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Green finance, sustainable infrastructure, and green technology innovation: pathways to achieving sustainable development goals in the belt and road initiative

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Abstract

Achieving the Sustainable Development Goals (SDGs) remains a significant challenge for many countries, particularly in the face of increasing environmental pollution. Balancing social, economic, and environmental sustainability under these conditions is especially complex. This study explores the role of green finance in promoting sustainable infrastructure, innovation in green technology, corporate social responsibility, economic stability, and environmental conservation within the framework of Belt and Road initiative (BRI), with a specific focus on the China-Pakistan Economic Corridor (CPEC) initiatives. Furthermore, the study examines the role of government support in facilitating the issuance of GF, emphasizing its significance in large-scale international development projects like CPEC. Data were collected through a structured questionnaire targeting a diverse group of respondents, including businessmen, CPEC officials, and representatives from the Ministry of Finance, Pakistan Environmental Protection Agency, and Ministry of Planning and Development. Partial Least Squares analysis was employed to test the proposed relationships and hypotheses. The results indicate a significant positive impact of green finance on the development of sustainable infrastructure and the innovation of green technology. Additionally, the results underscore the pivotal role of environmentally friendly technologies and sustainable infrastructure in driving the achievement of SDGs, especially in the social, economic, and environmental dimensions. The study findings offer actionable insights for policymakers, highlighting the critical need to integrate green finance with sustainable practices to foster economic growth and environmental protection. These findings provide a strategic roadmap for nations aiming to align their development goals with global sustainability standards.

1. Introduction

China initiated the largest international economic initiative, with the aim of fostering economic growth across a vast region spanning Asia, Europe, and Africa. This initiative covers regions with 64% of the world's population and 30% of its GDP [1]. BRI project fosters infrastructure development along both its terrestrial and maritime corridors. Robust infrastructure, comprising roads, airports, ports, power grids, railways, and telecommunications networks, is essential for a country's economic and social prosperity [2, 3]. The CPEC is considered one of Beijing's most fascinating and impressive projects to date. It is portrayed on the official CPEC website as a pathway toward regional economic integration in the era of globalization. Academic, cultural, and knowledge-based activities are encouraged along the trade route with the interests of improving transportation, fostering interpersonal relationships, and building regional ties [4]. Corridors are essential for leaders, consumers, and social and economic growth. The CPEC aims to promote inclusion and regional connectivity, benefiting China, Pakistan, India, Afghanistan, Iran, and the Central Asian republics [5].

There is an inverse relationship between economic sustainability, social sustainability, and environmental sustainability. When a country focuses solely on economic sustainability, it often overlooks the importance of social and environmental sustainability. This is because rapid economic growth often requires increased use of transportation, industries, and other activities that emit carbon [6]. Consequently, maintaining the social environment and the economy is crucial for every country. Appropriate policies must be regularly reviewed to increase the economy's sustainability without compromising the social and environment. Thus, to accomplish the SDGs, it is crucial to adopt environmentally-friendly practices that minimize carbon emissions while promoting economic growth. These activities include GF, GTI, and sustainable infrastructure of CPEC. Results of this study also investigate how sustainable infrastructure, GF, GTI effects on social, economic and environmental sustainability [7]. In addition, [8] conducted a study that evaluated the significant contribution of green innovation (GI), social globalization, and GF in reducing carbon emissions. Their findings indicate that GF significantly reduces CO_2 emissions. The primary reason for this GF facilitates the efficient allocation of financial resources, thereby increasing the availability of clean energy sources at a lower cost.

According to a study conducted by [9], over time, GF has become a powerful financial tool that supports significant investments in environmentally sustainable energy projects. The presence of green financing, green innovation, and political risk has a positive impact on environmental quality [10].

GTI seeks to combine technological advancements with environmental awareness. Through GTI, businesses launch new goods or processes, enhance existing ones, and foster harmony between the environment, the economy, and manufacturing methods. These situations companies either restructure themselves or significant improvements to their management and production procedures resulting the eliminate or significantly reduce harmful environmental impacts [11]. The idea of sustainable development is becoming increasingly popular in various fields, including infrastructure. The national infrastructure network defined priorities for preserving economic growth and social, and environmental, to improve sustainability [12]. The widespread consumption of coal and motor vehicles hurt the natural world. Specifically, the growing use of automobiles and heavy reliance on other resources that burn coal had a serious impact on the environment. It relevant the risk that people would become ill from breathing in contaminated air. Social and environmental health sustainability instability in different communities significantly affects people's ability to generate revenue.

The SDGs in CPEC demand a pathway that is minimal in carbon emissions and is capable of encouraging growth while also improving the well-being of communities and the climate's adaptability. Achieving social, economic, and environmental sustainability in CPEC projects is crucial to fulfilling sustainable development goals [13, 14]. Hence, it is crucial to prioritize the accessibility and cost-effectiveness of GF in order to facilitate the advancement of environmentally sustainable initiatives that align with the SDGs [15]. To address the social, economic, and environmental sustainability concerns under the SDGs, the Pak-China government provides funding for CPEC, which is crucial for promoting a healthy environment and job possibilities for the populace [16, 17]. Figure 1 show the Proposed SDGs contribution with sustainable infrastructure development.

This study aims to examine the impact of GF on achieving SDGs, particularly focusing on its effects on social, economic, and environmental sustainability dimensions. Moreover, this research explores how sustainable infrastructure and GTI mediate this relationship, providing a comprehensive understanding of the pathways through which GF can drive sustainable outcomes. Additionally, the study investigates the role of government support in the issuance of GF, particularly in the context of the CPEC projects under the BRI.

Furthermore, this study is unique in its focus on the BRI and CPEC projects, providing a specific geographic and strategic context that has been relatively underexplored in existing literature. By linking green finance with tangible outcomes in sustainable infrastructure and technology, this research fills a gap in understanding how financial mechanisms can be leveraged to achieve sustainability goals in large-scale international development projects. The findings will offer valuable insights for policymakers and stakeholders involved in similar initiatives, highlighting the critical role of government support and strategic investment in fostering sustainable development. The study has the flowing research questions:

- What is the present status of green finance mechanisms within the (BRI)?
- What empirical evidence supports the mediating role of GTI and SI in the relationship between GF and SDGs within the BRI?

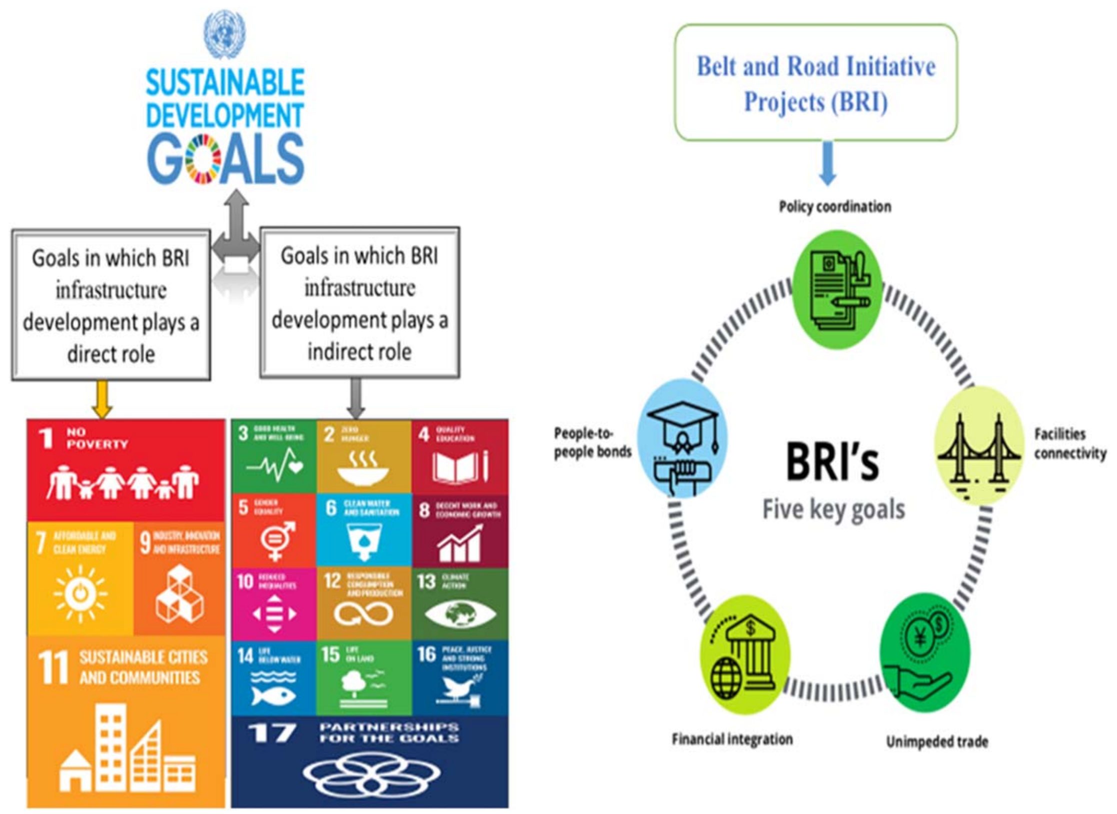

Figure 1. Proposed Sustainable development goals contribution with sustainable infrastructure development.

