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Review

Technological Cooperation for Sustainable Development Under the Belt and Road Initiative and the Sustainable Development Goals: Opportunities and Challenges

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Abstract: The Belt and Road Initiative (BRI) promotes sustainable development in the participating countries by facilitating technology transfer, talent development, and industrial upgrading. Technological cooperation under the BRI plays a crucial role in helping these countries achieve the Sustainable Development Goals (SDGs). However, BRI cooperation also faces significant challenges, including geopolitical, economic, social, environmental, and legal risks. This paper reviews the current research on BRI technological cooperation, covering cooperation models, influencing factors, mechanisms, and the economic and social impacts of such cooperation. It examines both the opportunities and challenges involved and provides policy recommendations and action plans. This review offers valuable insights for researchers interested in BRI technological cooperation and contributes to advancing sustainable development in BRI countries.

Keywords: Belt and Road Initiative (BRI); Sustainable Development Goals (SDGs); technological cooperation; risk assessment; implementation pathways

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1. Introduction

In the current globalized landscape, China's Belt and Road Initiative (BRI), proposed in 2013, has united numerous developed and developing economies in an open, inclusive cooperation network [1–3]. The "Silk Road Economic Belt" and the "21st Century Maritime Silk Road" cover over 60% of the world's population and contribute to 30% of global GDP (Figure 1) [4]. As of October 2014, 154 countries and regions had joined the BRI (Table 1), expanding its reach well beyond these two economic corridors [5–7]. As an innovative model for international cooperation and development, the BRI not only continually attracts additional member countries and regions but also promotes infrastructural development and economic trade cooperation along its routes, creating exciting opportunities for technological exchange and collaboration among nations [8–10].

The SDGs, introduced at the United Nations General Assembly in 2015, consist of 17 primary goals and 169 specific targets, aiming ultimately to eradicate poverty, safeguard the planet, and ensure prosperity and equality for all through global cooperation, innovation, and sustainable practices [11–13]. As an inclusive global development framework, the BRI prioritizes sustainable development across its participating nations, emphasizing

positive, enduring social and economic impacts [14–18]. Initially, the BRI aimed to foster shared growth among participating countries, including those along its routes, through infrastructural development and economic and trade cooperation [19–24]. Notably, technological cooperation plays an essential role in advancing the goals of both the BRI and the SDGs [25].

In this context, the SDGs provide a common framework for sustainable development among BRI countries. Technological cooperation, as a key means of achieving these goals, is essential, and identifying a clear path for its implementation is crucial [26–28]. This cooperation not only fosters the exchange and transfer of technologies but also strengthens the innovation capabilities of participating nations. As a result, they can jointly tackle global challenges such as climate change, environmental protection, food security, disease prevention, energy security, and sustainable urbanization [29–37]. By defining the implementation path for international technological cooperation (ITC) within the BRI, and engaging in collaborative research and development of new technologies, these countries can enhance their technological capabilities while providing innovative solutions to achieve the SDGs [38–40].



Figure 1. Geographical map of the Silk Road on the sea and the Silk Road on land.

Under the BRI, technological cooperation has emerged as a key driver for the shared development of countries along the route [41]. Scholars have approached this topic from diverse perspectives, exploring various dimensions of technological cooperation, including its models, influencing factors, mechanisms, and the economic and social impacts of collaboration [42]. For instance, Feng, Kang, Pan, and Yang [25] assessed the development trends of 17 SDGs in four Southeast Asian countries within the BRI, evaluating future cooperation opportunities and outlining a roadmap for sustainable development. Qiu et al. [43] focused on the impact of the BRI on global or regional political and economic networks and examined how these networks affect trade and investment flows. Guo et al. [44] proposed the Digital BRI as an ITC designed to share knowledge, expertise, technology, and data, highlighting the role of big data in supporting sustainable development. Wang et al. [45] conducted a quantitative literature review, exploring the mutual reinforcement between technological cooperation and knowledge production in BRI countries. Their findings suggest that knowledge production can stimulate scientific collaboration by fostering spe-

cialized disciplines, economic development, and political stability. Moreover, Gao and Yu [9] analyzed changes in the network structure of technological cooperation from the perspective of patent collaborations. They found that factors such as research capabilities, technological spillovers, geographical proximity, and technological closeness promote collaboration, whereas a country's financial and technological innovation capacities do not necessarily have a positive impact.

Under the framework of the SDGs, technological cooperation is a key driver for achieving global sustainable development. It plays an important role in deepening regional cooperation, enhancing mutual trust and understanding among BRI countries, and providing strong support for solving global challenges [46]. Additionally, technological cooperation fosters the flow of knowledge and technology, enabling countries to establish long-term, stable partnerships. These partnerships not only facilitate technological progress but also amplify the influence and voice of participating countries on the international stage [39]. Moreover, technological cooperation creates more job opportunities for participating countries, further promoting comprehensive and sustainable socio-economic development [47]. As globalization continues to advance, the landscape of ITC is becoming increasingly diversified and deepened. This evolution presents both opportunities and challenges, and exploring how technological cooperation under the Belt and Road Initiative (TCBRI) can navigate these opportunities and challenges warrants further research and discussion [48,49].

Table 1. The BRI countries.

Region	Number	Countries
Asia	41	Afghanistan, United Arab Emirates, Oman, Azerbaijan, Pakistan, Palestine, Bahrain, Timor-Leste, Philippines, Georgia, Kazakhstan, South Korea, Kyrgyzstan, Cambodia, Qatar, Kuwait, Laos, Lebanon, Maldives, Malaysia, Mongolia, Bangladesh, Myanmar, Nepal, Saudi Arabia, Sri Lanka, Tajikistan, Thailand, Turkey, Turkmenistan, Brunei, Uzbekistan, Singapore, Syria, Armenia, Yemen, Iraq, Iran, Indonesia, Jordan, Vietnam
Africa	53	Algeria, Egypt, Ethiopia, Angola, Benin, Botswana, Burkina Faso, Burundi, Equatorial Guinea, Togo, Eritrea, Cape Verde, Gambia, Congo (Brazzaville), Congo (Kinshasa), Djibouti, Guinea, Guinea-Bissau, Ghana, Gabon, Zimbabwe, Cameroon, Comoros, Ivory Coast, Kenya, Lesotho, Liberia, Libya, Rwanda, Madagascar, Malawi, Mali, Mauritania, Morocco, Mozambique, Namibia, South Africa, South Sudan, Niger, Nigeria, Sierra Leone, Senegal, Seychelles, São Tomé and Príncipe, Sudan, Somalia, Tanzania, Tunisia, Uganda, Zambia, Chad, Central African Republic
Europe	26	Albania, Estonia, Austria, Belarus, Bulgaria, North Macedonia, Bosnia and Herzegovina, Poland, Russia, Montenegro, Czech Republic, Croatia, Latvia, Lithuania, Luxembourg, Romania, Malta, Moldova, Portugal, Serbia, Cyprus, Slovakia, Slovenia, Ukraine, Greece, Hungary, Italy
North America	13	Antigua and Barbuda, Barbados, Panama, Dominican Republic, Dominica, Grenada, Costa Rica, Cuba, Honduras, Nicaragua, El Salvador, Trinidad and Tobago, Jamaica
South America	9	Argentina, Peru, Bolivia, Ecuador, Guyana, Suriname, Venezuela, Uruguay, Chile
Oceania	12	Papua New Guinea, Fiji, Kiribati, Cook Islands, Federated States of Micronesia, Nauru, Niue, Samoa, Solomon Islands, Tonga, Vanuatu, New Zealand

Data source: the BRI official website: https://www.yidaiyilu.gov.cn/country, URL (accessed on 1 October 2024).

