. When it comes to issues that occur in connection with the social components of sustainability, scholars haven't given nearly as much consideration as they should (Ecer, 2019). In the framework of sustainable development, certain literary works have examined the connections between the wide range of social sustainability issues, including gender equity, health, education, household economic position, social finance, employment and poverty. As a result, we provide a conceptual review and an empirical evaluation of previous research.

The concept of social sustainability has many facets, and the central question is, 'What are the social goals of sustainable development?' There is no agreement on how these goals should be defined, resulting in a wide range of viable replies (Hopwood et al., 2005; Littig and Griessler, 2005). Thus, the definition of social sustainability differs greatly across the literature (Weingaertner and Moberg, 2014). Surprisingly, the bulk of extant definitions of social sustainability generally relies on specific criteria (Sachs, 1999); some on core principles of democracy and values (e.g., Barbier and Markandya, 1989; De Koning et al., 2021); and yet others on the importance of nature and society (Hopwood et al., 2005; Littig and Griessler, 2005). According to Barbier (2016), social sustainability is the quality of a society that supports long-term circumstances for human well-being, particularly for marginalised people or groups. Therefore, social sustainability is generally concerned with three main factors – basic needs of society, personal development and health, as well as fulfilling conditions for a well-balanced society (Ecer et al., 2019). Sustainable finance is defined as inclusive financing that considers environmental, social and governance challenges (Forstater and Zhang, 2016; Rizzello and Kabli, 2020). It makes general recommendations for long-term economic and social sustainability. Sustainable finance is a funding model that considers governance, social and economic factors. This includes green finance and social finance, among others. Green finance is sometimes used interchangeably with green investment and can be defined as the overall capital cost of transitioning to an ecologically friendly economy, such as lowering pollution, increasing resilience and ensuring food security (Menget al., 2022). According to Wang et al. (2022b), Green Finance is a sustainable financial system that considers the Environmental, Social and Governance (ESG) components. Social finance refers to the collaboration between the commercial and public sectors to fund public goods production, such as education, health and social protection, also known as the 'third sector' of the economy. Social finance analysis evaluates the viability of impact investment in producing public goods (Savitri et al., 2020).

ICT infrastructure plays a revolutionary role in the distribution, management and deployment of finance. It serves as a platform for digital innovations that improve the effectiveness, accessibility and inclusivity of financial services. ICT infrastructure has liberalised access to finance, permitted new kinds of financial intermediation and facilitated increased transparency and accountability. Examples of these technologies include peer-to-peer lending platforms, electronic payment systems, blockchain and mobile banking. ICT infrastructure has the power to scale interventions, simplify procedures and increase effect in the context of social finance – all of which could hasten the achievement of sustainable development goals (Kiel et al., 2017).

The concept of institutional quality can be explained as the efficacy and integrity of public institutions, regulatory frameworks and governance structures. It lays the foundation of this mutually beneficial relationship (Nathaniel et al., 2021). Khan et al. (2019) argued that sturdy institutions are essential in forming laws that support sustainable financing projects. According to them, Institutional Quality is the framework required to promote responsibility, openness and confidence in the financial system, reducing risks and encouraging investment in sustainable development initiatives. The indices of institutional quality include regulatory quality, rule of law, control of corruption, political stability, government effectiveness and voice and accountability (World Governance Index).

2.1 Theoretical framework

The institutional Perspective theory is used in this study to explain the interactions between the variables of interest. The theory underscores that individuals and governments are not simply rational systems for providing public goods and services, but rather adjust to the conditions of suppliers, consumers and competitors (Priyanka et al., 2025). They represent a social and cultural systems that exist inside an 'institutional' environment of social expectations and prescriptions about what constitutes suitable ('legitimate') behaviour. For most businesses, the key context is the organisational field, which includes regulators, professional groups and the media. These characters make up the 'institutional infrastructure' that analyses and communicates its social and cultural rules (Hinings et al., 2017). The purpose of Institutional Perspective Theory is to gain legitimacy and support from external players such as governments, regulators and society (Ortiz-de-Mandojana et al., 2016). According to institutional perspective theory, every institution operates in institutional contexts in which the country or institution must deal with the numerous demands of society (Dillard et al., 2004; Comyns, 2016). Furthermore, Scott (2012) defined institutionalisation as the social process by which an individual accepts norms, habits and practices.

In contrast, Dillard et al. (2004) observed that expected habits are taught and established. The institutional environment reflects the nation's actions, which include laws, rules, policies, standards and procedures. It also demonstrates how governments are bound by accepted, mimetic and coercive limitations to follow established norms, standards and conventions in places with strong institutional systems.

Institutional theory has been widely used in discussions of climate change and environmental performance (Masud et al., 2018). Businesses are encouraged by several laws, rules and regulations to support green and climate efforts. In addition, green finance is an important and aspirational option for sustainable growth, where nations follow both mandatory and voluntary regulations. To successfully achieve their goals, nations are under pressure to adopt or alter institutional structures to meet the necessary needs. Additionally, the main forces behind green and social finance include normative, legal and institutional pressures that push nations to show leadership in environmental performance in order to gain a competitive advantage.

2.2 Empirical literature review

The sustainable finance – social sustainability nexus remains the prime research hotspot among contemporary researchers. A careful examination of extant literature reveals rich evidence of studies on the relationship among the dimensions of Sustainable Development. As far as the concern of direct and moderating relationships, researchers have varied opinions. Several studies provide extensive literature on the influence of sustainable finance on sustainable development.

2.2.1 Green finance and social sustainability

Several studies have undertaken the exploration of how green finance influences sustainable development. The findings from this research shed light on the dynamic interplay between these two crucial elements of global sustainability: Wang et al. (2022b) used the bootstrap rolling-window Granger causal association test to evaluate the causal relationship between green finance and sustainable development on a global scale. The empirical findings corroborate interaction theory by showing that green finance has beneficial effects on sustainable development throughout several subperiods. However, this article's conclusion regarding the direction from sustainable development to green finance is inconsistent. According to them, the role of green finance is amplified by various multilateral and government ecological regulatory laws, investor initiatives and improved supervision. This emphasises how crucially important collective socially sustainable behaviour and governmental rules have been in forming the landscape of green finance. Nile et al. (2024) conducted a thorough evaluation of the impact of green finance on sustainable development in sub-Saharan African nations between 1999 and 2023. Sub-Saharan African nations are thought to be the most vulnerable to climate change because of their unique geographic location, economic makeup, population density, social sensitivity and limited ability to adapt to the changing climate.

The Pooled Mean Group Autoregressive Distributed Lags (PMG/ARDL) approach was used because it can account for serial autocorrelation and endogeneity, which have been overlooked in earlier research. The results highlight the critical role that green finance plays in encouraging sustainable practices by raising investment in sectors that place a high priority on sustainability, conservation and biodiversity preservation through technological advancements and educational levels. In order to comprehensively assess the influence of green finance on sustainable finance, Fu et al. (2024) used the Fuzzy Analytic Hierarchy Process (AHP) and Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) techniques. Fuzzy AHP results show that green finance is the most important influencing factor for environmental sustainability. Xing et al. (2024) used reliable methods to quantify green finance that other research hasn't looked at, like the system-GMM method and using a variety of proxies. Specifically, panel data from 1985 to 2021. The results confirm that environmental degradation has the exact opposite effect of green finance, which often has a beneficial impact on sustainable development. Zhang et al. (2024) conducted an empirical analysis of how technological advancements and green finance have affected the Yangtze River Economic Belt's sustainable growth over 21 years. According to the research findings, regional sustainable development is facilitated by a greater degree of green finance and high-tech innovation. Low levels of advanced technology or green finance will both work against the region's overall development sustainability by impeding the collective effect of supporting sustainable development.