- What are the key SDGs targeted by the China-Pakistan BRI, and how have they been impacted by the implementation of SI and advanced GTI?

2. Literature review

2.1. Green finance role in sustainable infrastructure

The term GF refers to any type of economically structured activity that is formed in order to secure better environmental consequences. GF incorporates national and worldwide governmental and corporate measures taken to protect the environment. The creation of long term and profitable business strategies, activities associated with commerce and the environment, investments into a variety of projects, and numerous social programs, these are the many ways through which green finance contributes to the improvement of society [18, 19].

The study [20] examined the sustainable construction techniques applied to the enormous CPEC project. The findings of the study indicate that implementing green procurement practices has a positive and significant impact on environmental performance. Likewise, adopting green construction practices shows a favorable and substantial influence on both environmental and financial performance, and green design considerably influences economic performance. The study demonstrated that CPEC construction management should implement all aspects of green project practices simultaneously, minimizing adverse environmental consequences, maximizing positive environmental effects, and enhancing the region's long-term economic performance. The SDGs' components focused on humanity, environment, economic growth, and peace have the potential to be accelerated through green financing. Still, businesses, companies, and organizations that green stimulus measures result in sustainable economies and employment [21].

The study [22] explore there is a positive coordination connection between GF and Sustainable Development of the Regional Economy (SDRE). The findings indicate that GF and SDRE's linkage coordination will be improved if both are at a high level. Otherwise, the effect of cooperation will be reduced. GF role in sustainable infrastructure is critical in mobilizing capital towards projects that address climate change, reduce carbon emissions, enhance resource efficiency, and promote sustainable development. By integrating financial expertise with environmental and social considerations, professionals in this role help drive the transition to a more sustainable and resilient infrastructure system.

Investments in Green Public Transport Systems contribute positively to sustainability by reducing pollution and improving air quality. They also provide safer and more efficient mobility in urban areas, which enhances public health and social well-being [23]. Investments in sustainable infrastructure, such as renewable energy, water systems, and waste recycling initiatives, advance environmental sustainability by addressing greenhouse gas emissions, optimizing resource utilization, and enhancing resource efficiency and productivity [4]. However, the current literature still lacks adequate tools to effectively assess the environmental impacts and changes associated with certain forms of significant infrastructural development, such as projects with high initial environmental costs or those involving complex land-use practices.

Previous literature shows that sustainable infrastructure has a significant and positive impact on GF, such as improving environmental and financial performance in projects. However, there is a gap in the literature regarding the long-term relationship between sustainable infrastructure and GF, particularly in terms of social, economic, and environmental aspects. Most studies only examine the immediate effects on the environment, but an in-depth analysis of how GF systematically influences infrastructure development, especially in the context of large-scale international projects, is still lacking. This study is unique in addressing this gap by hypothesizing that:

H1: GF has a significant association with sustainable infrastructure.

2.2. The role of GF in the development of green technology innovation

Green finance serves as the backbone of GTI, particularly in the context of achieving SDGs. It channels funds directly into efforts to explore, innovate, and implement processes and products that minimize environmental impact, reduce reliance on fossil fuels, and promote the sustainable use of natural resources. Research shows that, in addition to enabling firms to invest in cleaner technologies, green finance also supports the widespread adoption of these innovations across the industrial sector [24]. In contrast to conventional finance, GF aims to reduce financial risks, more companies are launching more research and development (R&D) of green technologies [25]. Transitioning from traditional finance to more conventional financing models also helps reduce the risks and high costs associated with GTI, making it more feasible for businesses to pursue sustainable advancements. Additionally, the role of government policies and institutional support in guiding GF investments toward key sectors is crucial, as several recent studies have highlighted [23]. Government-backed green finance programs tend to focus on clean energy generation, recycling, and environmentally friendly production technologies. However, there is still a research gap in understanding how the regulatory frameworks governing green finance impact innovation performance across different sectors.

GTI refers to the utilization of scientific and technological advancements in order to develop and provide goods and services that have minimal or no negative impact on the environment [26]. Green technology products incorporate environmental sensitivity into manufacturing and use [27]. The organization known as GF is actively promoting technical advancements aimed at reducing carbon emissions, safeguarding the environment, and enhancing a nation's economic sustainability. The research [28] advances the field by presenting empirical data on the effects of GF on urban haze pollution from a fresh angle of corporate technical innovation. While most previous research focuses on the macro level, this study also examines the micro mechanism by which GF affects haze pollution and finds the mediating role of corporate innovation technology from a static perspective.

The study [29] explores strategies to promote ecological civilization, with a particular focus on the increasing attention given to GF. The results suggest that the implementation of 'command and control' regulations has a significant impact on the development regional technology innovation. Conversely, the adoption of GF and 'market incentive' environmental policies can facilitate such innovation. GF mitigates the adverse impacts of 'command and control' environmental regulations on the production of environmentally friendly technologies, while enhancing the positive outcomes of 'market-incentive' environmental laws [30]. An aspect of GTI that involves financing is important for raising funds for technologies that address environmental issues, advance sustainability, and promote economic growth. Professionals in this position help bridge the gap between innovation-to-commercialization by integrating their financial expertise with technological insights, accelerating the adoption of green technology, and promoting a more sustainable future.

Existing literature demonstrates how GF supports green technology innovation and the amount of funding it provides, such as for reducing CO_2 emissions and improving environmental sustainability across various sectors. However, in the context of long-term projects like the CPEC, there is a noticeable gap in the literature regarding how CPEC funding supports green technology adoption and promotes social, economic, and environmental sustainability. Limited debate exists on this subject. Therefore, this study is unique in addressing this gap and proposes the following hypothesis:

H2: GF has a significant association with the GTI.

2.3. Green finance role in social, economic and environmental sustainability

GF plays a critical role in advancing social, sustainable, economic, and environmental objectives by providing innovative financial products and efficient funding mechanisms for sustainable initiatives across various sectors. Economically, GF supports the development of sustainable infrastructure, renewable energy, and energy-efficient technologies, fostering economic growth without reliance on fossil fuel industries. This research emphasizes how GF contributes to the creation of an innovative, sustainable economy and green jobs during the transition to a green economy [31]. GF has significance because it promotes the movement of different financial tools and services to establish sustainable companies, investments in diverse initiatives, environment sustainability, and various social projects. The primary objective of the research conducted by [32] is to evaluate the impact of GF and economic inclusion on the overall macroeconomic stability of ASEAN nations. The study's results indicate that contamination of the environment must be reduced and that more innovative and environmentally friendly energy sources must be used instead.

The study [28] examines the impact of GF on sustainable economic and environmental growth in the 26 OECD nations. Findings indicate that GF encourages sustainable economic and environmental development. To promote the growth of GF, proponents advocate for the development of a strong GF market and rapid expansion of the green financial system in developing nations. The study [33] addresses the effects of different economic indicators on financial stability, considering the dual mediating roles of environmental sustainability and sustainable growth. The findings demonstrated a beneficial relationship among economic growth, enhanced infrastructure, ethical leadership, and income creation. Environmental sustainability is one of the concepts used most frequently while discussing climate change. GF fosters green innovation in underdeveloped nations and those with low levels of GF, however, it harms the development of green products in industrialized nations with robust sustainability or green innovation frameworks.

GF aligns financial goals with sustainability objectives, fostering a transition to a more socially inclusive, environmentally responsible, and economically resilient future. The inclusion of environmental, social, and governance considerations in investment choices directs capital towards initiatives that provide favorable social outcomes, foster sustainable economic development, and protect the natural environment [30].

There is a notable lack of critical reflection on how emerging GF solutions can incorporate social dimensions, such as gender and income equality, into the broader sustainability agenda. Despite the introduction of socially responsible investment models within GF, there remains a scarcity of concrete research assessing its social impacts, particularly on vulnerable and marginalized communities. Existing literature explores the benefits of sustainable infrastructure on economic and environmental sustainability, but no study has comprehensively examined the effects of sustainable infrastructure on multiple dimensions of the SDGs simultaneously. There is still a gap in understanding how sustainable infrastructure significantly contributes to long-term outcomes, particularly in terms of social, economic, and environmental sustainability. Our hypothesis addresses this gap by investigating how sustainable infrastructure supports the SDGs in these three domains: social, economic, and environmental.

H3a: Sustainable infrastructure has a significant relationship with social sustainability.