In addressing the issues of the TCBRI, many studies have focused on specific areas of industrial and technological collaboration, such as global trade, energy, infrastructural construction, land use, carbon emissions, steel and construction materials, environmental protection, and geological disasters. These studies examine the cooperation models and mechanisms within these fields [50–54]. For instance, Zhao et al. [55] developed a dynamic game model to identify key factors influencing the cooperation–competition relationship between China and the other BRI countries. Their results showed that in trade cooperation,

the additional benefits gained by both parties depend on external spillover effects from technology, trade costs, and the strategies of both sides. Meanwhile, Che et al. [56] analyzed nearly 20 years of cooperation data to assess the role of cooperation among the BRI countries. Their findings highlighted that differences in levels of development, openness, and economic scale among these countries significantly affect the strength of their cooperation.

The BRI aims to enhance interconnectedness between countries, fostering common development. In this regard, Gu and Liu [57] conducted a systematic literature analysis of scientific cooperation mechanisms among 65 countries under the BRI. They found that research strength and social proximity are the most critical factors in the formation of scientific cooperation networks, while the role of geographic distance in hindering cooperation has diminished. Additionally, China has taken a leading role in establishing these scientific connections.

In conclusion, the TCBRI plays a crucial role in promoting sustainable development in participating countries. It not only serves as a key pathway for achieving the SDGs but also contributes to the advancement of global governance reform. A comprehensive study of technological cooperation within the SDG framework among the BRI countries offers significant theoretical insights and practical guidance for ITC. This paper aims to review SDGs related to technological cooperation, analyze the risks and challenges of technological cooperation under the BRI, explore pathways to achieve sustainable development through technological cooperation, and provide relevant policy recommendations and action plans. This research contributes both a theoretical and practical review of technological cooperation under the BRI, offering new perspectives for exploring multilateral cooperation models in the context of globalization. The pathways and action plans for technological cooperation presented here may also serve as valuable references for other multinational cooperation projects. As the TCBRI deepens, the scope and depth of technological collaboration will continue to grow, presenting new opportunities for the technological development of participating countries.

2. SDGs Related to the TCBRI

2.1. Methodology

Under the framework of the SDGs, technological cooperation is critical for the achievement of multiple goals [58]. Specifically, within the context of the BRI, technological cooperation, technology transfer, and technological upgrading can significantly improve the technological capabilities and industrial competitiveness of recipient countries [59,60]. Following the synergy correlation analysis method proposed by Pradhan, Costa, Rybski, Lucht, and Kropp [61], this study employs "technological cooperation"-related SDG17 indicators as variable parameters, pairing them with indicators from SDG1 to SDG16. We then extract those SDG indicators that demonstrate synergistic effects as the TCBRI research objects [62,63]. The specific analytical process is illustrated in Figure 2.

1. Data Collection:

This study uses the 231 SDG indicators recommended by the United Nations Economic and Social Council [64], drawn from the UN Statistics Division's Global SDG Indicators Database. The data cover the 193 UN member states over the first decade of the BRI (2013–2023). After excluding countries without SDG17 data and those not participating in the BRI, 101 countries remain for analysis.

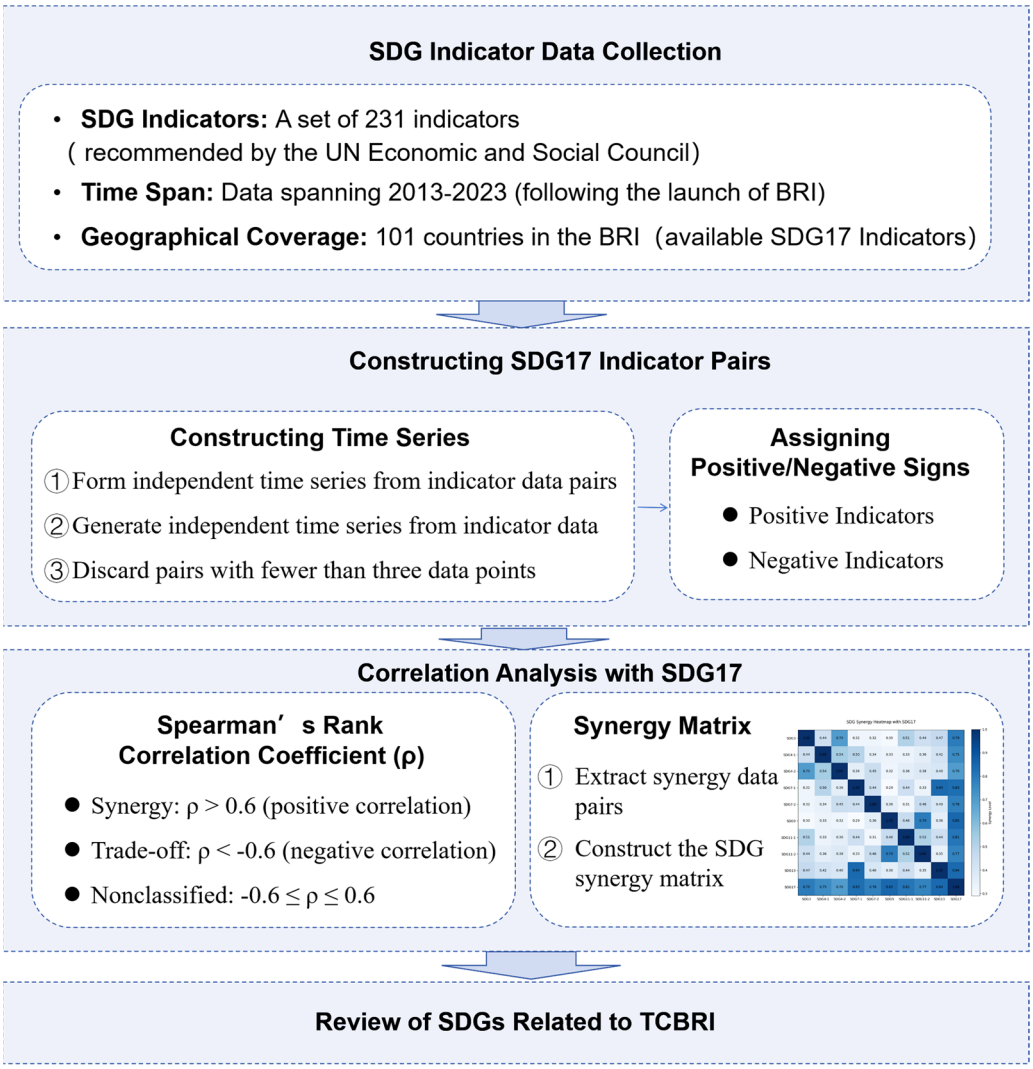


Figure 2. Workflow for TCBRI-related SDG indicators.

2. Data Processing:
   - Time Series Construction: Arrange SDG indicator values annually for each country. Exclude series with fewer than three data points.
   - Positive/Negative Classification: Positive Indicators: Increases signify progress (e.g., higher education rates, clean energy use). Negative Indicators: Increases signify setbacks (e.g., poverty rates, pollution levels).
3. Correlation Analysis with SDG17:

Spearman's rank correlation coefficient (ρ) is used to assess the relationship between other SDG indicators and SDG17.