Using the STIRPAT model, Chien et al. (2024) calculated the impact of green financing and technology developments on environmental sustainability as shown by ecological footprints in Indonesia. Time series data from various secondary sources covering the years 1995–2020 were gathered, and the Quantile Autoregressive Distributed Lag Model was used for empirical analysis. The results show that green finance and Information and Communication Technologies (ICT) have a beneficial impact on environmental sustainability over the complete quantile range (0.05–0.90), both in the short and long term. A mixed-methods approach is used by Raman et al. (2025) to examine how green and sustainable finance contribute to the UN Sustainable Development Goals (SDGs). To identify trends, they combined machine learning-based BER Topic modelling, case study analysis and quantitative bibliometric techniques. According to the findings, innovations like green bonds, social impact bonds and green fintech are essential for promoting sustainable development and reducing environmental effects. High transaction costs and inadequate institutional frameworks in underdeveloped nations are among the obstacles that have been cited as impeding the wider implementation of green finance technologies. Zhang (2024) used Fuzzy Multi-Objective Least Squares (FMOLS) and dynamic ordinary least squares (DOLS) econometric regression techniques to investigate the effects of China's public-private energy partnerships on CO2 emissions from 1990Q1 to 2022Q4. According to the findings, increasing credit availability has made it easier for green finance to emerge, which has improved the environmental effects of China's economic expansion and public-private partnerships. Using a Generalised Method of Moments approach, Chin et al. (2024) investigated whether green finance was important in reducing environmental degradation in the BRI region. They discovered a negative and significant correlation between green finance and environmental degradation, indicating that green finance is an important factor in halting the decline of environmental quality while simultaneously boosting economic growth.

The socio-ecological implications of green finance on social sustainability in various settings were considered in the reviewed literature; nevertheless, none of the literature established a firm conclusion on the nature of the relationship between them. By evaluating the influence of green finance on social sustainability and creating a comprehensive policy framework for accomplishing the SDGs, this study seeks to offer a distinctive contribution to the sustainability literature.

H1: Green finance is a significant positive predictor of social sustainability.

2.2.2 Social finance and social sustainability

Some researchers confirm that Islamic Social Finance (Zakat) benefits both individuals and society by achieving its social and economic objectives through the provision of financial relief to the poor. Utami et al. (2021) examined the impact of Islamic Social Finance on the general people. This study found that Islamic social finance reduces poverty by leveraging digital technologies in ATMs and improving collection efficiency. Dahlan et al. (2024) did a study on sources, discussions and Sunnah. A 2010 Tunisian family survey found that Islamic social finance plays a crucial role in reducing poverty.

Furthermore, Majid et al. (2022) studied credit comfort and the significance of microfinance using an arena study that categorises Pakistanis' attitudes toward poverty alleviation. Microfinance groups successfully alleviated poverty in Pakistan, despite the majority of the people lived below the poverty line. According to Iqbal et al. (2024) study, Zak'at has the potential to reduce poverty for a significant number of people. The study found that investing in Islamic social finance for the poor, widows, needy, orphans and disadvantaged had significantly reduced poverty. Clark et al. (2015) did a study on impact investment in emerging countries and discovered that it helps to promote long-term social development, particularly in emerging markets.

Using qualitative analytical techniques, including content analysis, narrative synthesis and thematic analysis, the research approach involves a thorough review of the existing body of literature. Key findings demonstrate the importance of sustainable finance in achieving environmental goals by directing funds to conservation efforts, supporting environmentally friendly initiatives and facilitating the transition to a low-carbon economy. The report also emphasises how important it is to use sustainable finance projects to address social issues, including community development, gender equality and labour rights. Hossain et al. (2025) assessed the contribution of Islamic social finance, particularly zakāt and Islamic microfinance, to sustainable economic growth in Bangladesh. Data for the study came from Bangladesh's capital city and was gathered using a quantitative research methodology. The study's conclusions demonstrate the substantial benefits of Islamic and zakāt microfinance for Bangladesh's long-term, sustainable economic growth. One of the major constraints of this study is data sampling, as it only gathered data from the capital city of Bangladesh.

Suprayitno (2024) assessed the impact of Islamic finance on the economic development of five Indonesian states using ECM analysis. The study discovered a strong positive relationship between governments' economic success and Islamic finance. Using a fuzzy technique, Belhadj et al. (2019) examined the possible value of social financing in reducing poverty in Tunisia's 2010 wellbeing surveys. According to the simulation results, seven regions saw a considerable decline in the nation's poverty index. For instance, Umar et al. (2022) evaluated how social finance and knowledge contributed to Sudan's poverty eradication efforts between 1990 and 2009. According to the study, social capital and knowledge played a major role in reducing poverty in the nation. According to Iqbal et al. (2024) study, zakāt has the potential to reduce poverty for a significant number of people. The study found that investing in Islamic social finance for the poor, widows, needy, orphans and disadvantaged had significantly reduced poverty. Clark et al. (2015) did a study on impact investment in emerging countries and discovered that it helps to promote long-term social development, particularly in emerging markets.

Bauer et al. (2021) found that organisations that integrate ESG principles outperform typical corporations in both financial and social sustainability indices. Based on the review of the literature above, the study seeks to test the hypothesis that.

H2: Social finance is a significant positive predictor of social sustainability.

2.2.3 ICT infrastructure and sustainable finance – social sustainability nexus

ICT has been deemed a useful instrument in lowering atmospheric carbon dioxide emissions worldwide through the development of smarter industrial operations, transportation networks, cities and cost-effective improvements (Higón et al., 2017; Ollo-López and Aramendía-Muneta, 2012). According to Shaaban-Nejad and Shirazi (2022), the overall efficiency and electricity consumption of building systems and other infrastructures are directly impacted by ICT. Although ICT is expected to contribute only 2% of world GHG emissions, according to the World e-sustainability Initiative report, ICT will reduce global GHG emissions by 15%, particularly CO2 emissions (Higón et al., 2017). Erumban and Das (2016) argued in a similar vein that while ICT boosts economic growth as measured by per capita GDP, this expansion also increases CO_2 emissions. Because of this, concerns are being raised about the potential impact of global ICT advancements on the creation of more ecologically friendly patterns in our everyday lives. Misuraca et al. (2018) asserted that information and communication technology drives innovation. The relatively new concept of 'going smart' is rapidly changing and having an impact on academic research and policymaking literature.

According to Shirazi and Hajli (2019), ICT is the primary driver of sustainable innovation. Empirical research by Higón et al. (2017) and Lu et al. (2018) demonstrated that ICT infrastructure negatively affects CO_2 emissions. In this sense, ICT is recognised as one of the key tactics implemented in numerous nations to reduce carbon dioxide emissions. Furthermore, causation findings indicate that GDP growth, energy consumption and financial development all lead to higher environmental pollution (Toader, 2023). An additional empirical study backs up the connection between environmental sustainability and the digital economy, or the adoption of ICT. They contend that ICT can support structural and economic development, better technologies and modifications to the industrial process. This will ultimately lead to improvements in environmental sustainability and quality, including reduced carbon emissions and an ecological footprint (Simpson and Daehnhardt, 2019; Sadorsky, 2014).

According to a different school of thinking, the digital economy's ICT adaptation is meant to be highly reliant on energy consumption, specifically electricity. This, in turn, would create a high demand for energy consumption, which will ultimately lead to environmental unsustainability (Tüzemen et al., 2023). Therefore, ICT does not affect environmental sustainability, according to the third argument. They contend that the ability of ICT to produce low energy consumption results in a rise in demand for energy, negating any beneficial effects on environmental quality (Kouton, 2019). The analysis above shows that there are three possible relationships between ICT infrastructure and sustainability: positive, negative and neutral. However, it says nothing about how ICT infrastructure affects the relationship between green finance and social sustainability. To close this gap, this paper aims to.

H3: Evaluate the moderating effect of ICT infrastructure on the sustainable finance – social sustainability nexus.

2.2.4 Institutional quality and sustainable finance – social sustainability nexus

Numerous studies have been conducted on the factors influencing environmental performance, and institutional quality is one of these variables. Ott et al. (2011) asserted that institutional quality – which ensures enforcement of various statutory standards –

plays a critical role in mitigating climate change. Abduqayumov et al. (2020) looked into how the environment was affected by institutional quality in the fifteen post-Soviet nations from 2001 to 2017. With the application of the Generalised Method of Moments (GMM). The study's conclusions show that the environment's quality is positively impacted by institutional quality. Climate change-related issues cannot be resolved without regulations of the executive branch (Wang et al, 2021). Kulin and Sevä (2021) emphasised the significance of the calibre of institutions in carrying out environmental protection programs of the government. Abbas and Khan (2023) looked at how, in panel Asian economies, energy consumption per capita, FDI and regulatory quality affected greenhouse gas emissions between 2001 and 2018. The explanatory variables in this study are regulatory quality and energy consumption per capita. The integrating variable in this model is foreign direct investment in conjunction with regulatory quality and energy consumption. According to their findings, energy use raises greenhouse gas emissions, whereas regulatory quality in Asia actively promotes lowering greenhouse gas emissions. Furthermore, when sufficient inflows of foreign direct investment are achieved, foreign direct investment plays an integrating role by significantly increasing renewable energy consumption and energy efficiency.