H3b: Sustainable infrastructure has a significant relationship with economic sustainability.

H3c: Sustainable infrastructure has a significant relationship with environmental sustainability.

2.4. Green technology innovation role in Social, economic, and environmental sustainability

The study [34] is being conducted to determine how the ecological balance in Western European countries will change when green technologies and green electricity are developed. Evidence shows that environmentally friendly technical advancements and renewable electricity both lower CO_2 emission. However, the financial crisis is positively connected with CO_2 emission, indicating that market expansion harms the environment. To reduce environmental harm, legislators in the area should devote more funds to GTI and renewable energy-producing capacity. The study [35] aims to explore the link between environmental performance, corporate social responsibility (CSR), and financial performance of businesses, along with the role that GTI plays as a mediator in this relationship. This study offers helpful recommendations for enhancing CSR and GTI in assessing production enterprises' financial and environmental performance for managers, directors, and policymakers. The association among GTI, the utilization of green energy, and the impact of carbon dioxide emission is examined in the research [36]. The findings also have several practical ramifications that may assist company executives. The empirical results demonstrate the long-term co-integration of innovation in green technology, efficient use of energy, and renewable consumption of energy, humanity, disposable income, and the production of carbon dioxide.

With an emphasis on the function of GTI as an arbitrator, the present research [35] intended to understand the association between CSR, a organizations financial success, and the environmental performance of Chinese manufacturing companies. The findings shoe that manufacturing firms promote the consideration of funding organizational social behavior and green innovation among all stakeholders in order to enhance overall performance. The study [37] explores the connections between using sustainable practices and investing in green technologies. The study results show that companies utilizing green technologies do not prioritize environmental sustainability over other objectives, like generating economic and social value. According to many experts in this field, the triple bottom line concept assesses corporate performance by considering the environmental impact, stakeholders, and profitability.

Literature has shown that industries adopting GTI not only enhance their competitiveness but also create employment opportunities in sectors such as renewable energy, organic farming, and environmentally friendly production [38]. Technologies in renewable energy, solid waste management, and pollution reduction hold significant potential to mitigate environmental impacts across various industries [39]. However, as highlighted by GTI, evidence suggests that implementing environmentally appropriate solutions in developing nations, where resources are limited, can be costly. Moreover, critical discussions around the lifecycle impacts of some green technologies, such as adoption of green technology for reducing environmental are still limited in the current literature.

The literature shows that green technology often examines its relationship with individual dimensions of the SDGs, such as environmental or economic aspects. However, no study has explored the combined effects of GTI on multiple SDG dimensions simultaneously. This study addresses that gap by hypothesizing and examining the impact of GTI on different dimensions of the SDGs specifically, the social, economic, and environmental aspects together, particularly in the context of long-term projects.

H4: GTI has a significant association with social sustainability.

H4a: GTI has a significant association with economic sustainability.

H4b: GTI has a significant relation with environmental sustainability.

2.5. Mediating role of sustainable infrastructure

Sustainable infrastructure plays a crucial role in both GF and social sustainability. Sustainable infrastructure projects create opportunities for private and public investments. Investors are increasingly interested in funding projects that align with environmental and social objectives, as they offer long-term returns and contribute to a green economy. These investments support the advancement and enlargement of sustainable infrastructure.

In a rising global financial center influenced by sustainable international development, the study [40] to examine the occurrences of implementing sustainability accounting, GF, and suitable regulatory standards. The convergence of a GF system is produced by the complementary impacts of legal policy and market-based finance, according to a theoretical framework that has been laid out. Regarding sustainability rules and cleaner production, the implications for the integrity of a GF system are stated. By supporting new sustainable infrastructure systems in Colombia, this study [41] investigates how sustainable financial mechanisms can increase clean infrastructure availability. Establishing a sustainable regional infrastructure should benefit from increased private and capital market participation as a result of this research.

The present study [42] employs Prosperity and foreign direct investment (FDI) as moderating variables to investigate the influence of GF and financial evolution on both environmental sustainability and growth within ASEAN economies. Research have demonstrated that the implementation of GF strategies produces favorable outcomes for ecological sustainability. The relationship between sustainable financial activities, investment in clean energy, a sustainable recovery in economics, and the environmental performance in G-20 nations is investigated in the [43, 44] to investigate the impact of GF on achieving SDGs, with a specific focus on China. The study proposes several legislative modifications for the business sector, encompassing the implementation of environmentally sustainable practices within the bond marketplace, banking system, and institutional investors.

According to [45], the concept of green investment acknowledges the significance of the environment, with the objective of boosting human well-being and social fairness while simultaneously addressing environmental hazards and promoting ecological sustainability. The implementation of GF, whether in the form of an institutional framework or a market mechanism, has a substantial impact on the sustainable infrastructure and the cultivation of economic sustainability [4]. The study conducted by [46] constructs an evaluation framework for the advancement of GF, utilizing its intrinsic mechanisms. The results indicate that the implementation of GF, which incorporates various indicators pertaining to economic, financial, and environmental progress, has the potential to foster the advancement of sustainable energy. Nevertheless, the restricted scope of GF, which heavily depends on market systems, poses difficulties in addressing the potential requirements for preserving and improving the social environment. The need for sufficient motivation for investors and financial institutions to join the green sector is mainly ascribed to the inherent lagging characteristics of GF [4, 47] investigated that sustainable infrastructure plays a crucial role in promoting GF and economic sustainability.

GF refers to financial activities that support projects and initiatives with environmental benefits, while economic sustainability focuses on long-term economic growth that is environmentally and socially responsible. GF encourages investments in sustainable infrastructure by considering environmental risks and incorporating them into financial decision-making processes. GF promotes long-term economic stability and resilience by integrating sustainability considerations into investment decisions.

Reference [48] explore that due to its enormous potential to promote the growth of social, environmental, and economic sustainability, sustainable infrastructure has been increasingly popular in recent years. To maximize environmental and financial policy frameworks and attain SDGs in developing markets, it is absolutely necessary to have a solid understanding how ecological constraints affect the relationship among economic constancy and biased technological development.

The study [49] explores the interplay between GF innovation, technical advancement, and environmental legislation in China's quest for sustainable growth. The findings from the analyses conducted on indigeneity and other related factors provide evidence supporting the presence of a causal relationship. Empirical results help shape the policy implications that maintain green funding, technical advancement, and environmental legislation as the key engines of sustainable growth within the Chinese economy [50]. Conduct a study on China carbon footprint, with the adoption of GTI, GF, natural resources and country economic stability. Results of this study indicate that adoption of GTI minimize the environmental effects and maximize the energy efficiency, government should encourage to the investors adopt GF technique, also define clear policy for the implications of green infrastructure, organizations also use energy efficient technologies, and take some serious actions to reduce the carbon emission, and boost sustainable development growth [45].

Sustainable infrastructure encompasses various elements, including energy efficiency in building usage, the deployment of renewable energy systems, the development of sustainable transport systems, and efficient water management, all aimed at reducing environmental impacts [51]. Infrastructure investments in smart grids, green building construction, and environmentally friendly transport systems positively impact reducing business costs and fostering the development of new markets for green technologies [52]. However, the current literature still lacks adequate tools to effectively assess the environmental impacts and changes associated with certain forms of significant infrastructural development, such as projects with high initial environmental costs or those involving complex land-use practices.

The literature reveals that no study has examined the combined effects of different dimensions of the SDGs such as social benefits, economic growth, and environmental quality together with sustainable infrastructure. Furthermore, there is a lack of research exploring how sustainable infrastructure mediates the relationship between GF and the various dimensions of the SDGs. This study addresses this gap through an in-depth analysis, investigating how sustainable infrastructure mediates the relationship between GF and social, economic, and environmental sustainability. This study addresses this gap by hypothesizing that;

H5: Sustainable infrastructure mediates the relationship among the GF and social sustainability, (**a**) GF and economic sustainability, (**b**) GF and environmental sustainability

2.6. Mediating role of green technology innovation

The present study [53] focuses on the relationship between CSR and GTI of businesses and the moderating effect of chief executive officer (CEO) narcissism. According to the findings, GTI significantly benefits from fulfilling internal CSR. GTI is significantly impacted negatively by external CSR, and the narcissism of the CEO fosters this relationship. According to a study [54], narcissistic CEOs are brazen, easily inspired by social approval, and possess a keen political awareness. They are, therefore, keen to acquire additional decision-making authority to match their preferences with the firm's strategies [55]. The study investigates the interactions between lean manufacturing, GTI, environmentally friendly innovation, social sustainability effectiveness, and green competition [56]. Lean manufacturing processes, social sustainability effectiveness, and green competition are all factors that the study further explores as mediators. The study's findings point to lean manufacturing processes as having a significant influence on adopting green technologies, developing green products, and competitiveness in the green market.