- Synergy ($\rho > 0.6$): Strong positive correlation, indicating aligned progress with SDG17.
- Trade-off ($\rho < -0.6$): Strong negative correlation, indicating conflicting progress with SDG17.
- Non-classified ($-0.6 \leq \rho \leq 0.6$): Weak or no clear correlation.

Compile correlation results into a synergy matrix to visually identify indicators aligned, conflicting, or unrelated to SDG17 progress.

4. Review of SDGs Related to Technological Cooperation:

After completing the correlation analysis and synergy matrix construction, a review is conducted on the SDG indicators related to technological cooperation under SDG17. This provides a reference for policy formulation and optimization.

2.2. TCBRI-Related SDG Indicators

Among all the analysis results, this study focuses exclusively on TCBRI-related SDG indicators, selecting only those with a Spearman correlation coefficient (ρ) above 0.6 for further analysis. As shown in Table 2, the indicators are finalized with a sample size ranging from 49 to 65 BRI countries, covering the period from 2013 to 2023. Except for one indicator (Educational Technology Equipment Penetration Rate, $\rho = 0.68$, $p < 0.05$), all correlations are statistically significant at the $p < 0.01$ level, demonstrating a high reliability of the results.

Table 2. Spearman synergy analysis results of SDG17 indicator pairs.

SDG17 Technological Cooperation Indicator	Identifier	Associated Indicator	ρ	*p*	Number of Countries
Proportion of Cross-Border R&D Funding	SDG3	Proportion of Medical Technology R&D Expenditure	0.79	<0.01	65
Funding for Cross-Border Educational Technology Projects	SDG4-1	Online Education Penetration Rate	0.75	<0.01	62
Funding for Cross-Border Educational Technology Projects	SDG4-2	Educational Technology Equipment Penetration Rate	0.68	<0.05	50
International Energy Technology Cooperation	SDG7-1	Proportion of Renewable Energy Technology R&D Funding	0.83	<0.01	58
International Energy Technology Cooperation	SDG7-2	Smart Grid Technology Penetration Rate	0.78	<0.01	60
Innovation and Technology Support Funding	SDG9	Growth Rate of Clean Technology Enterprises	0.85	<0.01	65
Smart City Technology Support Projects	SDG11-1	Coverage of Urban Smart Management Systems	0.81	<0.01	52
Smart City Technology Support Projects	SDG11-2	Green Building Technology R&D Funding	0.77	<0.01	49
Climate Technology Transfer Cooperation Projects	SDG13	Clean Energy Technology Deployment Rate	0.84	<0.01	57

High correlation values among other SDG goals reveal strong interconnections and synergistic effects across sustainable development fields (Figure 3). Key synergies include the following:

- SDG3 (Health) and SDG4 (Educational Technology Equipment Penetration): Positive correlation suggests that investments in health technology innovation may enhance education technology penetration, fostering mutual reinforcement through initiatives like health education and telemedicine.

- SDG7 (Renewable Energy R&D Funding) and SDG13 (Clean Energy Deployment): Strong correlation indicates that increased renewable energy R&D drives clean energy deployment, highlighting the importance of technological R&D and international collaboration in energy and climate action.
- SDG9 (Innovation Funding) and SDG11 (Green Building R&D Funding): Positive correlation shows that innovation funding supports green building technologies, promoting sustainable urban infrastructure and enhancing urban resilience and livability.

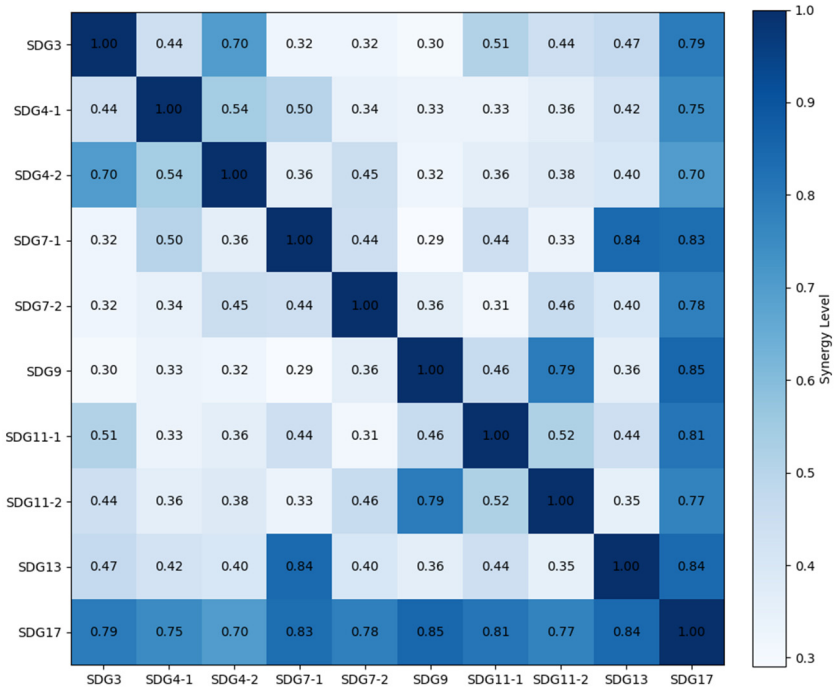


Figure 3. SDG synergy heatmap with SDG17.

The selected SDG correlations are grouped into three cooperation areas: healthcare and education (SDG3, SDG4), infrastructure and urban development (SDG9, SDG11), and energy and climate change (SDG7, SDG13). SDG6, SDG12, SDG14, and SDG15 show weaker relevance to technological cooperation ($\rho < 0.6$) and are not the focus of this review. This section explores how technological cooperation under the BRI promotes these prioritized goals. Figure 4 illustrates the SDG association framework for technological cooperation under the BRI, serving as the primary structural framework for this review.

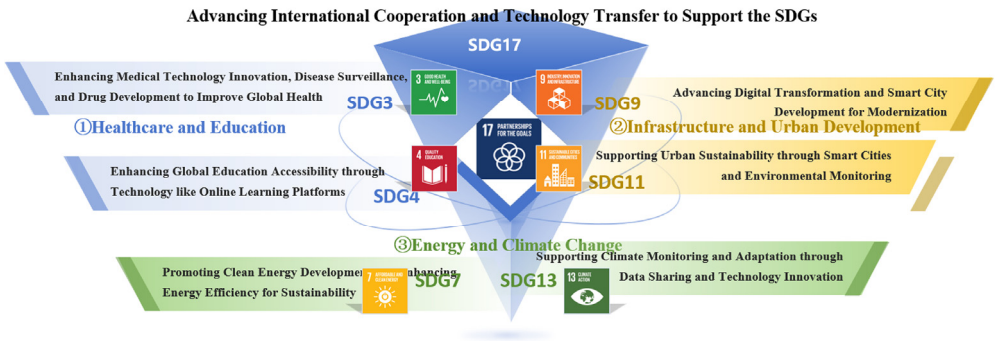


Figure 4. SDG framework of the TCBRI.

3. Evaluation of TCBRI-Related SDGs

3.1. Healthcare and Education (SDG 3, SDG 4)

SDG 3 is closely linked to TCBRI [65,66]. This goal aims to ensure healthy lifestyles and promote well-being across all age groups [67]. Technological cooperation plays a key role in improving healthcare, with significant contributions in the following areas, as shown in Figure 5.