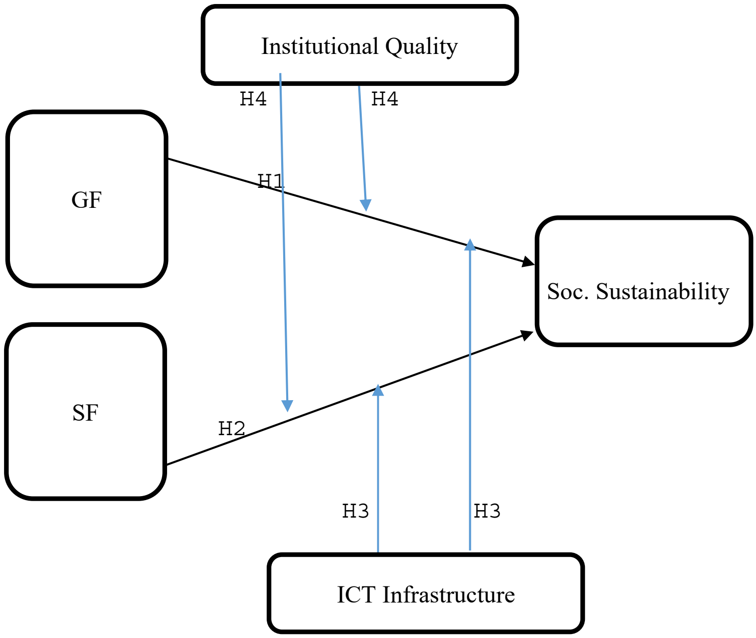
According to Ali et al. (2023), the ecological quality of 47 Organisation of Islamic Cooperation (OIC) countries was impacted by institutional efficiency as well as other factors like commerce, FDI inflows, and urbanisation. Apart from the institutions, they observed that all the other components exhibited a positive link with the ecological quality. Breaking down the various energy sources, Christoforidis et al. (2021) found that while institutional efficiency increased ecological sustainability, economic growth and the use of non-renewable energy sources had a negative environmental impact. They also explained how a country's institutional performance and the diversification of its energy mix relate to ecological sustainability. The motto for the Sustainable Development Goals (SDGs) and ecological advancements of the UN is 'Better Environment, Better Tomorrow.' The quality of a nation's institutions reduces environmental degradation even in low-income countries (Haider et al., 2022). This suggests that as future earnings rise, the environment will get better and that high-quality institutions can lessen the negative environmental effects of a sudden economic boom. As a result, comprehensive strategies for boosting environmental quality and advancing economic growth can also be found in improved institutional quality (Wan et al., 2022). According to Wawrzyniak and Doryń (2020), an effective governance structure promotes environmentally responsible behaviour and raises environmental standards.

To them, environmental quality will improve if institutions of government are powerful enough to apply ecological laws and policies.

The foregoing review indicates the influence of institutional quality on environmental sustainability and economic growth. There is, however, limited literature on the moderating role of institutional quality on green and social finance and social sustainability. This paper thus addresses this gap

H4: Evaluate the moderating effect of Institutional Quality on the sustainable finance – social sustainability nexus.

Figure 1 Conceptual framework



Source: Author's own construction

3 Data source and empirical estimation

3.1 Data source

The analysis uses an imbalanced panel of 171 nations with data from the World Development Indicators (WDI), ND Gain, OECD database and World Bank from 2000 to 2020. The period was chosen to evaluate the impact of sustainable finance following the establishment of the United Nations Environment Programme Finance Initiative (UNEP FI) in 1992 and the SDGs in 2015. This resulted in a growth in sustainable finance for member nations through bilateral and multilateral funds, particularly between 2000 and 2020. The dependent variable is social sustainability. This work creates an index framework as a measure of social sustainability. The indicators include Basic Needs, Personal Development and Health and a Well-balanced Society (Saisana and Philippas, 2012; World Bank, 2012). The independent variables are green finance and social finance. The study uses two moderators – Institutional Quality and ICT Infrastructure. Four control variables have been employed to address concerns regarding variable omission bias, and these are foreign direct investment, doing business, quality of trade and transportation infrastructure and economic growth (proxied by GDP). This is congruent with Shahbaz (2013), who claim that these variables cause CO_2 emissions, which impact sustainability because they flow into industrial firms. Details are included in Table 1.

Table 1 Variable description

	Secondary	*Tertiary*	*Description*	*Symbol*	*Source*	*Reference*
Social Sustainability Index	Basic needs	Food Sufficient	Prevalence of undernourishment (% of population)	FS	World Bank	Sustainable Society Index V2 (2023)
		Sufficient drinking water	People using at least basic drinking water services (% of population)	SDW	world Bank	Sustainable Society Index V2 (2023)
		Safe sanitation	People using at least basic sanitation services (% of population)	SS	World Bank	Sustainable Society Index V2 (2023)
	Personal devt and health	Education	Gross enrolment ratio, primary and secondary, both sexes (%)	ED	World Bank	Sustainable Society Index V2 (2023)
		Health life years	Life expectancy at birth, total (years)	HF	World Bank	Sustainable Society Index V2 (2023)
		Gender equality	Gender Gap Index	GE	World Economic Forum	Sustainable Society Index V2 (2023)
	Well-balanced society	Income distribution	The level of equality of the distribution between the people in a country	ID	Standardised World Income Inequality Database (SWIID)	Sustainable Society Index V2 (2023)
		Population growth	Population growth (annual %)	PG	World Bank	Sustainable Society Index V2 (2023)
		Good governance	The sum of the values of the six Worldwide Governance Indicators	GG	World Bank	Sustainable Society Index V2 (2023)

Table 1 Variable description (continued)

	Variable	*Proxy*	*Symbol*	*Description*	*Sign*	*Source*
Independent	Social finance	Education Finance	EF	Government exp. on education as a % of GDP	+	WDI
		Health Finance	HF	Government exp. on Health as a % of GDP	+	WDI
		Social Protection Finance	SF	Government military exp. as a % of GDP	+	WDI
	Green finance	Renewable Energy Finance	ReF	Public expenditure on renewable energy	+	IRENA 2022
		Carbon Finance	CF	Expressed as the ratio of CO2 emissions to PGDP	+	WDI
		Climate Finance	CLF	Climate mitigation and adaptation finance from bilateral, multilateral and private philanthropic sources	+	OECD
		Institutional quality	IQ	PCA of World Governance Index variables	+	WGI
Moderators		ICT Infrastructure	ICTI	A composite indicator from 4 sub-indicators that consider both the access to and the use of ICT infrastructure: mobile phone subscription per 100 persons, fixed phone subscription per 100 persons, fixed broadband subscription per 100 persons and percent of individuals using the internet	+	ND-GAIN
Control	Economic Growth	Per capita GDP	PGDP	GDP per capita growth (annual %)	+	ND-GAIN
	FDI	Foreign Direct Investment	FDI	The degree of foreign direct investment ratio to GDP		WDI
	Quality of trade and transport infrastructure	Quality of trade and transport infrastructure	QTTI	Logistics professionals' perception of the country's quality of trade and transport-related infrastructure. Rating from 1(very low) to 5 (very high)	+	ND-GAIN
	Doing business	Ease of Doing Business	EDB	Ease of Doing Business		ND-GAIN

3.2 Model specification

A linear panel data model was used to investigate the effects of green and social financing on social sustainability and the moderating role of Institutional Quality and ICT Infrastructure on the relationship. To evaluate its marginal influences, this model conducts a spatial-temporal evaluation of empirical patterns of the independent variables on the dependent variable. The parameterised equation that linearly estimates the effect of independent and moderating factors on the dependent variable for the chosen empirical data is shown below.

$$\begin{aligned} SS_{it-1} = {} & \beta_0 + \beta_1 GF_{it-1} + \beta_2 SF_{it-1} + \beta_3 ED_{it-1} + \beta_4 QTTI_{it-1} \\ & + \beta_5 GDP_{it-1} + \beta_6 FDI_{it-1} + \varepsilon_{it-1} \end{aligned} \tag{1}$$

$$\begin{aligned} SS_{it-1} = {} & \beta_0 + \left(\beta_1 GF_{it-1} * IQ_{it-1}\right) + \left(\beta_2 SF_{it-1} * IQ_{it-1}\right) + \beta_3 ED_{it-1} + \beta_4 QTTI_{it-1} \\ & + \beta_5 GDP_{it-1} + \beta_6 FDI_{it-1} + \varepsilon_{it-1} \end{aligned} \tag{2}$$

$$\begin{aligned} SS_{it-1} = {} & \beta_0 + \left(\beta_1 GF_{it-1} * ICT_{it-1}\right) + \left(\beta_2 SF_{it-1} * ICT_{it-1}\right) + \beta_3 ED_{it-1} + \beta_4 QTTI_{it-1} \\ & + \beta_3 GDP_{it-1} + \beta_3 FDI_{it-1} + \varepsilon_{it-1} \end{aligned} \tag{3}$$

where equation (1) shows, SS_{it-1} Social Sustainability ; GF_{it-1}; Green Finance, SF_{it-1}; Social Finance, IQ_{it-1}; Institutional Quality; $ICT_{it-1} = ICT\ Infrastructure$; ED_{it-1}; Doing Business FDI_{it-1}; $Foreign\ Direct\ Investment$, $GDP_{it-1,}$; $Economic\ Growth, and\ QTTI_{it-1}$ Quality-of-Trade and Transport Infrastructure. Further β_0; β_1; β_2; β_3; β_4; β_5; β_6; represent the coefficients of corresponding explanatory indicators and ε_{it} reports the error term.