Reference [57], investigate that such type of procedure provides an effective framework to organizations to produce environmentally friendly products, maximize profit, improve green competitiveness in the society. Moreover, adoption of green technology firm minimizes environmental harmful wastage and increase your sustainable performances. Adoption of GTI, Eco friendly farming technique, sustainable energy solution's, activate social sustainability. Such type of innovative technique give the unique opportunity to the investor for investment, provide job opportunities, clean the environment and cause the economic growth [58]. This trend has led to the growth of sustainable finance instruments like green bonds, green loans, and impact investing funds [29].

In conclusion, the creation of environmentally friendly technologies is absolutely necessary in order to drive sustainable green financial and social practices. By providing sustainable solutions, attracting investments, creating jobs, and addressing environmental challenges, these innovations contribute to a more resilient, inclusive, and sustainable future.

The most recent breakthrough in integrating innovation, technology, and sustainability is called 'green technology'. Despite this, China has a number of challenges in this area due to the expensive nature of environmentally friendly goods and services. To speed the adoption of green technology, they must address the issues that various organizations are experiencing with their financial systems and establish a framework that supports the development of GTI. The results suggest that in order to address the banks' hesitancy to provide loans, it is imperative for the financial system to provide a comprehensive framework for financing and risk management that encompasses several aspects such as the stock market, expenditures, assurance, and guarantees. Green initiatives have less of an impact on the environment, and it's cheaper to finance enterprises that use GTI because of government incentives like incubation, guarantees, rate of interest subsidies [59].

The study [60] investigate the relationship among innovative green technology and the financial impact of the environmental friendly transition from the perspective of local government struggle. The findings show that developing of green technologies considerably aids the transition to a low-carbon economy. Competition between local governments not only makes the economic low-carbon transition much more difficult, but it also significantly lessens the positive effect that innovations in GTI have on this transition. To achieve economic excellence at the lowest feasible environmental cost. There was a positive correlation between GTI and both property and carbon emissions, and a negative correlation between the two over the long and short term, according to the results [61]. GTI enables the developing and implementation environmentally friendly solutions, such as energy-efficient technologies, and sustainable agriculture practices. GF channels capital towards sustainable businesses and projects, fostering a transition to a low-carbon economy. These innovations create opportunities for GF by attracting investments in clean technologies and infrastructure projects that reduce carbon emissions, conserve resources, and mitigate climate change.

GTI plays a transformative role in driving the adoption of sustainable practices, promoting GF, and achieving economic sustainability [29]. By fostering innovation, reducing costs, mitigating environmental risks, and creating market opportunities, GTI contribute to a more sustainable and resilient economy.

GTI encourages new knowledge creation by lowering greenhouse gas emissions, easing environmental stress, and boosting ecologically responsible industries [46]. The goal of this study is to analyze the impact on ecological sustainability of sustainable finance innovation and pilot zones, this study [62] builds a quasi-natural experiment and applies the difference-in-difference model. The results suggest that the implementation of the pilot zones for GF improvements and innovations policy has led to an improvement in the environmental condition. Additionally, digital finance and GTI play a crucial role in influencing environmental quality during the implementation of green financial reform [63]. Conducted a study that investigates the impact of digital financial services on the energy and environmental performance of China. The findings indicate that digital banking significantly improves China's long-lasting energy-environmental effectiveness. The transmission of GTI is influenced by digital finance, which in turn affects energy-environmental performance.

GI, as described by [64] refers to technological advancements that decrease energy consumption, air pollution, waste management, environmental deterioration, and the burning of fossil fuels. In today's corporate world, GI has played a crucial role in preventing the negative impacts of climate change. According to the study [65], environmental sustainability may be attained at the highest income level but at the cost of investment risk. In light of this, GF is anticipated to significantly improve banking institutions' environmental performance during the epidemic. GTI is closely linked to GF and environmental sustainability. By driving the development and adoption of sustainable technologies, GF plays a crucial role in accelerating the transition to a low-carbon and resource-efficient economy, contributing to environmental protection, and addressing climate change challenges. GTI are integral to transitioning towards a circular economy, where resources are used efficiently, waste is minimized, and materials are recycled or repurposed. GF can drive investments in circular economy businesses and projects, promoting sustainable production and consumption patterns.

GTI acts as a crucial mediator between GF and the attainment of social, economic, and environmental sustainability. It also plays an essential role in converting green financial investments into innovations that offer sustainable solutions across various sectors. For instance, Green Finance enables firms to fund innovations in renewable energy systems, energy-efficient technologies, and sustainable infrastructures, all of which are essential for driving economic development while minimizing environmental harm [66]. A vast amount of literature exists that examines how GTI directly contributes to individual aspects of sustainability, such as fostering economic growth and reducing carbon emissions. However, a significant gap remains in understanding how GTI mediates the relationship between GF and different SDG domains, such as social, economic, and environmental sustainability. This study fills that notable research gap by demonstrating that GTI not only drives advancements in environmental technologies but also promotes social and economic development.

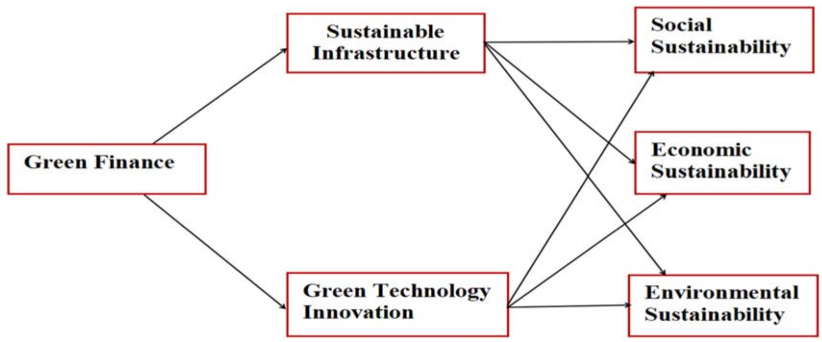

Figure 2. Conceptual framework.

H6: GTI mediates the association among GF and social sustainability, (**a**) GF and economic sustainability, (**b**) GF and environmental sustainability.

Figure 2 illustrates the theoretical framework of the study, suggesting that one independent variable, green finance, influence on three different dimensions of SDGs (Social sustainability, economic sustainability and environmental sustainability). This influence is mediated through sustainable infrastructure and green technology innovation.

3. Research methodology

The data was analyzed using Partial Least Square Structural equation Modeling (PLS-SEM), to test the hypothesized research model. This technique is considered superior to other analytical methods because it calculates dynamic models and diversified relationships, and it is particularly effective when the goal is not estimate population parameters [67]. Furthermore, PLS has been used widely for models that contain multiple number of moderating and mediating variables, as is the case in our model. We used smart PLS version 4 to evaluate the collected data and divided our analysis in two parts. First part involves pls algorithm i.e., validation of the measurement model, whereas, in second part we run pls bootstrapping procedure to evaluate the structural model [68].

3.1. Data collection procedure

The authors used a quantitative research approach and collected the data from various sources, such as entrepreneurs, officials from the CPEC, representatives from the Ministry of Finance, the Pakistan environmental protection agency, and the Ministry of Planning, Development and Special Initiative. Using a non-probability sampling technique, data were collected from Pakistan's five major provinces: Punjab, KPK, Sindh, Baluchistan, and Gilgit Baltistan. The researcher personally visited the relevant ministry offices and solicited feedback on the performance of CPEC in term of GF, sustainable infrastructure, GTI, social sustainability, economic sustainability, and environmental sustainability using a questionnaire. The questionnaire for this study was created using a five-point Likert scale, with 'strongly disagree' assigned a value of 1 and 'strongly agree' assigned a value of 5 [69].

In the present research, 750 questionnaires were distributed among the population that were targeted; before to the distribution of the questionnaires, the respondents were provided with a comprehensive explanation of the purpose of the study, which ensured that they were willing to participate in the survey. The data was collected from January 2024 to March 2024. Finally, the survey concluded with a total of 630 respondents who provided valid responses. In this research, questions are split into two different sections. The respondents' demographic information was included in the first section of the questionnaire. The second part had 37 factors related to the six variables, GF, sustainable infrastructure, GTI, and social sustainability, economic sustainability, and environmental sustainability. Table 1 summarizes the demographic information, such as gender, married status, and living province, level of education, working department, Job position, and job experiences. We decided to create the survey in English because it is an international language widely understood by Pakistan's educated population. First, these surveys were sent to the English departments of two universities (University of Sargodha and International Institute of Arts Science and technology Gujranwala) to look for problems with grammar, spelling, and accuracy. Furthermore, to help in rectifying and providing suggestions for the survey content, the author requested certain professors from different universities (Department of Economics, environmental sciences, planning, and Development); due to their suggestions, some survey items were changed.

Table 1. Socio-demographic characteristics.