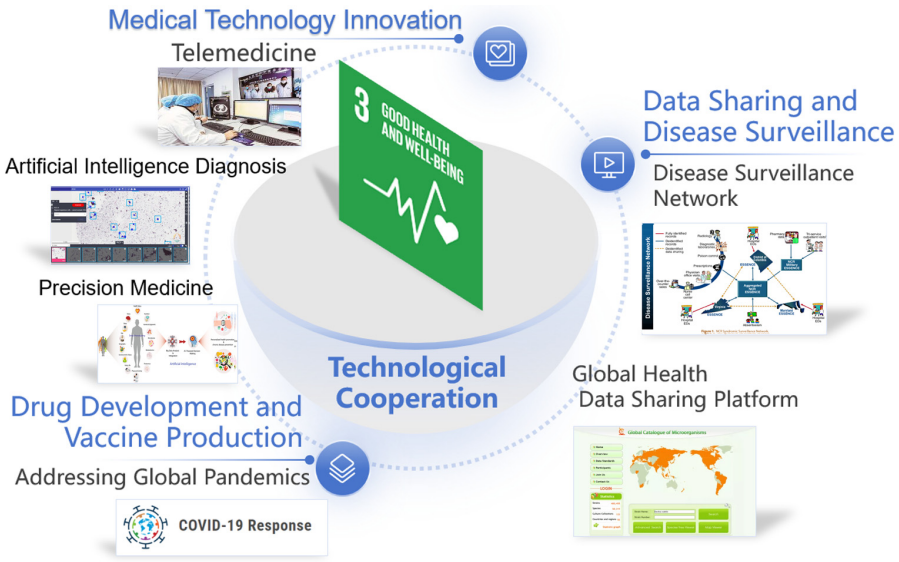


Figure 5. Technological cooperation framework for SDG 3.

1. Medical technology innovation: Advancements in disease prevention, diagnosis, and treatment technologies, such as telemedicine, AI-based diagnostics, and precision medicine, are driving progress in healthcare [68–70].
2. Data sharing and disease monitoring: Global platforms for health data-sharing and monitoring networks enhance the ability to respond quickly to infectious disease outbreaks and improve public health management [71–73].
3. Drug development and vaccine production: ITC accelerates the development of new drugs and vaccines, which is particularly vital in addressing global pandemics and emerging diseases [74–76].

SDG 4 emphasizes that education is not only a fundamental human right but also the foundation for achieving other Sustainable Development Goals [77]. The successful realization of both SDG 3 and SDG 4 requires global efforts, with ITC playing an essential role in this process [78,79]. Table 3 outlines the key aspects of the TCBRI that are related to SDG 3 and SDG 4. The contributions of the TCBRI can be grouped into three main areas: (1) enhancing global health education and improving access to healthcare; (2) fostering multinational collaboration to address global health crises and disruptions in education; and (3) working together to promote health and education development in low-income countries. Through innovations in health and education technologies, as well as the global sharing of educational resources and healthcare services, technological cooperation not only improves public health worldwide but also ensures equitable education, particularly in low-income countries and remote regions [80,81].

Table 3. The TCBRI for SDG 3 and SDG 4.

Aim	Content	Expected Outcomes
Enhancing global health education and improving access to healthcare	• Develop digital tools for health education, such as mobile health apps and online platforms. • Enhance global health literacy through technological cooperation.	Technology cooperation can improve global health education, increasing awareness of health knowledge and promotion methods [82].
Cross-border cooperation to address global health crises and educational disruptions	• Promote telemedicine and online health platforms to improve accessibility of disease diagnosis and treatment. • Establish online education platforms to ensure continuous learning, especially during pandemics.	Technological cooperation can address healthcare and education disruptions during global health crises (e.g., the COVID-19 pandemic), ensuring the continuous provision of resources [83].
Jointly promote health and education development in low-income countries	• Promote the development of affordable vaccines and basic medical equipment to improve healthcare quality in low-income countries. • Share educational platforms, online courses, and mobile learning tools to improve education accessibility.	ITC promotes the adoption of low-cost healthcare and education technologies in low-income countries, alleviating resource shortages [84].

Under the BRI, technological cooperation plays a significant role in enhancing both the accessibility and quality of education by providing innovative solutions and resources. This cooperation also promotes educational equity and flexibility, ensuring that everyone can access education tailored to their individual needs [85]. Talent cooperation in technology is a key component of the TCBRI, although it is still in its early stages [86]. To strengthen talent cooperation, it is crucial not only to cultivate practical, industry-relevant technological talents but also to foster exchanges among high-level experts and facilitate cross-border collaboration among researchers [46,57].

3.2. Infrastructure and Urban Development (SDG 9, SDG 11)

Under the frameworks of SDG 9 and SDG 11, the ITC in infrastructural development and urbanization plays a strategic role. SDG 9 encourages the construction of resilient infrastructure, while the BRI promotes inclusive and sustainable industrialization and supports innovation [87,88]. SDG 11 focuses on making cities and human settlements inclusive, safe, resilient, and sustainable. The development and application of smart city technologies under the BRI require international collaboration to share best practices and technological solutions [89]. Through technological cooperation, research and knowledge sharing can be enhanced, facilitating digital transformation and the development of smart cities, thereby supporting infrastructural modernization and industrial innovation [27,90]. Global cooperation and technological innovation can drive sustainable industrialization, smart city development, and infrastructural modernization, addressing the challenges of rapid urbanization and promoting inclusive, safe, resilient, and sustainable urban growth.

Figure 6 illustrates the contributions of the TCBRI to SDG 9 and SDG 11. ITC plays a crucial role in driving global sustainable development, particularly in infrastructure and urban development [91]. By fostering cross-border technological research and development (R&D), knowledge sharing, and the exchange of best practices, countries can collectively tackle challenges such as urbanization, climate change, and resource depletion. This collaboration helps build more inclusive, safe, smart, and green cities and communities [92]. Table 4 presents the BRI technological cooperation related to SDG 9 and SDG 11, along with its expected outcomes, which will be further elaborated in the following section.



Figure 6. Technological cooperation framework for SDG9 and SDG11.

Table 4. TCBRI for SDG 9 and SDG 11.

Aim	Content	Expected Outcomes
Infrastructural Modernization and Smart Cities	• Cross-border cooperation applies technologies such as big data, artificial intelligence, IoT, and 5G to improve urban resource efficiency. • Promotion and application of smart grids and intelligent transportation systems.	The TCBRI drives infrastructural modernization, particularly in the fields of renewable energy infrastructure, smart transportation, and smart grids, accelerating technology transfer and application [93].
Digital Construction and Digital Cities	• Application of IoT technologies in infrastructural intelligence, such as smart monitoring, remote management, and data analysis. • Cross-border cooperation to promote the application of digital city technologies in urban planning and public service management.	ITC advances the application of digital technologies (e.g., IoT, big data, AI) in infrastructural construction, enhancing efficiency, resilience, and sustainability [94].
Global Experience and Engineering Practice Sharing	• Collaboration among nations to share experiences in designing and implementing intelligent transportation systems, improving traffic efficiency, and reducing congestion and pollution. • Sharing advanced construction methods and materials science in infrastructural development.	The TCBRI facilitates the sharing of best practices and engineering design experiences in urban development, reducing redundant construction, shortening implementation periods, and improving construction efficiency [95].
Eco-Manufacturing and Green Cities	• Promoting BRI cooperation in green building technologies and low-carbon materials to reduce resource consumption and pollution in urban construction. • Standardized cooperation in green finance and green infrastructure to promote sustainable development.	Technological cooperation promotes green building, energy-efficient design, renewable energy technologies, and green infrastructure, supporting global industrial upgrading and enhancing urban ecological sustainability [96].