We use the natural logarithm to standardise equations (1), (1) and (1). Normalisation is crucial because putting all variables on a comparable scale allows for clearer comparisons and reduces bias in outcomes. It allows coefficients to be interpreted in terms of standard deviations, making results easier to understand.

Equations (1), (1) and (1) can be rewritten as follows:

$$\begin{aligned} lnSS_{it-1} = {} & \beta_0 + \beta_1 lnGF_{it-1} + \beta_2 lnSF_{it-1} + \beta_3 lnED_{it-1} + \beta_4 lnQTTI_{it-1} \\ & + \beta_5 lnGDP_{it-1} + \beta_6 lnFDI_{it-1} + \varepsilon_{it-1} \end{aligned} \tag{4}$$

$$\begin{aligned} lnSS_{it-1} = {} & \beta_0 + \left(\beta_1 lnGF_{it-1} * lnIQ_{it-1}\right) + \left(\beta_2 lnSF_{it-1} * lnIQ_{it-1}\right) + \beta_3 lnED_{it-1} \\ & + \beta_4 lnQTTI_{it-1} + \beta_5 lnGDP_{it-1} + \beta_6 lnFDI_{it-1} + \varepsilon_{it-1} \end{aligned} \tag{5}$$

$$\begin{aligned} lnSS_{it-1} = {} & \beta_0 + \left(\beta_1 lnGF_{it-1} * lnICT_{it-1}\right) + \left(\beta_2 lnSF_{it-1} * lnICT_{it-1}\right) \\ & + \beta_3 lnED_{it-1} + \beta_4 lnQTTI_{it-1} + \beta_5 lnGDP_{it-1} + \beta_6 lnFDI_{it-1} + \varepsilon_{it-1} \end{aligned} \tag{6}$$

3.3 Empirical estimation

This study conducted various tests to see how green and social financing influence societal sustainability. The current study's empirical modelling technique consists of five parts. First, descriptive statistics were employed to identify the features of the study's variables. Second, following Pesaran et al. (2004), Cross-sectional Dependency (CD) was assessed. Third, the Cross-sectionally Augmented Dickey–Fuller test (CADF) and cross-sectionally augmented IPS (CIPS) (Second generation) unit root tests (Pesaran,

2007) were employed to determine the presence of stationarity for all variables of interest. This study investigated the effects of GF and SF on SS, using IQ and ICT as moderators. The PMG-ARDL technique was employed in the research of 20 G-20 nations and 151 non-G-20 economies from 2000 to 2020.

3.3.1 Summary of statistics

Descriptive statistics in Table 2 show significant structural and distributional differences between G20 and non-G20 countries. The mean scores for Social Sustainability (0.19), Green Finance (0.30) and Social Finance (0.36) are all positive, indicating stronger institutional frameworks and more advanced sustainable financial ecosystems. The median values for Social Sustainability are somewhat higher than the mean, showing modest left-skewness, whereas the negative median for Green Finance indicates that, despite outstanding performance, some nations trail severely. The maxima for Green Finance (20.00) and GDP (23.59) demonstrate the presence of advanced economies with extraordinary potential, while the minima, particularly for Social Sustainability (–8.15) and GDP (–15.89), indicate periods of extreme socioeconomic or environmental stress in some members.

The dispersion is substantial, with standard deviations of 2.21 for Social Sustainability, 1.93 for Green Finance and a particularly massive 26.46 for FDI, indicating significant variation among the G20. High positive skewness in Green Finance (6.59) and FDI (9.78) demonstrates that extreme positive outliers drive a portion of average performance; however, high kurtosis values (52.95 for Green Finance and 127.45 for FDI) imply infrequent but extreme deviations from the norm. Jarque-Bera tests show that none of the variables have a normal distribution ($p < 0.01$), highlighting the need for reliable estimation methods.

Table 2 Summary descriptive statistics

	SS	*GF*	*SoF*	*ED*	*QTTI*	*GDP*	*FDI*
Mean	0.193	0.296	0.356	0.472	0.509	2.282	7.035
Median	0.896	– 0.210	0.322	0.453	0.536	2.264	2.941
Maximum	3.059	20.001	4.179	0.881	0.849	23.590	449.083
Minimum	– 8.151	– 0.768	– 2.214	0.044	0.144	– 15.890	– 117.375
Std. Dev.	2.215	1.928	1.098	0.159	0.176	3.688	26.465
Skewness	– 1.216	6.592	0.209	0.196	– 0.265	– 0.466	9.778
Kurtosis	3.814	52.953	2.756	2.454	1.909	6.953	127.445
Jarque – Bera	320.813	130118.2	11.466	22.035	71.695	804.394	773619.5
Probability	0.000	0.000	0.003	0.000	0.000	0.000	0.000
Sum	225.513	346.568	416.724	553.092	596.456	2670.522	8231.477
Sum Sq. Dev.	5734.671	4346.696	1411.418	29.406	36.194	15900.33	818752.8
Observations	1170	1170	1170	1170	1170	1170	1170

According to the data in Table 3, SS has a positive correlation with GF (0.487), ICT (0.401), QTTI (0.568) and ED (0.523), indicating that these variables have a significant impact on social sustainability. GF has a good correlation with SoF (0.511), GDP (0.627) and ED (0.564)*, showing that green finance is related to economic growth, ease of doing business, and social finance. Also, SF has a favourable correlation with IQ (0.436) and ICT (0.452). A variance-inflating factor was utilised to confirm the data's multicollinearity. There was no multicollinearity problem in the data since the VIF of all the variables was less than 10 (Shrestha, 2020).

Table 3 Correlation matrix and test for multicollinearity

Var	*SS*	*GF*	*SoF*	*IQ*	*ICT*	*QTTI*	*GDP*	*FDI*	*ED*	*VIF*	*1/VIF*
SS	1									3.120	0.321
GF	0.487**	1								2.890	0.346
SoF	0.342*	0.511***	1							4.010	0.249
IQ	0.203	0.387**	0.436**	1						2.450	0.408
ICT	0.401**	0.431**	0.452**	0.296*	1					3.770	0.265
QTTI	0.568***	0.517***	0.484***	0.529***	0.618***	1				2.980	0.336
GDP	0.295*	0.627***	0.291	0.303*	0.522***	0.598***	1			1.920	0.521
FDI	0.246	0.392*	0.308	0.229	0.412**	0.478**	0.416**	1		3.050	0.328
ED	0.523***	0.564***	0.428**	0.476**	0.589***	0.617***	0.478**	0.367*	1	2.710	0.369

3.2.2 Cross-sectional dependency (CD) test

This study used the most recent econometric method available to determine cross-sectional dependency among indicators because standard econometric methods are incapable of dealing with this issue. In panel data analysis, a CD may form as a result of geographical factors, interconnections across nations in the same economic and social network, and other unobserved traits. According to recent empirical research (Zafar et al., 2019), the economies under consideration are linked by a range of factors, including geography, religion, finance, import-export and border sharing. It is usual practice not to examine panel data for cross-sectional dependence between series.