	Sample Size (n = 630)	Frequency	Percentage
Gender	Female	54	8.6
	Male	576	91.4
Married status	Unmarried	152	24.1
	Married	478	75.9
Leaving province	Gilgit Baltistan	45	7.1
	Punjab	221	35.1
	KPK	171	27.1
	Sindh	112	17.8
	Baluchistan	81	12.9
Job position	Ass. director	95	15.1
	Research officer	117	18.6
	Secretary	39	6.2
	Finance officer	92	14.6
	Admin officer	287	45.6
Level of education	Secondary/ higher	32	5.1
	Associate degree	164	26.0
	Bachelors	177	28.1
	Postgraduate	257	40.8
Working department	CPEC officials	173	27.5
	Ministry of Finance	87	13.8
	Ministry of Planning	113	17.9
	Ministry of Env.	70	11.1
	Businessman	187	29.7

Table 2. Summery of describe variables.

S. No	Variables	Abbreviations	Variables in the model	Source	Item scale
1	Green finance	GF	Independent Variable	[46]	Six
2	Green technology innovation	GTI	Mediator Variable	[57]	Five
3	Sustainable infrastructure	SI	Mediator Variable	[70]	Six
4	Environmental sustainability	EN	Dependent Variable	[6]	Six
5	Social sustainability	SS	Dependent Variable	[72]	Six
6	Economic sustainability	ES	Dependent Variable	[6]	Six

3.2. Research instruments

With the help of smart PLS 4, structural equation modeling is used to reach the study's goals. Table 2 show the measurements and scales come from well-known, well-organized research in each relevant field. The current research GF served as the dependent variable in this study. Six scale items are used to measure GF, which come from [46]. This study used sustainable infrastructure and GTI as mediator variables. Sustainable infrastructure and GTI served as the mediators in this study. Six scale items are used to measure sustainable infrastructure, and five items are used to measure GTI, which come from [57, 70]. This current study also used social sustainability, economic sustainability, and environmental sustainability as an independent variables, and six items are each variables come from [6, 71].

4. Results

This section demonstrates the research methodology results and discussions such as socio-demographic variables, standardized root mean square residual (SRMR), assessment of the outer measurement model, testing of hypotheses, discussion, and implications.

Table 3. Reliability and validity analyses of the sample.

Constructs	Items	Loadings	VIF	Cronbach's Alpha	C.R	AVE
Green finance	GF1	0.798	2.268	0.813	0.877	0.641
	GF2	0.860	3.073			
	GF3	0.886	2.885			
	GF4	0.805	2.103			
	GF5	0.783	1.997			
Sustainable infrastructure	SI1	0.757	2.072	0.847	0.891	0.622
	SI2	0.781	2.679			
	SI3	0.771	2.473			
	SI4	0.762	2.084			
	SI5	0.734	1.699			
	SI6	0.708	1.657			
Green technology innovation	GT1	0.766	1.684	0.866	0.904	0.653
	GT2	0.837	2.018			
	GT3	0.783	1.765			
	GT4	0.814	1.718			
Economic sustainability	ES1	0.726	1.545	0.849	0.887	0.567
	ES2	0.841	2.055			
	ES3	0.838	2.112			
	ES4	0.809	2.113			
	ES5	0.719	2.714			
Social sustainability	SS1	0.743	1.545	0.793	0.866	0.618
	SS2	0.828	2.055			
	SS3	0.825	2.112			
	SS4	0.833	2.113			
	SS5	0.807	1.714			
Environmental sustainability	EN1	0.782	1.642	0.884	0.915	0.685
	EN2	0.830	1.831			
	EN3	0.767	1.551			
	EN4	0.763	1.521			

4.1. Evaluation of outer measurement model

Factor loading is a statistical method employed to evaluate the correlation between latent factors and observed variables. It signifies the strength and direction of the relationship between each item and the underlying factor. Factor loading's often lie on a spectrum from −1 to +1, with closer values near 1 signifying a stronger association [73]. The factor loading values for each item are presented in table 3 and figure 3. According to the convention established by [73], each item has a factor loading over 0.7. Six components were used to assess sustainable infrastructure, with factor loading's ranging from 0.757 to 0.708. The factor loading range for GF has been observed to be between 0.798, and 0.783. The factor loading for GTI is between 0.767 and 0.814. In addition, the factor loading for social sustainability is between 0.743 and 0.807. Factor loadings for economic sustainability range from 0.726 to 0.719. In the final step, factor loading for environmental sustainability range from 0.782 to 0.763. According to the results, all items meet the threshold. In addition, the multicollinearity of each item was evaluated based on the value of the variable influence factor (VIF). VIF acceptable value is five, if this value is greater than five it's problematic and exists multicollinearity among the variables, there is no multicollinearity issue in this work because all constructs have VIF values below 5 [73]. A set of items reliability and internal consistency can be measured statistically using Cronbach's alpha. Higher values of Cronbach's alpha, a statistical measure that can take on values between 0 and 1, indicate more internal consistency. According to table 3, Cronbach's alpha coefficients for each variable exceed 0.9, indicating a high level of internal consistency [73], suggests that the scale demonstrates reliability and consistently measures the desired construct. composite reliability (CR) is a statistical measure employed in structural equation modeling to evaluate the reliability of a composite or latent variable. Like Cronbach's alpha, it looks at the reliability of several indicators or seen variables to reveal latent variables. Composite reliability levels that exceed 0.8 are deemed to be within an acceptable range [73]. As shown in table 3, the CR of each variable is more than 0.8, indicating that the composite variable consistently and reliably measures the underlying construct.

4.2. Fronell-Larcker criterion

The Fronell-Larcker technique (1981) was utilized to evaluate the discriminant validity. They argue that construct variance should be greater with its own indicators than with other constructs. Table 4 shows good discriminant validity because construct correlations are smaller than the square roots of their respective AVEs.

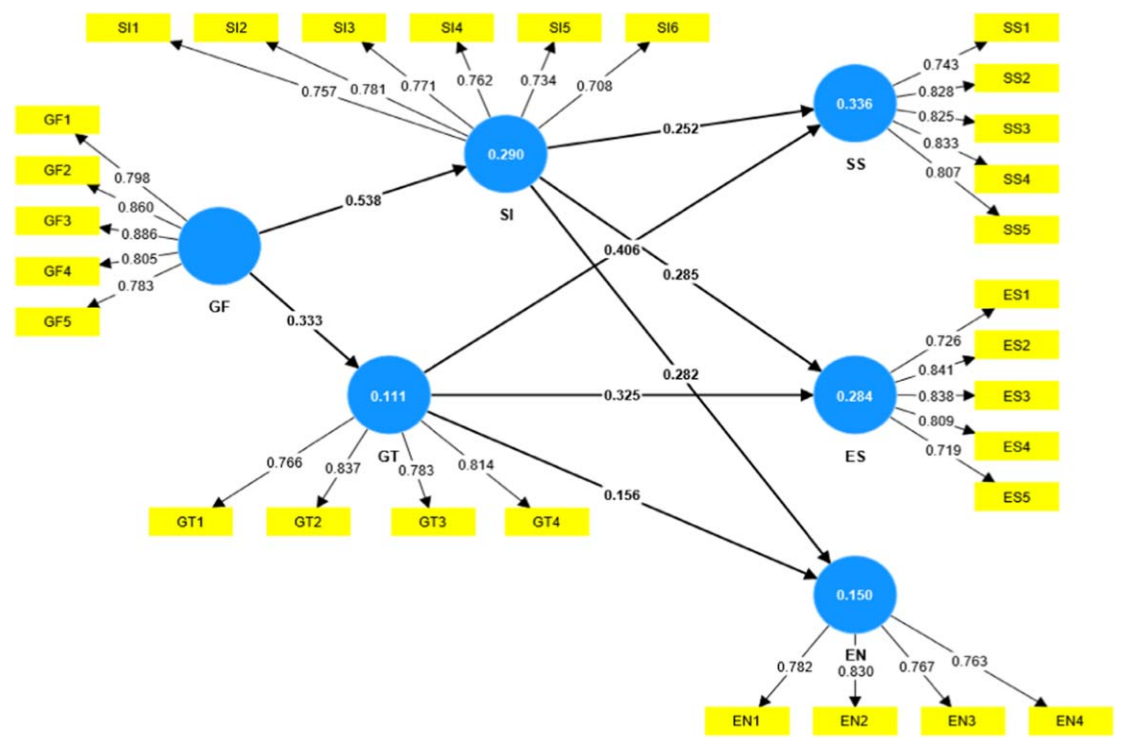

Figure 3. Measurement model.

Table 4. Fronell-Larcker criteria.