1. Infrastructural Modernization and Smart Cities: ITC provides a platform for sharing innovation and knowledge in infrastructural development [97]. By exchanging advanced engineering techniques, materials science, and construction methods, countries can accelerate the development and upgrading of infrastructure, particularly in areas such as new energy infrastructure, smart transportation systems, and smart grids [98,99]. Through global collaboration, sharing best practices and innovative technologies enhances the ability of countries to respond to extreme weather events and strengthens the resilience of cities and communities to climate change [100,101].

2. Digitalization and Digital Cities: Technological cooperation under the BRI promotes the application of digital technologies that drive the smart and digital transformation of infrastructure [44,102]. ITC facilitates the use of IoT, big data, and AI technologies in infrastructure, such as smart monitoring, remote management, and data analysis, thereby improving efficiency, resilience, and sustainability [103,104].
3. Global Experience and Engineering Practice Sharing: Through the TCBRI, countries can draw on the successful experiences of other cities, avoiding unnecessary duplication and shortening project implementation cycles [105]. In urban transportation planning, many countries collaborate to share the design and implementation experiences of smart traffic management systems, leading to improved traffic efficiency and reduced congestion and pollution [106]. This cooperation also accelerates the development and application of energy-saving technologies in construction and industry, such as efficient insulation materials, smart temperature control systems, and energy-efficient industrial equipment, which enhances energy efficiency, especially in developing countries [107].
4. Eco-Manufacturing and Green Cities: The TCBRI not only promotes the sharing of technologies but also fosters the development of innovative ecosystems, particularly in areas like Industry 4.0 and smart manufacturing [108]. Through these collaborations, the BRI countries can jointly explore innovative business models and sustainable technological solutions, supporting global industrial upgrading and contributing to greener, more sustainable urban development [27].

3.3. Energy and Climate Change (SDG 7, SDG 13)

SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action) are two crucial goals in the sustainable development framework, closely connected in addressing global climate change, promoting energy transition, and improving energy access [109]. Technological cooperation plays a key role in achieving both goals, especially in advancing clean energy technologies, increasing energy efficiency, reducing greenhouse gas emissions, and enhancing climate resilience [110–113].

Under the framework of SDG 7 and SDG 13, ITC is essential [114,115]. It supports the development of low-carbon, green energy systems, aids climate change mitigation and adaptation efforts, and contributes to the achievement of the SDGs [116]. Through cross-border R&D and technology sharing, backed by green finance and climate funds, technological cooperation facilitates the widespread adoption of clean energy, boosts energy efficiency, reduces emissions, and strengthens global capacities to respond to climate change (Figure 7) [44,117–119].

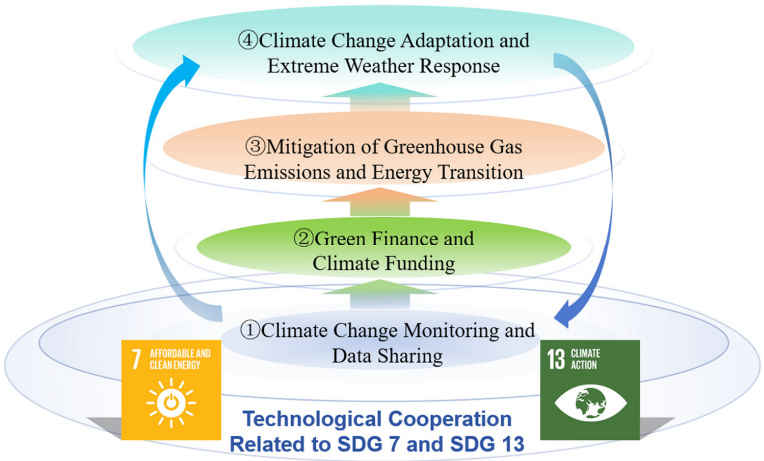


Figure 7. Technological cooperation framework for SDG 7 and SDG 13.

Table 5 presents the TCBRI related to SDG 7 and SDG 13 and their expected outcomes, followed by a comprehensive analysis.

1. Climate Change Monitoring and Data Sharing: Through BRI technological cooperation, climate monitoring data, remote sensing technologies, and climate models can be shared to track greenhouse gas emissions and climate trends in real-time [109]. This cross-border cooperation enhances the precision of global climate change monitoring, enabling countries to develop scientifically informed and accurate response strategies [120]. The use of big data and AI for climate prediction and modeling helps identify potential climate impacts, enabling countries to formulate more effective mitigation and adaptation strategies [121,122].

Table 5. The TCBRI for SDG 7 and SDG 13.

Aim	Content	Expected Outcomes
Climate Change Monitoring and Data Sharing	• Cooperation on climate monitoring data sharing and remote sensing technology to enhance monitoring accuracy. • Use of big data and AI for climate change forecasting and pattern analysis.	Through BRI technological cooperation, climate monitoring data, remote-sensing technologies, and climate models can be shared, enabling real-time tracking of climate trends and aiding in the formulation of response measures [123].
Green Finance and Climate Funding	• BRI cooperation promotes green finance policies to ensure the flow of funds for clean energy and climate adaptation projects. • Encouraging green investment to provide financial support for low-carbon projects.	Technological cooperation facilitates green finance policies and capital flows, supporting low-carbon and climate adaptation projects, thus accelerating the low-carbon transition [124].
Mitigating Greenhouse Gas Emissions and Energy Transition	• The TCBRI on clean energy technologies such as solar, wind, battery storage, and hydrogen. • Cross-border cooperation to promote cost-effective, efficient solar PV and wind power technologies.	By accelerating the global adoption of clean energy technologies, BRI cooperation fosters a low-carbon energy transition, reduces greenhouse gas emissions, and supports global climate change mitigation efforts [125].
Climate Change Adaptation and Extreme Weather Response	• Development and application of smart grids, microgrids, and distributed energy systems. • R&D on energy-efficient technologies (e.g., insulation materials, smart temperature control systems).	BRI cooperation promotes the development of climate adaptation technologies, particularly in disaster early warning, smart grids, and energy storage systems, helping to respond to extreme weather events [126].

2. Mitigating Greenhouse Gas Emissions and the Energy Transition: The intersection of SDG 7 and SDG 13 in technological cooperation is especially significant in the areas of clean energy innovation and application [34]. By accelerating the global adoption of clean energy technologies (such as solar, wind, battery storage, and hydrogen), BRI cooperation drives a low-carbon energy transition, reduces greenhouse gas emissions, and supports global climate action [59,120]. International cooperation fosters the research and deployment of clean energy technologies, particularly in the renewable energy sectors of solar and wind [36]. Cross-border R&D collaboration facilitates the innovation and application of more efficient, cost-effective solar PV and wind power technologies, promoting the global adoption of renewable energy [127].
3. Climate Change Adaptation and Extreme Weather Response: BRI cooperation not only promotes the dissemination of clean energy technologies but also helps countries address the impacts of climate change, particularly in climate monitoring, disaster early warning, and climate adaptation technologies [40]. By advancing smart grids, microgrids, and distributed energy systems, BRI cooperation addresses the intermit-

tency of renewable energy, ensuring the stability and reliability of energy supply. The integration of energy storage technologies further supports this by stabilizing renewable energy sources. Zhou and Tong [52] developed a network model to examine renewable energy trade cooperation among BRI countries, revealing a dynamic of both cooperation and competition between internal and network-driven forces. Their study offers policy recommendations to ensure a sustainable renewable energy supply.