The existence of cross-sectional dependence must therefore probably be investigated empirically using panel data. Some tests were used extensively in the study. According to Herwartz (2006), Breusch and Pagan proposed the Lagrange multiplier (*L*) test, (CD_{lm}), which is the scaled version of the LM test following Pesaran et al. (2004) and the CD test following Pesaran et al. (2006). It is preferred when the cross-section (*N*) is larger than the time (*T*). The CD_{lm} test statistics can be constructed using the following equation:

$$SS_{it} = \alpha_i + \beta_1 x_{it} + \varepsilon_{it} \tag{7}$$

where *i*= cross-section indicator (*N*), *t* = time (*T*), SS_{it} = Social Sustainability, β_1 = slope coefficient and ε_{it} = error term.

$Ho = COV\left(\mu_{it}\mu_{it}\right) = 0$ for all t and $t \neq j$ is the null hypothesis of cross-section independence in the LM cross-section dependency test. This is opposed to the alternative hypothesis of cross-sectional dependence, which is ($Ho = COV\left(\mu_{it}\mathrm{j}_{\mathrm{it}}\right) \neq 0$ for at least $t \neq j$. Pesaran et al. (2006) suggested the following Lagrange multiplier $\left(CD\right)_{lm}$ test:

$$CD_{lm} = \mathrm{T}\sqrt{\frac{N}{N\left(N-1\right)}\sum_{i=1}^{N-1} \cdot \sum_{J=I+1}^{N}}\left(T\rho_{IJ} - 1\right). \tag{8}$$

The results (see Table 5) for all economies indicate that the alternative hypothesis is accepted at the 1% significance level, rejecting the null hypothesis of cross-sectional independence. These findings thus demonstrate the cross-sectional dependence of the chosen data series for the G20 and Non-G20 economies during the 2000–2020 study period. This is in line with Pesaran and Yamagata (2008).

Table 5 Cross-sectional dependence (CD) test results

Variables	*Pesaran et al. (2004) CD Test*	*P-value (CD Test)*	*Breusch-Pagan LM Statistic*	*P-value (LM Test)*
InSS	3.456***	0.000	22.345***	0.000
InGF	3.210***	0.001	21.874***	0.000
InSoF	2.925**	0.005	20.542***	0.000
InIQ	2.992***	0.003	21.655***	0.000
InICT	3.498***	0.000	24.128***	0.000
InQTTI	2.873**	0.004	22.451***	0.000
InED	2.546**	0.011	19.874***	0.000
InGDP	2.341**	0.019	17.890***	0.000
InFDI	2.456**	0.015	16.234***	0.001

3.3.3 Unit root test

After determining cross-sectional dependency, the integration order of the researched factors is assessed. We do not use the first-generation unit root test since our data contains CD, which could result in skewed results. We further confirmed the indicators' stationarity using the second-generation unit root tests, the IPS (i.e., CADF) and CIPS (i.e., CIPS) (Pesaran, 2007). The unit root test is used to determine whether a variable is stationary at level I(0) or first difference $I(1)$.

Table 6 shows that all variables in the data set are stationary, with significant p-values (< 0.05) for SS, GF, SF, IQ, ICT, QTTI, GDP, FDI and ED. We can be positive that these variables are stationary, which means they do not have a unit root. They display constant statistical properties over time and can be used in future studies without being differentiated. The unit root test findings indicated that the characteristics series was an integrated series of order I (1). Therefore, the necessity to apply the PMG-ARDL model is ensured when all the characteristics are integrated at I (1).

Table 6 Panel unit root results

Variable	*CADF Statistic*	*CADF p-value*	*CIPS Statistic*	*CIPS p-value*	*Bai & Ng Statistic*	*Bai & Ng p-value*
InSS	–3.450	0.002	–3.120	0.010	–4.560	0.005
InGF	–2.850	0.020	–2.900	0.019	–3.750	0.018
InSoF	–3.100	0.010	–3.250	0.009	–4.300	0.007
InIQ	–3.000	0.015	–3.100	0.014	–4.000	0.010
InICT	–2.950	0.017	–2.850	0.020	–3.600	0.016
InQTTI	–2.500	0.050	–2.550	0.045	–3.450	0.040
InED	–3.700	0.001	–3.650	0.002	–5.200	0.001
InGDP	–2.910	0.015	–3.050	0.018	–4.100	0.012
InFDI	–3.210	0.005	–3.150	0.006	–4.500	0.004

3.3.4 Pooled mean group (PMG) panel ARDL

The PMG-ARDL model, proposed by Pesaran et al. (1999), was employed in this study. This model is applied when the variables are stationary at I(0), I(1) or a mix of the two, but not at I(2). This has become applicable in this investigation, as evidenced by our unit root test results in Table 6, which reveal the variables to be stationary at first difference. Furthermore, this model has the capability of investigating long- and short-term effects among variables. One advantage of this model over others is its ability to overcome endogeneity, heteroscedasticity, autocorrelation and multicollinearity in models (Wang and Huang, 2021).

The estimation of PMG involves a two-step technique. The first step involves estimating long-term slope coefficients across units using a concentrated maximum likelihood approach. The estimated long-term slope coefficients, intercepts and short-term coefficients are used to compute the speed of adjustment and error variances on a unit-by-unit basis using maximum likelihood (Odugbesan and Rjoub, 2019, 2020). Odugbesan and Rjoub (2019) found that the long-term slope coefficients in the PMG are homogeneous across cross-sections but still allow for heterogeneity. Samargandi (2021) found that the PMG approach consistently calculates the mean of short-term coefficients across units by averaging individual unit coefficients due to lagged cross-unit dimensions. The empirical models for the PMG-ARDL are shown below:

$$\begin{aligned}\Delta lnSS_{it} = {} & \beta_0 + \beta_1 lnEF_{i,t-1} + \beta_2 lnHF_{i,t-1} + \beta_3 lnSF_{i,t-1} + \beta_4 lnED_{i,t-1} \\ & + \beta_5 lnQTTI_{i,t-1} + \beta_6 lnGDP_{i,t-1} + \beta_7 lnFDI_{i,t-1} + \sum_{j=1}^{k} \gamma 1 j \Delta lnEF_{i,t-j} \\ & + \sum_{j=1}^{k} \gamma 2 j \Delta lnHF_{i,t-j} + \sum_{j=1}^{k} \gamma 3 j \Delta lnSF_{i,t-j} + \sum_{j=1}^{k} \gamma 4 j \Delta lnED_{i,t-j} \\ & + \sum_{j=1}^{k} \gamma 5 j \Delta lnQTTI_{i,t-j} + \sum_{j=1}^{k} \gamma 6 j \Delta lnGDP_{i,t-j} + \sum_{j=1}^{k} \gamma 7 j \Delta lnFDI_{i,t-j} \\ & + \acute{\omega} ECT_{i,t-1} + \varepsilon_{it}\end{aligned} \tag{9}$$

where Δ is the first contrast term; β_0; β_1; β_2; β_3; β_4; β_5; β_6; β_7 is the impart to the 'long-run coefficients', ε_{it} is the error term and $\gamma 1j$, $\gamma 2j$, $\gamma 3j$, $\gamma 4j$, $\gamma 5j$, $\gamma 6j$, $\gamma 7j$, is the short-run assessment.

The long-run condition is determined by the following:

$$\begin{aligned} lnSS_{it} = {} & \beta_0 + \beta_1 lnEF_{i,t-1} + \beta_2 lnHF_{i,t-1} + \beta_3 lnSF_{i,t-1} + \beta_4 lnED_{i,t-1} \\ & + \beta_5 lnQTTI_{i,t-1} + \beta_6 lnGDP_{i,t-1} + \beta_7 lnFDI_{i,t-1} + \varepsilon_{it} \end{aligned} \tag{10}$$

When variables show a long-term association, the ECM is performed. The conditions of the ECT are as follows:

$$\begin{aligned} \Delta \ln SS_{it} = {} & \beta_0 + \sum_{j=1}^{k} \gamma 1j \Delta \ln EF_{i,t-j} + \sum_{j=1}^{k} \gamma 2j \Delta \ln HF_{i,t-j} + \sum_{j=1}^{k} \gamma 3j \Delta \ln SF_{i,t-j} \\ & \sum_{j=1}^{k} \gamma 4j \Delta \ln ED_{i,t-j} + \sum_{j=1}^{k} \gamma 5j \Delta \ln QTTI_{i,t-j} + \sum_{j=1}^{k} \gamma 6j \Delta \ln GDP_{i,t-j} \\ & \sum_{j=1}^{k} \gamma 7j \Delta \ln FDI_{i,t-j} + \acute{\omega}\, ECT_{i,t-1} + \varepsilon_{it} \ldots \ldots \end{aligned} \tag{11}$$

where $\acute{\omega}$ denotes the next period's slack, implying the Error adjustment Term (ECT). The definition of ECT is the rate at which a balanced circumstance transitions from a state of disequilibrium. ECT assessment should be considered in econometric tests to develop a long-term relationship.