	EN	EF	GF	GT	SI	SS
EN	0.786					
EF	0.543	0.788				
GF	0.304	0.339	0.827			
GT	0.304	0.474	0.333	0.800		
SI	0.363	0.455	0.538	0.524	0.753	
SS	0.402	0.603	0.385	0.538	0.465	0.808

GF = green finance, SI = Sustainable infrastructure, GT = Green technology innovation, SS = Social sustainability, ES = Economic sustainability, EN = Environmental sustainability

The results indicate that the constructs are distinct and unrelated, demonstrating that the model accurately distinguishes between the latent constructs.

4.3. Model fit summary

The standardized residuals between the predicted and actual covariance matrices were compared using the Standardized Root Mean Square Residual (SRMR) index [73]. It assesses the specified model fit that has been Predicted and estimated [74]. Indicating appropriate performance, a decent fit, and that the research framework is acceptable, the SRMR score must be equal to or less than 0.08. As indicated in table 5, the outcome demonstrates the SRMR value of 0.068, which is a satisfactory fit for the model. The NFI value in table 5 is 0.771, and the Chi-Square (2) value is 1519.845.

4.4. Test of hypothesis (Direct effects)

The present study proposed a total of fourteen hypotheses, with eight focused on assessing direct relationship, additionally six hypotheses were formulated to evaluate indirect relationships through mediation. The result shows in table 6 and figure 4 green finance is associated with sustainable infrastructure and green technology innovation as their $p < 0.05$ and $\beta = 0.538$ and 0.333, respectively. We also observed a strong correlation between sustainable infrastructure and sustainability across the domains of social, economic, and environmental sustainability as their $p < 0.05$ and $\beta = 0.252$, 0.285, and 0.282 respectively. Green technology

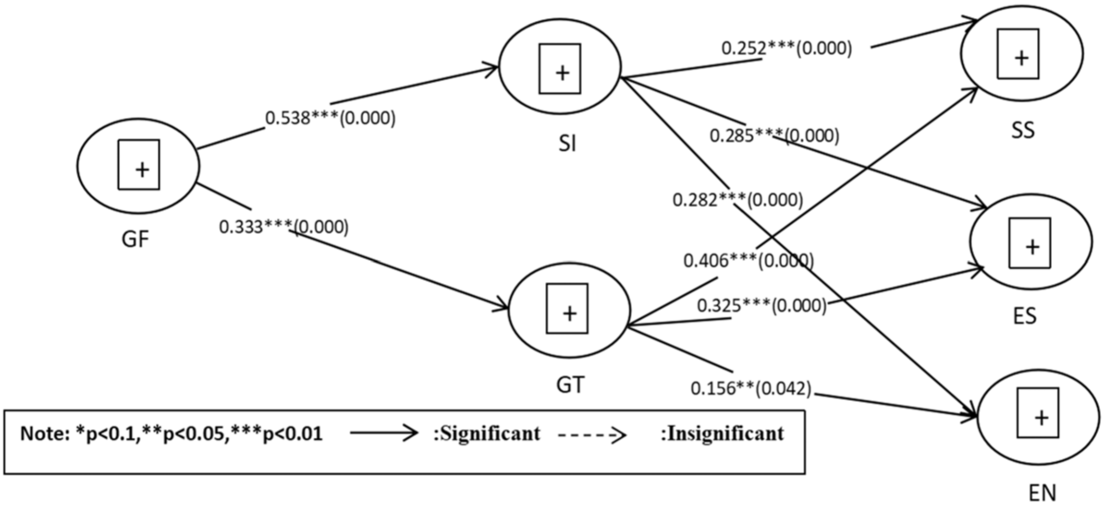

Figure 4. Relationship of direct hypothesis.

Table 5. Model fit summary.

	Estimated Model
SRMR	0.068
d_ULS	2.021
d_G	0.620
Chi-Square	1519.845
NFI	0.771

Table 6. Test of hypothesis (Direct effect).

Hypothesis	Std. Beta (β)	S.TD	T-Statistics	P-Value	Result
GF -> SI	0.538	0.040	13.617	0.000	Accepted
GF -> GT	0.333	0.057	5.815	0.000	Accepted
SI -> SS	0.252	0.057	4.423	0.000	Accepted
SI -> ES	0.285	0.060	4.735	0.000	Accepted
SI -> EN	0.282	0.068	4.114	0.000	Accepted
GT -> SS	0.406	0.056	7.304	0.000	Accepted
GT -> ES	0.325	0.065	5.019	0.000	Accepted
GT -> EN	0.156	0.077	2.032	0.042	Accepted

innovation results also show a significant and positive relationship with social sustainability, economic sustainably, and environmental sustainability as their $p < 0.05$ and $\beta = 0.406$, 0.325, and 0.156 respectively. Overall, all the hypotheses are supported and accepted as the findings align with the expected outcomes.

4.5. Mediation effects

In table 7, the results of the indirect effects are shown. Results indicates a strong mediation effect of sustainable infrastructure in the relationship between GF and sustainability across the domains of social, economic, and environmental sustainability as their $p < 0.05$ and $\beta = 0.136$, 0.153, and 0.152 respectively. These findings highlight the significance of sustainable infrastructure in maximizing the positive impacts of GF on social, economic, and environmental sustainability. In addition, it has been found that GTI plays a mediating role in the connection between GF and both social and economic sustainability as their $p < 0.05$ and $\beta = 0.135$ and 0.108, respectively. However, GTI does not support the mediation relationship between GF and environmental sustainability. As a result, our hypothesis, H6B is rejected.

4.6. Discussion

This study investigates the impact of GF on sustainable infrastructure, GT, economic stability, and environmental conservation within the framework of BRI funding, with a particular focus on its application in

Table 7. Test of hypothesis (Indirect/Mediation effect).

Hypothesis	Std. Beta (β)	S.TD	T-Statistics	P-Value	Result
GF -> SI -> SS	0.136	0.033	4.111	0.000	Accepted
GF -> SI -> ES	0.153	0.035	4.338	0.000	Accepted
GF -> SI -> EN	0.152	0.040	3.795	0.000	Accepted
GF -> GT -> SS	0.135	0.034	3.970	0.000	Accepted
GF -> GT -> ES	0.108	0.032	3.438	0.001	Accepted
GF -> GT -> EN	0.052	0.030	1.727	0.084	Rejected

the CPEC initiatives. Moreover, this research aligns with the UN SDGs related to sustainable infrastructure, innovation, and environmentally friendly production and consumption by integrating green technology, and GF. Data was gathered from Pakistani government employees involved in the CPEC Funds and officers in charge of fund distribution, and it was evaluated using statistical methods, including smart PSL. In this approach, fourteen hypotheses are proposed, including eight direct and six indirect.

The relationship between GF and sustainable infrastructure is examined in Hypothesis 1, focusing on the direct impact. The findings indicate a positive correlation between GF and sustainable infrastructure, suggesting that increasing green finance can enhance the development of sustainable infrastructure. These results are consistent with previous research, which has also highlighted the beneficial effects of green finance on environmentally friendly infrastructure [63]. Hypothesis 2 demonstrates that GF has a positive impact on green technology innovation. Our findings support Hypothesis 2, aligning with the studies of [22, 75], which also found a positive relationship between GF and green technology innovation. Thus, both Hypothesis 1 and Hypothesis 2 are significantly supported by our study.

Hypothesis 3, 3a, and 3b explore the impact of sustainable infrastructure on social, economic, and environmental sustainability. Results in table 6 demonstrate positive and significant relationship between sustainable infrastructure and all three dimensions of the SDGs. Therefore, our hypothesis 3, 3a and 3b are successfully supported. These findings are consistent with previous research, which also explore the important role of sustainable infrastructure in achieving the SDGs [76, 77].

Hypothesis 4, 4a, and 4b explore the impact of green technology innovation on social, economic, and environmental sustainability. Results demonstrate positive and significant relationship between green technology innovation and all three dimensions of the SDGs. Therefore, our hypothesis 4, 4a and 4b are successfully supported. These findings are consistent with previous research, which also explore the important role of green technology innovation in achieving the SDGs [78].

Furthermore, this research set up six hypotheses concerning indirect effect. Hypothesis 5, 5a and 5b indicate that sustainable infrastructure show mediates the positive and significant relation between GF and three dimensions of SDGs (Social, economic and environmental). Our hypothesis is also successfully supported and results are consistent with previous research [79]. Hypotheses 6, 6a, and 6b suggest that green technology mediates the positive and significant relationship between GF and all dimensions of the SDGs, including social, economic, and environmental aspects. Our findings successfully support these hypotheses, aligning with previous research that highlights the mediating role of green technology in the relationship between GF and SDGs [66, 80].

5. Conclusion

This study investigates the intricate relationships between green finance, sustainable infrastructure, and green technology innovation as pathways to achieving SDGs within the BRI, specifically focusing on the CPEC. By examining the direct and indirect effects of these variables, we aimed to provide a comprehensive understanding of how GF can facilitate the achievement of social, economic, and environmental sustainability.