4. Green Finance and Climate Funds: Technological cooperation supports the development of green finance policy frameworks and capital flows, particularly for clean energy and climate adaptation projects [128]. BRI cooperation expands support for green investments, ensuring adequate funding for low-carbon and climate adaptation projects [129]. By fostering green finance policies and promoting the flow of climate funds, cross-border cooperation ensures the financial sustainability of clean energy and climate adaptation projects, accelerating the global low-carbon transition and advancing global climate action [130].

4. Risks and Challenges of the TCBRI

4.1. Current Risks of the TCBRI

The implementation of the BRI faces a range of challenges and constraints. These difficulties arise not only from the inherent complexity of the projects themselves but also from the diverse political, economic, social, and cultural contexts of the countries involved [131]. The following section provides a detailed analysis of the key challenges and limitations that the TCBRI encounters in promoting the United Nations' 2030 Agenda for Sustainable Development (SDGs), as outlined in Table 6.

Table 6. Risks and impacts of the TCBRI.

Risk	Description	Related Impact
Geopolitical Risk	Political instability in partner countries, such as territorial disputes and ethnic conflicts.	Increases investment risks and uncertainties [132]. For example, territorial disputes in the South China Sea affect the stability of the Maritime Silk Road and investments by Chinese companies [133].
Economic Risk	Low levels of economic development, underdeveloped capital markets, and high demand for infrastructural investment.	Difficulties in attracting and utilizing funds, uncertainty in investment returns, and potential losses due to market instability [134].
Social Risk	Cultural, language, religious, and social custom differences, such as land acquisition, migration, and labor rights protection.	Social issues may hinder project implementation, such as labor rights disputes and social tensions [135].
Environmental and Legal Risks	Potential environmental impacts requiring strict environmental assessments; legal system differences between countries.	Requires strict adherence to environmental standards, ensuring compliance with national laws to avoid legal conflicts and environmental damage [136].

1. Geopolitical Risks: Geopolitical risks represent a major challenge for the BRI. Many countries along the route face political instability, such as territorial disputes and ethnic conflicts, which introduce significant uncertainty and increase investment risks [137]. Zhang et al. [138] developed a new indicator system based on five dimensions—policy, infrastructure, trade, finance, and culture—to assess the BRI's connectivity. The study found that policy coordination was the weakest dimension, while the top 10 countries with the highest connectivity index were primarily in East Asia, the Pacific, Europe, and Central Asia. These countries exhibit large economic and geographical differences. For example, the South China Sea dispute has placed considerable pressure on the Maritime Silk Road, posing uncertainty for Chinese investments and operations in the region [139].

2. Economic Risks: Economic risks are another significant concern for technological cooperation under the BRI. Many countries along the route have low levels of economic development, high infrastructural investment needs, underdeveloped capital markets, and limited fiscal space. These factors make attracting and utilizing funds challenging. Additionally, uncertainties about investment recovery and profitability, along with potential losses caused by market instability, further exacerbate the risks [140,141]. Wu et al. [142] found that while the BRI has driven growth in renewable energy investments, it also introduces long-term and diverse risks, primarily political, economic, and resource-related.
3. Social Risks: Social risks related to BRI technological cooperation should not be overlooked. Due to significant cultural, linguistic, religious, and social differences among countries along the route, projects may encounter various social issues, such as land acquisition, migration, and labor rights protection [143]. For example, the employment and labor rights of Chinese workers in Indonesia and Cambodia, and how these issues are addressed, require careful consideration [144].
4. Environmental and Legal Risks: Environmental and legal risks are also critical challenges for BRI technological cooperation. The construction process may lead to unforeseen environmental impacts, necessitating rigorous environmental assessments and appropriate mitigation measures [134]. Moreover, varying legal systems and enforcement standards across countries pose a challenge to ensuring compliance with local laws while progressing with projects. Achieving the SDGs remains a long-term endeavor, and many technology-related SDGs face considerable obstacles [145].

4.2. Challenges in Advancing the TCBRI

While the BRI has contributed to the economic development and technological progress of participating countries, it also faces several challenges. These include fluctuations in the international political and economic environment, political instability, difficulties in coordinating cooperation mechanisms and policies, varying cooperation models and their depths, as well as issues related to talent cooperation and facilitating personnel exchanges [40]. To effectively address these challenges, it is crucial for all parties involved to strengthen communication and coordination, improve cooperation mechanisms, streamline processes, and enhance talent development and exchange. Such efforts will help ensure the sustainable and healthy development of technological cooperation under the BRI [146].

Figure 8 outlines the primary challenges facing technological cooperation under the BRI, which are divided into three main areas: "Policy and Institutional Coordination", "Delayed Investment and Financing Mechanisms", and "Project Implementation Complexity". Below is a detailed analysis of the specific challenges within each area.



Figure 8. Challenges of the TCBRI.

1. Policy and Institutional Coherence: Coordinating policies and institutions is a critical challenge in cross-border projects [147]. Given the numerous countries involved in the BRI, there are significant differences in policy enforcement, legal systems, and institutional development, which can create barriers to project implementation [148]. For example, in some BRI countries, strict licensing requirements and complex customs procedures can negatively affect both project efficiency and costs [149,150]. A study by Wang et al. [151] highlighted the role of key countries among the BRI countries as intermediaries in green development cooperation, with findings showing that these nations bridge the gaps in the policy coordination of BRI projects.
2. Delayed Investment and Financing Mechanisms: The development of investment and financing mechanisms has been slow, especially in regional and domestic capital markets, where a comprehensive system has yet to be established [152]. In this context, multilateral investment institutions often focus more on poverty alleviation projects, while infrastructural investments receive relatively less attention [153]. The limited funding channels hinder the financial support necessary for infrastructural projects, which restricts their expansion and progress [154]. This funding shortfall has become a bottleneck in the development of many projects, preventing the implementation of innovative technologies and efficient solutions. Consequently, regional economic development is impeded, and overall infrastructural improvements are limited [97].
3. Project Implementation Complexity: The complexity of project implementation is reflected in several factors. First, the large number of countries involved, each with its unique political system, economic development level, cultural background, and legal framework, makes coordination more difficult [155]. Second, coordination among project stakeholders is another major challenge. Each party may have different interests and working styles, and balancing these while ensuring smooth project progress requires effective communication and coordination. Furthermore, the complexity of managing and implementing projects increases when taking into account the different needs and conditions of each country [156]. Therefore, formulating plans that meet project objectives while balancing the interests of all parties is crucial [157,158]. These factors contribute to the uncertainty and complexity of project execution.

In summary, the BRI faces a range of geopolitical, economic, social, environmental, and legal challenges in advancing the United Nations' 2030 Agenda for Sustainable Development. Overcoming these challenges requires collective effort and long-term cooperation to ensure that the BRI effectively aligns with the SDGs and contributes to sustainable, inclusive development for participating countries.

5. Promoting Sustainable Development via the TCBRI

5.1. Pathways to Achieving the TCBRI

Technological cooperation is a crucial means of achieving the SDGs. It facilitates technology exchange and transfer, enhances innovation capacity, and provides robust support for addressing global challenges [47]. Strengthening technological cooperation among the BRI countries can drive technological advancement and industrial upgrades, while simultaneously offering new pathways and momentum for achieving global sustainable development. Table 7 outlines the pathways for advancing technological cooperation under the BRI, which are further elaborated below.