Both G20 and non-G20 countries

In the short run, Social Finance (SF) exerts a positive influence on Social Sustainability (SS) in both G20 and non-G20 countries, although the effect is weaker compared to the long run. Green Finance (GF) also promotes SS across both groups of nations. The moderating effect of ICT on SF reveals a diminishing influence, slightly reducing the short-term impact of SF while moderately enhancing the effect of GF.

In the long run, both SF and GF have a significant positive impact on SS in G20 and non-G20 countries. Specifically, a one-unit increase in SF and GF raises SS by 32.6% and 21.5%, respectively, with both effects being highly significant ($p < 0.01$). However, the interaction between ICT and SF is negative in the long run, while ICT strengthens the relationship between GF and SS. Institutional Quality (IQ) amplifies the positive effect of SF on SS but reduces the impact of GF on SS. Overall, the results underscore the critical roles of SF, GF, ICT and IQ in fostering social sustainability, with the moderating effects of ICT and IQ (SoF × ICT and GF × IQ) yielding unexpected patterns.

G20 countries

In the long run, Green Finance (GF) and Social Finance (SF) exert substantial positive effects on Social Sustainability (SS) in G20 countries, with a one-unit increase in GF and SF enhancing SS by 28.9% and 47.8%, respectively – both highly significant ($p < 0.01$). While ICT independently supports SS, its interaction with SF slightly reduces SF's positive effect on SS. Conversely, ICT positively moderates the GF–SS relationship, strengthening its impact. Institutional Quality (IQ) is positively associated with the SF–SS nexus, indicating that stronger institutions amplify the benefits of social finance.

However, IQ reduces the influence of GF on SS. In the short run, both GF and SF maintain positive and significant effects on SS. Similar to the long-run findings, ICT negatively moderates the SF–SS relationship, marginally weakening its effect, but positively moderates the GF–SS nexus, enhancing it. IQ again increases the impact of SoF on SS while diminishing the effect of GF on SS.

Non-G20 countries

For non-G20 countries, the long-run analysis shows that Green Finance (GF) and Social Finance (SF) have a significant positive impact on Social Sustainability (SS). A one-unit increase in GF and SF raises SS by 24.9% and 41.2%, respectively, both highly significant ($p < 0.01$). While ICT independently supports SS, its interaction with SF slightly weakens SF's positive effect. In contrast, ICT positively moderates the GF–SS relationship, strengthening its impact. Institutional Quality (IQ) demonstrates a positive association with the SoF–SS nexus, indicating that stronger institutions enhance the benefits of social finance. However, IQ reduces the influence of GF on SS. In the short run, GF and SoF continue to exert positive and significant effects on SS. Similar to the long-run results, ICT negatively moderates the SoF–SS relationship, marginally reducing its impact, but positively moderates the GF–SS nexus. Likewise, IQ increases the influence of SF on SS while diminishing the effect of GF.

The Error Correction Term coefficients for G20 and non-G20 countries are 0.587 and 0.507, respectively, with a p-value of 0.000. This suggests that G20 countries have a strong system that corrects itself at a rate of 58.7% each period in the event of a disequilibrium, whereas non-G20 countries react slightly slower, at a rate of 50.7%. The LM Test (Autocorrelation) scores of 0.137 and 0.143 suggest no autocorrelation problem exists.

The Breusch-Pagan results (0.398 and 0.417) indicate that no heteroskedasticity problem occurs.

The Jarque-Bera values of 0.382 and 469 suggest that all residuals are regularly distributed in both G 20 and non-G 20 nations. On the combined analysis, the results show that the ECT is negative (–0.507) and significant (p-value = 0.000), indicating a significant (50.7%) rate of adjustment to long-run equilibrium.

4 Discussion of findings

The findings show that social and green finance have a major impact on social sustainability for G20, non-G20 and both economic blocs. This means that social and green finance play an important role in promoting social sustainability across economies. This finding was supported by Xiao et al. (2019), Chien et al. (2021); Prajapati et al. (2021); Nguyen et al. (2018); Utami and Basrowi (2021) and Zainal et al. (2020). They argue that access to green and social finance has long-term implications for social and societal development. They say that social finance minimises income disparity in society by providing opportunities for education and healthcare, as well as support for young entrepreneurs to achieve economic sustainability (Banerjee et al., 2015). Also, green finance provides for climate, renewable energy and carbon finance, which are used for climate mitigation and adaptation programs, renewable energy, and carbon resilient projects.

The results further reveal that the interaction of ICT with the social finance–social sustainability nexus tends to diminish the effectiveness of social finance in both G20 and non-G20 countries. This outcome is consistent with the OECD report (Sachs et al., 2021), which notes that even in technologically advanced economies, persistent digital divides remain. Disadvantaged groups, such as low-income individuals, older populations and remote communities, often face barriers to accessing digital financial services. Since access to government-funded social protection, education programs and other welfare benefits is increasingly mediated through digital platforms, those lacking digital literacy or reliable internet connectivity are at risk of exclusion from social finance benefits. For instance, in the USA, approximately 19 million people still lack broadband connectivity, and around 30% of low-income households have limited or no internet access, constraining their ability to participate in digital-based financial programs (Rosenberg, 2022). This underscores how technological advancement alone does not guarantee equitable access to social finance.

Similarly, Dizerega (2020) supported this interpretation, arguing that while ICT infrastructure expansion may foster efficiency, it can also cause unintended socio-economic consequences, such as job displacement in traditional sectors, which in turn exacerbates income inequality – contradicting the very aims of social sustainability. The European Commission (Silander, 2019) also observes that the high capital and maintenance costs of ICT infrastructure can divert public and private resources away from direct social investments, thereby diluting the intended impact of social finance initiatives on communities. Conversely, some researchers hold a more optimistic perspective. For example, Chien et al. (2021) contend that ICT, when effectively integrated into social finance frameworks, can enhance transparency, broaden financial inclusion, enable innovative financing mechanisms and improve monitoring and evaluation of funded projects. From this viewpoint, ICT serves as a catalytic tool that strengthens the capacity of social finance to achieve long-term social sustainability goals.

Taken together, these contrasting perspectives highlight the complexity of the ICT–social finance relationship. While ICT offers potential benefits in expanding reach and improving governance, without deliberate measures to bridge digital divides and address socio-economic imbalances, its interaction with social finance may inadvertently hinder rather than enhance social sustainability outcomes.

The results show that ICT Infrastructure enhances the impact of green finance on social sustainability. To Raji et al. (2024), digital platforms and enhanced reporting tools, including ESG reporting systems, allow for real-time monitoring of green finance performance. Improved transparency boosts investor and stakeholder confidence in green finance projects, reinforcing responsibility and promoting long-term outcomes.

The ICT-moderated transparency effect (β_6 = +0.072, Table 7) can help corporate Treasury teams manage green bond financing costs directly. Firms can mitigate perceived greenwashing risks by incorporating robust ICT systems for real-time environmental performance reporting, automated data verification and digital disclosure to stakeholders. This increased transparency reassures investors about the legitimacy and continuous compliance of green initiatives, boosting market confidence. Higher investor trust can reduce the required risk premium, resulting in smaller green bond coupon spreads and a lower total cost of capital. Treasury teams can use these technologies to measure performance against sustainability goals, demonstrate compliance with international reporting standards and effectively communicate progress to rating agencies and institutional investors.