Our findings indicate that green finance significantly influences sustainable infrastructure development, as hypothesized. This suggests that increased investments in GF can lead to substantial improvements in infrastructure that support sustainability goals. Furthermore, the study confirms the positive impact of GF on GTI, highlighting the essential role of financial mechanisms in driving technological advancements that promote environmental sustainability.

The mediating role of sustainable infrastructure between GF and the three dimensions of SDGs social, economic, and environmental sustainability was also supported by our results. This indicates that sustainable infrastructure serves as a crucial conduit through which GF can realize broader sustainability outcomes. Similarly, GTI was found to mediate the relationship between GF and the SDGs, reinforcing the idea that innovation is pivotal in translating financial investments into tangible sustainability benefits. Additionally, the study provides empirical evidence that sustainable infrastructure positively affects all three dimensions of SDGs. Social sustainability is enhanced through improved living standards and community well-being; economic sustainability is bolstered by robust, resilient infrastructure that supports economic activities; and environmental sustainability is promoted through infrastructure that minimizes ecological impact.

5.1. Policy implication of the study

We propose a set of comprehensive policy recommendations. First, policymakers should increase funding for green finance initiatives, ensuring that adequate resources are allocated to support sustainable infrastructure and green technology innovation. Additionally, developing clear regulatory frameworks is essential. Policymakers should establish robust regulations that define the standards and criteria for green finance, sustainable infrastructure, and green technology innovation. Creating comprehensive monitoring and evaluation systems to track the progress and impact of green finance initiatives is another key recommendation. Policymakers should establish clear benchmarks, performance indicators, and regular reporting mechanisms to assess the effectiveness of policies and projects. Furthermore, fostering innovation through research and development activities that contribute to sustainability goals can drive significant progress. Governments can support these activities through grants, subsidies, and tax incentives, encouraging the development and adoption of green technologies.

Finally, facilitating knowledge sharing and the exchange of best practices among countries participating in the BRI is recommended. This can include international conferences, workshops, and online repositories of successful case studies and lessons learned. By implementing these specific, actionable steps and utilizing the detailed framework for policy implementation, policymakers can bridge the gap between theoretical research and practical application, advancing sustainable development goals within the context of the BRI and the CPEC.

5.2. limitations and future directions of the study

This study investigates the significant relationships among variables that benefited the aims of sustainable infrastructure and GF, among other sectors. Even though this study made a lot of important contributions, it has some limitations that future researchers should consider. The current study examines the role of GF in sustainable infrastructure, adaptation of GTI and corporate SDGs, but it didn't address several other goals for sustainable growth. Future research could delve into the role of micro-enterprises in green finance, exploring how these smaller entities can contribute to and benefit from sustainable financial practices. Additionally, investigating the impact of cultural and regional differences on the implementation of green finance initiatives within the BRI framework could provide valuable insights. Furthermore, exploring the integration of advanced technologies, such as blockchain and artificial intelligence, in green finance practices could reveal innovative solutions for enhancing transparency, efficiency, and effectiveness. Research could also focus on the policy and regulatory frameworks necessary to support green finance, sustainable infrastructure, and green technology innovation. Comparative studies across different countries and regions participating in the BRI could highlight best practices and areas for improvement. Finally, assessing the role of public awareness and education in promoting green finance and sustainable practices can provide insights into how to foster a culture of sustainability among stakeholders.

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Data availability statement

The data includes detailed financial information, infrastructure project specifics, and green technology innovations that are subject to confidentiality agreements with various stakeholders, including governmental and private entities in Pakistan. The data that support the findings of this study are available upon reasonable request from the authors.

Competing interests

The authors have no relevant financial or non-financial interests to disclose.

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References

[1] Ylander A 2017 *The impact of 'One Belt, One Road'and its Effects on GDP growth in China.*
[2] Mahmood S *et al* 2022 Belt and road initiative as a catalyst of infrastructure development: assessment of resident's perception and attitude towards China-Pakistan economic corridor *PLoS One* **17** e0271243
[3] Dossani R, Bouey J and Zhu K 2020 Demystifying the belt and road initiative: a clarification of its key features, objectives and impacts (No. WR-1338)
[4] Mahmood S *et al* 2024 Sustainable infrastructure, energy projects, and economic growth: mediating role of sustainable supply chain management *Ann. Oper. Res.* **33** 1–32
[5] Hassan K 2020 CPEC: a win-win for China and Pakistan *Human Affairs* **30** 212–23
[6] Al-Emran M 2023 Beyond technology acceptance: development and evaluation of technology-environmental, economic, and social sustainability theory *Technology in Society* **75** 102383
[7] Sahoo S and Goswami S 2024 Theoretical framework for assessing the economic and environmental impact of water pollution: a detailed study on sustainable development of India *Journal of Future Sustainability* **4** 23–34
[8] Sharif A *et al* 2022 Nexus between green technology innovation, green financing, and CO_2 emissions in the G7 countries: the moderating role of social globalisation *Sustainable Development* **30** 1934–46
[9] Kirikkaleli D and Adebayo T S 2022 Political risk and environmental quality in Brazil: role of green finance and green innovation *International Journal of Finance & Economics* **29** 1205–12018
[10] Adebayo T S 2022 Renewable energy consumption and environmental sustainability in Canada: does political stability make a difference? *Environmental Science and Pollution Research* **29** 61307–22
[11] Abbas J and Sağsan M 2019 Impact of knowledge management practices on green innovation and corporate sustainable development: a structural analysis *J. Clean. Prod.* **229** 611–20
[12] Munyasya B M and Chileshe N 2018 Towards sustainable infrastructure development: drivers, barriers, strategies, and coping mechanisms *Sustainability* **10** 4341
[13] Ali M 2018 The China-Pakistan economic corridor: tapping potential to achieve the 2030 agenda in Pakistan *China Quarterly of International Strategic Studies* **4** 301–25
[14] Menhas R *et al* 2019 Sustainable development under belt and road initiative: a case study of China-Pakistan economic corridor's socio-economic impact on Pakistan *Sustainability* **11** 6143
[15] Cao L 2023 How green finance reduces CO_2 emissions for green economic recovery: Empirical evidence from E7 economies *Environmental Science and Pollution Research* **30** 3307–20
[16] Nitza-Makowska A 2020 China–Pakistan economic corridor and sustainable development goal implementation in Pakistan: fostering sustainable connectivity in a fragile context? *Journal of Peacebuilding & Development* **15** 377–82
[17] Mahmood S, Sabir M and Ali G 2020 Infrastructure projects and sustainable development: discovering the stakeholders' perception in the case of the China–Pakistan economic corridor *PLoS One* **15** e0237385
[18] Yu C-H *et al* 2021 Demand for green finance: resolving financing constraints on green innovation in China *Energy Policy* **153** 112255
[19] Hyung K and Baral P 2019 Use of innovative public policy instruments to establish and enhance the linkage between green technology and finance *Handbook of Green Finance: Energy Security and Sustainable Development* ed J D Sachs *et al* 1–24
[20] Ullah S *et al* 2023 Green practices in mega development projects of China–Pakistan Economic Corridor *Sustainability* **15** 5870
[21] Angom J 2021 The potential role of green finance in realizing sustainable recovery from COVID-19 and achievement of sustainable development goals *International Journal of Research and Innovation in Social Science* **4** 218–25
[22] Ma H *et al* 2023 How does green finance affect the sustainable development of the regional Economy? Evidence from China *Sustainability* **15** 3776
[23] Chen D, Hu H and Chang C P 2023 Green finance, environment regulation, and industrial green transformation for corporate social responsibility *Corporate Social Responsibility and Environmental Management* **30** 2166–81
[24] Wang K-H *et al* 2022 Does green finance inspire sustainable development? Evidence from a global perspective *Economic Analysis and Policy* **75** 412–26
[25] Brunnhuber S and Brunnhuber S 2021 Beyond the mantra of traditional finance: significance and limits of the conventional approach *Financing Our Future: Unveiling a Parallel Digital Currency System to Fund the SDGs and the Common Good* 31–66
[26] Umar M *et al* 2021 The imperativeness of environmental quality in the United States transportation sector amidst biomass-fossil energy consumption and growth *J. Clean. Prod.* **285** 124863
[27] Umar M *et al* 2021 The impact of resource curse on banking efficiency: evidence from twelve oil producing countries *Resour. Policy* **72** 102080
[28] Zakari A 2022 The role of green finance in promoting sustainable economic and environmental development *Studies of Applied Economics* **40**
[29] Fang Y and Shao Z 2022 Whether green finance can effectively moderate the green technology innovation effect of heterogeneous environmental regulation *International Journal of Environmental Research and Public Health* **19** 3646
[30] Xu B and Lin B 2024 Green finance, green technology innovation, and wind power development in China: evidence from spatial quantile model *Energy Econ.* **132** 107463
[31] Yu B, Liu L and Chen H 2023 Can green finance improve the financial performance of green enterprises in China? *International Review of Economics & Finance* **88** 1287–300
[32] Saydaliev H B and Chin L 2022 Role of green financing and financial inclusion to develop the cleaner environment for macroeconomic stability: inter-temporal analysis of ASEAN economies *Economic Change and Restructuring* **56** 1–21
[33] Mahmood S *et al* 2023 Exploring the China-Pakistan economic corridor project performance during Covid-19 pandemic *Heliyon* **9** e22835
[34] Oyebanji M O and Kirikkaleli D 2023 Green technology, green electricity, and environmental sustainability in Western European countries *Environmental Science and Pollution Research* **30** 38525–34