1. Sustainable Improvements in Healthcare and Education Capacity Building: Technological cooperation projects focused on sustainability can promote technological progress in BRI countries while achieving significant advancements in talent development and educational cooperation. These projects will contribute to raising education

standards, particularly in areas related to sustainable healthcare and education, thus providing a solid talent foundation for the realization of SDG 3 (Good Health and Well-being) and SDG 4 (Quality Education). This approach not only drives technological innovation but also cultivates a skilled workforce equipped with sustainable development knowledge, laying the groundwork for the SDGs.

Table 7. Pathway to implementation of the TCBRI.

Technological Cooperation Pathway	Relevance to SDGs	Specific Effects
Sustainable improvement of healthcare, supporting education and capacity building	Supports SDG 3 (Good Health and Well-Being) and SDG 4 (Quality Education), providing talent support for the BRI countries and promoting sustainable development	Through technological cooperation projects, enhances technological progress in the healthcare and education sectors in participating countries, and cultivates talent with knowledge and skills for sustainable development [75,159].
Improving infrastructural production technology and innovation capacity, promoting regional cooperation and knowledge sharing	Supports SDG 9 (Industry, Innovation, and Infrastructure) and SDG 11 (Sustainable Cities and Communities), promoting regional cooperation and technological innovation	Improves production technology, promotes technology transfer and upgrading, enhances the green construction capacity of infrastructure, and promotes the development of smart cities and environmental monitoring [160].
Promoting the application of clean energy and energy-saving technologies, enhancing climate change response capabilities	Supports SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action), advancing the popularization of clean energy and climate change response through technological cooperation	Accelerates the research and application of clean energy technologies such as solar, wind, and hydro energy, promotes resource recycling, and mitigates climate change [101].

2. Enhancing Infrastructural Production Technology and Innovation Capacity, Promoting Regional Cooperation and Knowledge Sharing: Sustainable technological cooperation can improve production technology, facilitate technology transfer, and upgrade industrial capabilities in participating countries. This will lead to enhanced production efficiency, reduced resource waste, and the creation of new job opportunities, contributing to long-term socio-economic development [161]. Within the BRI framework, sustainable technological cooperation holds a unique position, as it not only promotes green infrastructural development but also strengthens smart city capabilities and environmental monitoring in BRI countries. This will support the achievement of SDG 9 (Industry, Innovation, and Infrastructure) and SDG 11 (Sustainable Cities and Communities), contributing to the creation of a green and sustainable BRI.
3. Promoting the Application of Clean Energy and Energy-Saving Technologies, Enhancing Climate Change Resilience: Sustainable technological cooperation accelerates the development and application of advanced clean energy technologies, such as solar, wind, and hydroelectric power. This helps reduce fossil fuel consumption and mitigate greenhouse gas emissions, making it essential for achieving SDG 7 (Affordable and Clean Energy) [119]. Moreover, such cooperation facilitates the exchange of best practices related to circular economies and resource efficiency, helping countries improve their resource recycling rates and minimize waste generation. In addition, sustainable technological cooperation enhances countries' capacity to adapt to and mitigate climate change through joint development of low-carbon and adaptive technologies, contributing to SDG 13 (Climate Action).

5.2. Policy Recommendations and Action Plan

This section explores policy recommendations and specific action plans for fostering the innovative TCBRI in the context of the SDGs. Given the vast scope and diverse objectives of the BRI, technological cooperation plays a crucial role in driving sustainable development. Figure 9 outlines the action plan for technological cooperation among the BRI countries, and the following section provides a detailed discussion of the proposed steps.

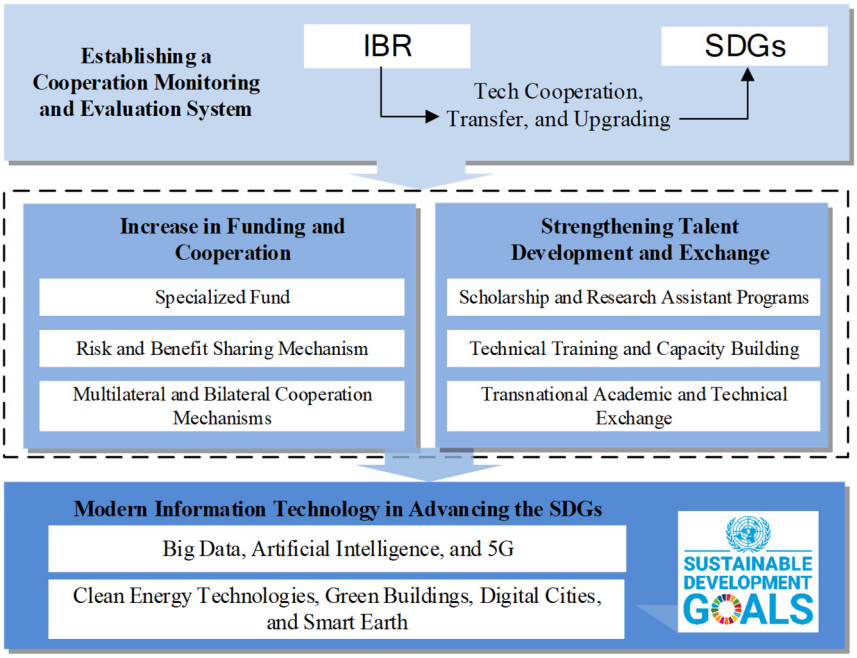


Figure 9. Action plan framework for the TCBRI.

1. Establish a Monitoring and Evaluation System for Cooperation:
   - Evaluate the progress and outcomes of BRI technological cooperation to ensure transparency and long-term sustainability.
   - Implement a monitoring system that helps improve the effectiveness of projects and ensures alignment with the SDGs.
   - Conduct technological capacity assessments among the BRI countries to tailor cooperation plans to each country's needs.
   - Encourage technology transfer and upgrades, while enhancing local technological capacities through these projects.
2. Increase Financial Support and Strengthen Cooperation Efforts:
   - Provide special funds, intergovernmental loans, and incentives for private sector investment to support technological projects.
   - Create mechanisms for risk-sharing and benefit-sharing to attract more private capital to these projects.
   - Establish multilateral and bilateral cooperation frameworks, including innovation centers, joint laboratories, and research platforms.
3. Strengthen Talent Development and Exchange:
   - Offer scholarships and research assistant programs for students and young researchers from the BRI countries to pursue higher education and research opportunities.
   - Organize advanced technical training programs in partnership with international organizations to build expertise in key areas like clean energy, smart manufacturing, and smart cities.

- Facilitate international academic and technical exchanges through conferences, workshops, and exhibitions, promoting the exchange of ideas, research outcomes, and technological expertise across countries.

4. Leverage Modern Information Technologies to Enhance Sustainable Development:
   - Increase the application of big data, artificial intelligence, 5G, and other advanced technologies to enhance local technological capabilities.
   - Use these technologies to improve management, innovation capacity, and social development across the BRI countries.
   - Focus on collaborative research and technology transfer in areas like clean energy, green building, and digital city planning, supporting the sustainable development of these countries.

6. Conclusions

This study provides quantitative insights for evidence-based decision-making by revealing the synergies between TCBRI initiatives and the SDGs. Through a comprehensive review of the SDGs related to the TCBRI, it highlights the potential to optimize synergies across multiple goals and underscores the transformative impact of technological cooperation in advancing global sustainable development. The synergy matrix method [61] was employed to identify interdependencies among SDG targets, offering actionable insights for sustainable development.

Future research should integrate empirical data and investigate the causal mechanisms that enhance the TCBRI's effectiveness, contributing more fully to the achievement of the SDGs. This review summarizes the insights from the TCBRI in terms of methodology, assessment applications, challenges and risks, sustainable development, and study limitations, as well as offering suggestions for future research directions.