Table 7 PMG – ARDL model results for G20 countries, non-G20 countries and both

	G20				*Non-G20*				*Both*			
Variable	*Coefficient*	*Std. Error*	*t-Statistic*	*p-value*	*Coefficient*	*Std. Error*	*t-Statistic*	*p-value*	*Coefficient*	*Std. Error*	*t-Statistic*	*p-value*
Long-Run Estimates												
SoF	0.478	0.104	4.596	0.000	0.412	0.099	4.162	0.000	0.326	0.057	5.726	0.000
GF	0.289	0.091	3.176	0.002	0.249	0.082	3.037	0.004	0.215	0.089	2.419	0.016
ICT	0.316	0.109	2.899	0.005	0.292	0.101	2.891	0.005	0.142	0.062	2.290	0.022
IQ	0.135	0.078	1.731	0.089	0.157	0.071	2.211	0.030	0.183	0.054	3.389	0.001
SoF × ICT	–0.114	0.041	–2.780	0.008	–0.092	0.038	–2.421	0.016	–0.093	0.035	–2.657	0.009
GF × ICT	0.039	0.019	2.053	0.042	0.028	0.011	2.545	0.013	0.072	0.040	1.809	0.071
SoF × IQ	0.082	0.037	2.216	0.029	0.062	0.029	2.138	0.037	0.116	0.045	2.578	0.011
GF × IQ	–0.097	0.048	–2.021	0.045	–0.083	0.037	–2.243	0.027	–0.080	0.038	–2.102	0.036
FDI	0.137	0.042	3.262	0.001	0.112	0.034	3.294	0.001	0.075	0.012	6.250	0.000
GDP	0.079	0.027	2.926	0.005	0.067	0.023	2.913	0.005	0.089	0.021	4.243	0.000
QTTI	0.091	0.032	2.844	0.007	0.081	0.030	2.700	0.011	0.047	0.016	2.938	0.004
ED	0.051	0.045	1.133	0.260	0.052	0.041	1.268	0.210	0.029	0.008	3.625	0.000
ECT	–0.587	0.083	–7.072	0.000	–0.507	0.079	–6.418	0.000	–0.375	0.064	–5.859	0.000
LM Test	1.932			0.137	1.872			0.143	0.052			0.820
Breusch-Pagan	0.927			0.398	0.891			0.417	0.075			0.783
Jarque-Bera	1.421			0.382	1.511			0.469	0.561			0.755
RESET Test	1.589			0.174	1.732			0.172	0.432			0.649
Short-Run Estimates												

Table 7 PMG – ARDL model results for G20 countries, non-G20 countries and both (continued)

	G20				Non-G20				Both			
Variable	*Coefficient*	*Std. Error*	*t-Statistic*	*p-value*	*Coefficient*	*Std. Error*	*t-Statistic*	*p-value*	*Coefficient*	*Std. Error*	*t-Statistic*	*p-value*
D(SS(-1))	0.265	0.094	2.819	0.008	0.246	0.090	2.733	0.010	0.430	0.112	3.839	0.000
D(SoF)	0.142	0.048	2.958	0.004	0.125	0.046	2.717	0.011	0.091	0.040	2.285	0.024
D(GF)	0.102	0.034	3.000	0.003	0.096	0.032	3.000	0.003	0.067	0.052	1.287	0.198
D(ICT)	0.072	0.039	1.846	0.072	0.061	0.038	1.605	0.109	0.113	0.065	1.738	0.084
D(IQ)	0.048	0.026	1.846	0.072	0.042	0.025	1.680	0.094	0.095	0.059	1.616	0.107
D(SoF × ICT)	–0.068	0.028	–2.429	0.016	–0.058	0.027	–2.148	0.036	–0.055	0.042	–1.314	0.189
D(GF × ICT)	0.031	0.014	2.214	0.029	0.022	0.012	1.833	0.072	0.084	0.046	1.826	0.068
D(SoF × IQ)	0.056	0.025	2.240	0.027	0.046	0.023	2.000	0.048	0.075	0.048	1.563	0.119
D(GF × IQ)	–0.039	0.020	–1.950	0.054	–0.035	0.018	–1.944	0.053	–0.042	0.040	–1.050	0.294
D(FDI)	0.089	0.033	2.697	0.011	0.082	0.031	2.645	0.012	0.038	0.013	2.923	0.004
D(GDP)	0.049	0.021	2.333	0.021	0.038	0.016	2.375	0.019	0.061	0.022	2.773	0.006
D(QTTI)	0.074	0.035	2.114	0.037	0.062	0.033	1.879	0.067	0.026	0.017	1.529	0.127
D(ED)	0.054	0.031	1.742	0.087	0.048	0.029	1.655	0.101	0.019	0.009	2.030	0.043
LM Test	1.716			0.178	1.624			0.178	0.143			0.706
Breusch-Pagan	0.946			0.410	0.854			0.464	0.092			0.760
Jarque-Bera	1.612			0.453	1.439			0.487	0.402			0.818
RESET Test	1.781			0.163	1.628			0.192	0.321			0.748

According to Jøranson et al. (2023), strong ICT infrastructure, including mobile banking, fintech innovations and digital payment systems, promotes financial inclusion for marginalised people. This inclusion not only broadens access to green financial products but also enables communities to participate in and benefit from sustainable development projects. This finding is, however, countered by Razzaq et al. (2023). They claim that ICT infrastructure may help green finance achieve social sustainability by closing gaps in openness, access, creative thinking and transparency.

The findings indicate that institutional quality can significantly enhance the long-term impact of social finance on social sustainability in both G20 and non-G20 countries. This aligns with Bebbington and Unerman (2018), who argued that effective institutions foster transparency, policy consistency and enforcement of social finance regulations. Such institutional strength reduces corruption and the misallocation of funds, ensuring that resources are directed toward programs with genuine and measurable social impact. Similarly, Leal Filho et al. (2022) highlighted that institutions prioritising strategic, long-term thinking are more inclined to support sustained investments in social programs. This approach ensures that social finance is not diverted toward short-term gains but is instead deployed to fund enduring initiatives that build social capital, infrastructure and community resilience.

In contrast, Haldar and Sethi (2023) questioned this premise, suggesting that institutional quality alone may not guarantee optimal social finance outcomes, especially in contexts where structural inequalities, political interests or informal networks override formal governance mechanisms. They opine that institutional quality can lead to excessive regulation, high enforcement costs, drowning out private efforts, elite control and rigid policy design, all of which can reduce the efficiency of social finance in promoting social sustainability.

The findings show that institutional quality negatively affects the link between green financing and social sustainability. The results are consistent with the findings of Khan et al. (2022). According to them, institutional quality might result in too strict regulatory regimes. When laws are overly tight or bureaucratic, they might slow the approval and implementation of green finance initiatives. This delay may impede timely investment in socially beneficial green projects, diminishing their influence on social sustainability. Furthermore, even well-functioning institutions are susceptible to political capture, in which influential advocacy groups control policymaking. If green finance policies favour the wealthy or urban sectors, the benefits of green finance may not reach underprivileged areas (Wang and Yang, 2021). However, some studies disprove the assertion with the view that strong institutions create concise, unified and enforced environmental standards to guide green finance. They help guide investments toward projects that not only lower ecological impacts but also produce significant social benefits (Hussain and Dogan, 2021).

The study further strengthened the empirical findings' robustness by breaking down institutional quality into two of the six generally accepted Worldwide Governance Indicators (WGI): regulatory quality and corruption control (Refer to Appendix A). The relationship between sustainable finance and social sustainability may be impacted differently by different governance elements, as this approach recognises that institutional quality is a multifaceted construct. The findings reveal that control of corruption and regulatory quality aspects considerably affect the relationship between social sustainability and sustainable finance. A fair and equal distribution of sustainable funds is ensured by effective corruption control, which also lessens elite capture and rentseeking practices, improving societal outcomes (Mauro, 1995; Pistor, 2019). Strong regulatory quality also promotes credible, enforceable and predictable policy frameworks that draw in ethical capital and make it easier to carry out sustainability projects (Kaufmann et al., 2011; Ziegler et al., 2018). These findings suggest that financial innovations targeted at accomplishing the Sustainable Development Goals (SDGs) require the support of governance changes, including anti-corruption initiatives and regulatory capacity-building. Social returns and long-term development effects can be increased for emerging economies by including institutional strengthening in sustainable finance initiatives.

The study tested the post-COVID robustness of the findings using tentative 2021–2022 data (available for 148 of the 171 nations). The findings in the main study and those in Appendix B are mainly in agreement. On a worldwide scale, however, Green Finance has little discernible impact on social sustainability. Furthermore, the relationship between Green Finance and Social Sustainability is not substantially impacted by the interplay between Institutional Quality and ICT Infrastructure. This finding aligns with the post-COVID scenario, where the potential impact of green finance projects on wider social sustainability outcomes may have been obscured or reduced by resource allocations toward rapid economic recovery and health system resilience. In a similar vein, whereas ICT infrastructure and institutional quality continue to be critical for governance and economic performance, their interplay does not seem to have increased the impact of green finance on social dimensions throughout the recovery phase. These data, taken together, demonstrate the strength of our conclusions and shed light on how green finance and social sustainability are changing in the immediate wake of the COVID-19 epidemic.