[35] Xu X *et al* 2022 The mediating role of green technology innovation with corporate social responsibility, firm financial, and environmental performance: the case of chinese manufacturing industries *Sustainability* **14** 16951
[36] Shan S *et al* 2021 Role of green technology innovation and renewable energy in carbon neutrality: a sustainable investigation from Turkey *J. Environ. Manage.* **294** 113004
[37] Vimala D, Evangelin M R and Vasantha S 2022 *Sustainability and Green Technology Innovation* **7** 12–24
[38] Chen Z *et al* 2022 Can green credit policy promote low-carbon technology innovation? *J. Clean. Prod.* **359** 132061
[39] Yang Z *et al* 2024 Can renewable energy development facilitate China's sustainable energy transition? Perspective from Energy Trilemma. *Energy* **304** 132160
[40] Ng A W 2018 From sustainability accounting to a green financing system: Institutional legitimacy and market heterogeneity in a global financial centre *J. Clean. Prod.* **195** 585–92
[41] Ruiz J G, Arboleda C and Botero S 2016 A proposal for green financing as a mechanism to increase private participation in sustainable water infrastructure systems: the Colombian case *Procedia Engineering* **145** 180–7
[42] Fu W and Irfan M 2022 Does green financing develop a cleaner environment for environmental sustainability: empirical insights from association of southeast Asian nations economies *Frontiers in Psychology* **13** 904768
[43] Ma M *et al* 2023 Combining the role of green finance and environmental sustainability on green economic growth: evidence from G-20 economies *Renewable Energy* **207** 128–36
[44] Behera B, Behera P and Sethi N 2024 Decoupling the role of renewable energy, green finance and political stability in achieving the sustainable development goal 13: empirical insight from emerging economies *Sustainable Development* **32** 119–37
[45] Chin M-Y *et al* 2024 The impact of green finance on environmental degradation in BRI region *Environment, Development and Sustainability* **26** 303–18
[46] Zheng G-W *et al* 2021 Green finance development in Bangladesh: the role of private commercial banks (PCBs) *Sustainability* **13** 795
[47] Zhang l, Huang F, Lu L and Ni X 2021 Green financial development improving energy efficiency and economic growth: a study of CPEC area in COVID-19 era (No. 2021-017). IRTG 1792
[48] Soraggi D and D'Amato G I 2024 The limitations of EMSs in comparison with the SDGs when considering infrastructure sustainability: the case of the Terzo Valico Dei Giovi, Italy *Sustainability* **16** 1558
[49] Hasan M M and Du F 2023 Nexus between green financial development, green technological innovation and environmental regulation in China *Renewable Energy* **204** 218–28
[50] Zhang H *et al* 2022 A road towards ecological development in China: The nexus between green investment, natural resources, green technology innovation, and economic growth *Resour. Policy* **77** 102746
[51] Singh S and Ru J 2023 Goals of sustainable infrastructure, industry, and innovation: a review and future agenda for research *Environmental Science and Pollution Research* **30** 28446–58
[52] Mahmood S *et al* 2024 Active learning-based machine learning approach for enhancing environmental sustainability in green building energy consumption *Sci. Rep.* **14** 19894
[53] Yang H, Shi X and Wang S 2021 Moderating effect of chief executive officer narcissism in the relationship between corporate social responsibility and green technology innovation *Frontiers in Psychology* **12** 717491
[54] Gupta A, Nadkarni S and Mariam M 2019 Dispositional sources of managerial discretion: CEO ideology, CEO personality, and firm strategies *Administrative Science Quarterly* **64** 855–93
[55] Chatterjee A and Hambrick D C 2011 Executive personality, capability cues, and risk taking: how narcissistic CEOs react to their successes and stumbles *Administrative Science Quarterly* **56** 202–37
[56] Manurung M, Anizar A and Ishak A 2024 Implementation of lean manufacturing methodology and its application: a literature review *Jurnal Sistem Teknik Industri* **26** 35–46
[57] Afum E *et al* 2021 Lean production systems, social sustainability performance and green competitiveness: the mediating roles of green technology adoption and green product innovation *Journal of Engineering, Design and Technology* **21** 206–27
[58] Bamidele R O *et al* 2023 Realizing green airport performance through green management intransigence, airport reputation, biospheric value, and eco-design *Sustainability* **15** 2475
[59] Mansour N 2023 Green technology innovation and financial services system: evidence from China *Businesses* **3** 98–113
[60] Xu Y *et al* 2023 The impact of local government competition and green technology innovation on economic low-carbon transition: new insights from China *Environmental Science and Pollution Research* **30** 23714–35
[61] Meirun T *et al* 2021 The dynamics effect of green technology innovation on economic growth and CO_2 emission in Singapore: new evidence from bootstrap ARDL approach *Environmental Science and Pollution Research* **28** 4184–94
[62] Hou H *et al* 2023 Will green financial policy help improve China's environmental quality? The role of digital finance and green technology innovation. *Environmental Science and Pollution Research* **30** 10527–39
[63] Cao S *et al* 2021 Digital finance, green technological innovation and energy-environmental performance: evidence from China's regional economies. *J. Clean. Prod.* **327** 129458
[64] Li Z, Deng X and Peng L 2020 Uncovering trajectories and impact factors of CO_2 emissions: a sectoral and spatially disaggregated revisit in Beijing *Technol. Forecast. Soc. Change* **158** 120124
[65] Alola A A and Ozturk I 2021 Mirroring risk to investment within the EKC hypothesis in the United States *J. Environ. Manage.* **293** 112890
[66] Zhang L, Saydaliev H B and Ma X 2022 Does green finance investment and technological innovation improve renewable energy efficiency and sustainable development goals *Renewable Energy* **193** 991–1000
[67] Fornell C and Bookstein F L 1982 Two structural equation models: LISREL and PLS applied to consumer exit-voice theory *Journal of Marketing research* **19** 440–52
[68] Hair J F *et al* 2021 *Partial Least Squares Structural Equation Modeling (PLS-SEM) Using R: A Workbook* (Springer Nature)
[69] Ahmad S *et al* 2023 The impact of CSR and green consumption on consumer satisfaction and loyalty: moderating role of ethical beliefs *Environmental Science and Pollution Research* **30** 1–15
[70] Chan M, Jin H and van Kan D 2022 Assessment of driving factors for sustainable infrastructure development *Resour. Conserv. Recycl.* **185** 106490
[71] Abbas J *et al* 2019 The impact of knowledge sharing and innovation on sustainable performance in islamic banks: a mediation analysis through a SEM approach *Sustainability* **11** 4049
[72] Abbas J *et al* 2019 The effects of corporate social responsibility practices and environmental factors through a moderating role of social media marketing on sustainable performance of business firms *Sustainability* **11** 3434
[73] Hair J F, Ringle C M and Sarstedt M 2013 Partial least squares structural equation modeling: Rigorous applications, better results and higher acceptance *Long Range Planning* **46** 1–12

[74] Hair J *et al* 2017 An updated and expanded assessment of PLS-SEM in information systems research *Industrial Management & Data Systems* **117** 442–58

[75] Sethi L, Behera B and Sethi N 2024 Do green finance, green technology innovation, and institutional quality help achieve environmental sustainability? Evidence from the developing economies *Sustainable Development* **32** 2709–23

[76] Dipeolu A A and Ibem E O 2020 Green infrastructure quality and environmental sustainability in residential neighbourhoods in Lagos, Nigeria *International Journal of Urban Sustainable Development* **12** 267–82

[77] Leal Filho W *et al* 2022 An assessment of requirements in investments, new technologies, and infrastructures to achieve the SDGs *Environmental Sciences Europe* **34** 1–17

[78] Lv C, Shao C and Lee C-C 2021 Green technology innovation and financial development: do environmental regulation and innovation output matter? *Energy Econ.* **98** 105237

[79] Fei W *et al* 2021 The critical role of the construction industry in achieving the sustainable development goals (SDGs): delivering projects for the common good *Sustainability* **13** 9112

[80] Susan E B and Pan Y 2024 Trust as a determinant of green finance through information sharing and technological penetration: integrating the moderation of governance for sustainable growth *Technology in Society* **77** 102565