6.1. Insights from the Methodology

This study systematically analyzes the TCBRI-related SDGs, identifying significant synergies among multiple SDGs, particularly SDG 3 (Health), SDG 4 (Education), SDG 7 (Clean Energy), SDG 9 (Innovation), SDG 11 (Cities), SDG 13 (Climate Action), and SDG 17 (Partnerships). Compared to previous studies that focused on individual SDG targets [44] or performed analyses of synergy quantification [25], this study employs the synergy matrix method to clarify the interrelationships among clean energy promotion, green city development, and innovations in health and education technologies. This approach addresses the limitations of prior research by providing a comprehensive methodology for exploring interdependencies across multiple goals.

By incorporating data from 101 BRI countries (2013–2023), this study broadens the scope compared to earlier theoretical work, shifting from isolated goal analysis to a more integrated approach to sustainable development. The findings align with previous research emphasizing technological cooperation in health and education [35,83], but our methodology provides a more holistic view by examining synergies across a broader set of SDGs.

6.2. Insights from Assessment Applications

The TCBRI has achieved significant results in healthcare and education (SDG 3 and SDG 4), particularly in the deployment of telemedicine and digital education tools. Technological cooperation has facilitated the transfer of medical technologies and improved healthcare conditions in low-income countries, while online education has advanced educational equity [35,77]. Moving forward, additional support—especially through technology

training and knowledge sharing—should prioritize enhancing healthcare and education in these nations.

In the areas of infrastructure and urban development (SDG 9 and SDG 11), technological cooperation has accelerated the development of smart cities and sustainable infrastructure. By leveraging big data, IoT, and 5G technologies, countries are able to efficiently manage urban resources and transition to low-carbon economies [54,142]. Strengthening smart infrastructure and supporting green finance will further promote sustainable urban development.

Regarding energy and climate change (SDG 7 and SDG 13), technological cooperation has driven innovation in renewable energy technologies, enabling countries to accelerate energy transitions and reduce greenhouse gas emissions [34,157]. Future initiatives should focus on enhancing clean energy research and technology dissemination, particularly in developing countries, while also promoting cross-border carbon markets and green financing mechanisms.

In comparison to prior studies, our findings on healthcare and education closely align with research demonstrating the positive impacts of technological transfer in these areas [77,84]. However, unlike earlier studies, our review includes a broader set of SDGs, such as SDG 9 (Infrastructure) and SDG 11 (Sustainable Cities), revealing synergies that were previously unexplored. Furthermore, our study highlights the role of smart cities and sustainable infrastructure in advancing the SDGs, expanding the scope of previous research that focused solely on individual sectors.

6.3. Insights from Challenges and Risks

The TCBRI faces a range of risks, including geopolitical, economic, social, environmental, and legal challenges. Geopolitical instability and territorial disputes can disrupt projects, while economic disparities and financial instability complicate project financing [20,50]. Social and cultural differences, as well as legal discrepancies, further complicate international cooperation [135,136]. Effective diplomacy and policy coordination are crucial in mitigating these risks.

Several structural challenges also hinder the TCBRI's advancement. The lack of policy coordination and institutional frameworks complicates cross-border project execution, and delayed financing mechanisms may cause project delays [152,153]. Additionally, the complexity of multinational cooperation demands effective project management to address diverse interests and technical requirements [34].

To address these challenges, we recommend the following measures: Strengthening geopolitical and economic stability through diplomatic efforts to reduce political conflicts and enhance financial system stability [118]; improving cross-cultural communication to reduce social conflicts and misunderstandings [159]; establishing robust legal and environmental frameworks to ensure compliance and mitigate risks [23]; and enhancing policy coordination alongside the development of multilateral investment mechanisms to support the smooth implementation of technological cooperation projects [24].

Our study corroborates prior research, which identified significant barriers to international cooperation under the BRI [20,50]. However, unlike earlier studies, we propose new strategies such as strengthened diplomacy, green financing, and enhanced policy coordination to mitigate these risks. While previous work focused primarily on identifying barriers, our study provides comprehensive solutions. Moreover, we emphasize robust legal and environmental frameworks [23], an area less explored in prior research, which mainly focused on financial and political risks. This comparison highlights how our study not only supports existing findings but also offers new insights into risk mitigation for large-scale technological cooperation projects.

6.4. Insights from Sustainable Development

To enhance the TCBRI's contribution to sustainable development, a focus on technological innovation and green transformation is essential, particularly in sectors like energy, education, healthcare, and infrastructure. Sharing technologies and best practices and providing talent training can accelerate the impact of technological cooperation [50]. Promoting clean energy and green technologies within BRI countries will help foster low-carbon economies and support the achievement of environmental sustainability goals [158].

At the policy level, strengthening international cooperation and policy coordination is vital for establishing frameworks that support technological cooperation and technology transfer. Green financing mechanisms should be established to meet the funding needs of clean energy and smart city projects [90]. Additionally, fostering cross-border R&D collaboration, talent training, and technology sharing will enhance technological capabilities and innovation, particularly in developing countries [83]. To ensure the sustainable development of the TCBRI, countries must reinforce cooperation, prioritize green financing, and stimulate technological innovation to accelerate progress towards achieving the global SDGs. Policy support, multinational cooperation, and technology transfer are key to the success of future collaborations.

In comparison with prior research, our findings are consistent with studies highlighting the role of technological cooperation in advancing green transformation and sustainable development [158]. However, this study extends the existing literature by emphasizing the importance of green financing and cross-border R&D collaboration in accelerating SDG achievement. Previous studies have often overlooked these mechanisms, but our findings suggest they are essential for ensuring the TCBRI's success in driving sustainable development. We also stress the need for stronger international policy coordination and green financing mechanisms to support sustainable projects—areas that have not been fully addressed in earlier research [98].

6.5. Research Limitations and Future Prospects

The data used in this study are sourced from the United Nations SDG database, which contains inconsistencies in data quality and variations in country/region coverage. Some countries had incomplete or unreliable data during the study period, underscoring the need for further empirical validation through regional field studies [56]. Future research should focus on improving data accuracy and completeness through more comprehensive regional investigations.

Although the synergy matrix method is useful for identifying interdependencies, the limited availability of regional empirical research constrains our understanding of the causal mechanisms behind these synergies. Future studies should explore how varying levels of economic development and policy environments influence regional synergies, potentially through comparative case studies or region-specific modeling approaches [49]. By developing scientific models and a more systematic framework, future research could offer deeper insights into the interdependencies among SDG targets and provide clearer guidance for sustainable development policymaking.

While this study offers valuable insights into the synergies between TCBRI initiatives and the SDGs, it is important to highlight how these findings contribute to advancing global sustainability efforts. As noted in the editorial for the "Development Goals towards Sustainability" article [162], our research aligns with the core goals of the SDGs by demonstrating how technological cooperation can drive progress across multiple SDG targets, including health, education, clean energy, and infrastructure. Specifically, by using the synergy matrix method to analyze the interrelationships between SDGs, this study presents a more integrated perspective on sustainable development, which is crucial for achieving

the global SDGs outlined in the 2030 Agenda for Sustainable Development. Our findings support the view that enhancing technological cooperation, strengthening international partnerships, and promoting cross-border innovation are essential for meeting the SDGs, especially in low-income countries, where these initiatives can have the greatest impact. Future research should build on this holistic approach to deepen our understanding of how regional synergies and tailored policy frameworks can accelerate progress toward global SDGs, particularly in the context of technology transfer and green finance initiatives.

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