5 Conclusion and implications

5.1 Conclusion

This study shows that sustainable finance can be a potent tool for attaining social sustainability, but it is substantially more effective when accompanied by excellent institutional quality and robust ICT infrastructure. This study examines the moderating role of institutional quality and ICT infrastructure in the relationship between sustainable finance (green and social finance) and social sustainability, using the PMG-ARDL model to analyse panel data from 171 countries from 2000 to 2020. The findings show that green and social finance are important drivers of social sustainability in both the short and long run in G20 and non-G20 nations. The findings also show that ICT's interaction with the social finance-social sustainability nexus reduces its effectiveness in both G20 and non-G20 countries because some disadvantaged groups (for example, low-income individuals, older people and remote communities) struggle to access digital financial services, limiting their ability to reap the benefits of social finance. The findings reveal that ICT Infrastructure improves the impact of green finance on social sustainability through digital platforms and improved reporting tools, such as ESG reporting systems, which enable real-time monitoring of green finance performance. Improved openness increases investor and stakeholder confidence in green finance projects, strengthening accountability and encouraging long-term results. The findings indicate that institutional quality potentially enhances the impact of social finance on social sustainability in both

G20 and non-G20 nations. This is based on the notion that effective institutions provide the transparency and enforcement of social finance policies and laws. This prevents corruption and incorrect money allocation, ensuring that social finance resources are directed toward projects that have a social impact. The findings show that institutional quality has a negative impact on the link between green financing and social sustainability because it can result in overly strict regulatory regimes, which slow the approval and implementation of green finance initiatives. This delay may hinder timely investment in socially beneficial green projects, reducing their impact on social sustainability.

5.2 Theoretical implications

The study contributes to the sustainable finance literature by investigating the moderating roles of institutional quality and ICT infrastructure, two factors that are frequently addressed separately, in determining the relationship between sustainable finance (green and social finance) and social sustainability. It challenges the widely held belief that ICT infrastructure is universally helpful, demonstrating that, while ICT improves green finance outcomes, it may lower the efficacy of social finance due to digital accessibility gaps among disadvantaged groups. The study distinguishes between green finance and social finance based on their response to institutional quality and ICT, providing a more detailed understanding of their paths to social sustainability. The study compares G20 and non-G20 nations to give a cross-context perspective on how institutional and technological contexts influence the global impact of sustainable finance.

5.3 Practical implications

The findings emphasise the need to tackle digital exclusion among vulnerable groups to ensure that ICT-enabled financial services offer broad social benefits. The study emphasises the importance of ICT tools, such as ESG reporting systems, in increasing transparency, accountability and investor confidence in green financing initiatives. Governments should establish clear regulations to guide the implementation of green and social finance projects, ensuring transparency, reducing corruption and fostering investor trust to maximise their societal impact. They should include anti-corruption in the sustainable finance policy's design; That is, they should require open contracting data standards, e-procurement, beneficial-ownership disclosure and independent audits for projects funded as 'green/social'. Concessional lines and financial incentives should be linked to performance evaluation and integrity protections (World Bank, 2017; UNDP, 2021).

Governance-adjusted impact-at-risk models will more accurately forecast realised social results and negative risk; therefore, investors and donors should factor in control of corruption and regulatory quality scores (such as WGI) when determining pricing and allocation (Kaufmann et al., 2011). To unleash greater social multipliers from the same capital envelope, development partners could combine finance with governance technical support (anti-corruption systems, procurement reforms, impact) (World Bank, 2017; UNDP, 2021).

Policyholders should also invest in robust, nationwide ICT infrastructure to provide reliable connectivity in both urban and rural areas, while promoting digital literacy among citizens and local entrepreneurs. This will strengthen the reach and effectiveness of long-term financing programs for social development. Policymakers must recognise that effective policy design requires consideration of each country's unique challenges and opportunities. Where appropriate, they should promote decentralised decision-making to enable context-specific solutions that advance social sustainability.

5.4 Limitations and future research

The current study combined the different governance components into a single moderating variable. Future studies can look into how specific institutional components affect the relationship between sustainable finance and development. However, this does not invalidate the results of this study.

Declarations

All authors declare that they have no conflicts of interest.

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APPENDIX A

Control of Corruption (CC) as moderator				
Variable	*Coefficient*	*Std. Error*	*t-Statistic*	*Prob.*
GF X CC	0.007	0.001	5.843	0.000
SoF X CC	0.004	0.001	7.536	0.000
ED	–0.359	0.469	–0.764	0.445
GDP	–0.003	0.003	–0.965	0.335
QTTI	–0.514	0.216	–2.375	0.018
FDI	0.000	0.005	–0.008	0.994
R-squared	–3.270	Mean dependent var		0.629
Adjusted *R*-squared	–3.859	S.D. dependent var		1.871
S.E. of regression	4.125	Sum squared resid		14053.140
Long-run variance	0.007			
Regulatory Quality (RQ) as moderator				
Variable	*Coefficient*	*Std. Error*	*t-Statistic*	*Prob.*
GFRQ	–0.571	0.109	–5.240	0.000
SoFRQ	–0.012	0.050	–0.241	0.810
ED	–0.209	0.486	–0.431	0.667
GDP	–0.002	0.004	–0.692	0.489
QTTI	–0.964	0.183	–5.255	0.000
FDI	–0.009	0.006	–1.571	0.117
R-squared	–5.098	Mean dependent var		0.629
Adjusted *R*-squared	–5.940	S.D. dependent var		1.871
S.E. of regression	4.930	Sum squared resid		20072.890
Long-run variance	0.007			
ICT INFRASTRUCTURE (ICT) as moderator				
Variable	*Coefficient*	*Std. Error*	*t-Statistic*	*Prob.*
GFICT	–1.621	0.136	–11.960	0.000
SoFICT	0.457	0.098	4.640	0.000
ED	–0.165	0.491	–0.336	0.737
GDP	0.000	0.003	–0.047	0.962
QTTI	–0.656	0.228	–2.871	0.004
FDI	–0.002	0.005	–0.368	0.713
R-squared	–4.732	Mean dependent var		0.649
Adjusted *R*-squared	–5.500	S.D. dependent var		1.858
S.E. of regression	4.737	Sum squared resid		19095.410
Long-run variance	0.006561			

Appendix B

Robustness Checks using Dynamic Ordinary Least Squares (DOLS)

Dependent Variable: Social Sustainability

	G20				*Non-G20*				*Both*			
Variable	*Coefficient*	*St. Error*	*T Statistics*	*P-value*	*Coefficient*	*St. Error*	*T Statistics*	*P-value*	*Coefficient*	*St. Error*	*T Statistics*	*P-value*
SoF	0.428	0.112	3.821	0.000	0.482	0.115	4.187	0.000	0.163	0.058	2.810	0.006
GF	0.305	0.097	3.144	0.002	0.263	0.089	2.955	0.004	−0.047	0.062	−0.758	0.449
ICT	0.612	0.143	4.280	0.000	0.071	0.083	0.855	0.395	0.182	0.051	3.569	0.000
IQ	0.221	0.089	2.483	0.014	0.324	0.106	3.057	0.003	0.156	0.053	2.943	0.004
SoF × ICT	0.187	0.055	3.400	0.001	0.211	0.074	2.851	0.005	0.228	0.063	3.619	0.000
GF × ICT	−0.094	0.063	−1.492	0.137	0.145	0.060	2.417	0.016	0.191	0.059	3.237	0.002
SoF × IQ	0.132	0.051	2.588	0.011	0.192	0.067	2.866	0.004	0.247	0.068	3.632	0.000
GF × IQ	−0.072	0.059	−1.220	0.225	0.167	0.072	2.319	0.021	0.203	0.064	3.172	0.002
FDI	0.085	0.033	2.576	0.011	0.054	0.078	0.692	0.490	0.039	0.036	1.083	0.281
GDP	0.541	0.128	4.227	0.000	0.389	0.120	3.242	0.001	0.072	0.064	1.125	0.262
QTTI	0.194	0.066	2.939	0.004	−0.036	0.082	−0.439	0.662	0.149	0.046	3.239	0.002
ED	−0.261	0.092	−2.837	0.006	0.278	0.093	2.989	0.003	0.132	0.049	2.694	0.009
R^2	0.623				0.764				0.569			
Adjusted R^2	0.581				0.732				0.549			
Durbin-Watson Test	1.920				1.987				2.013			
Breusch–Pagan Test (p-value)	0.218				0.217				0.423			
Jarque–Bera Normality Test (p-value)	0.364				0.341				0.694			
Ramsey RESET Test (p-value)	0.349				0.298				0.271			