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Addressing Climate Change and Advancing Green Development: Regional Transition Mechanisms for a Sustainable Future in Belt and Road Initiative Nations

Atta Ullah[1] | Haitham Nobanee[2,3,4] | Saif Ullah[5] | Saba Khan[6]

[1]School of Management, Huazhong University of Science and Technology (HUST), Wuhan, China | [2]College of Business, Abu Dhabi University, Abu Dhabi, UAE | [3]Oxford Centre for Islamic Studies, University of Oxford, Oxford, UK | [4]Faculty of Humanities & Social Sciences, University of Liverpool, Liverpool, UK | [5]Ziauddin University, Karachi, Pakistan | [6]College of Public Administration, Huazhong University of Science and Technology, Wuhan, China

Correspondence: Haitham Nobanee (nobanee@gmail.com)

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ABSTRACT

This study examines the impact of regional transition and multilateral cooperation mechanisms on green development (GD) and climate change mitigation across 64 Belt and Road Initiative (BRI) partner nations (21 Asia, 22 Europe, 21 Africa and Middle East) from 2006 to 2021. Using advanced econometric methods like two-step system GMM, 2SLS, dynamic fixed effect, and cointegration, the research reveals that regional transition significantly enhances GD, supporting sustainability and climate action. However, specific factors within multilateral cooperation, such as trade, investment, and institutional cooperation, negatively affect GD and climate resilience, while money and finance show insignificant negative impacts. Infrastructure and connectivity positively correlate with GD, and the movement of people has a positive but statistically insignificant effect. The impact of regional transition on GD varies across regions. The study highlights BRI's substantial contribution to GD, both pre- and post-introduction of spillover variables, emphasizing its role in promoting sustainable development, particularly in Asia and Europe. However, differential impacts in Africa and the Middle East raise concerns about the environmental effects of large-scale infrastructure investments. This research provides valuable insights into multilateral partnerships, green development, and climate change, offering theoretical and practical evidence for sustainable futures. It underscores the importance of balancing economic cooperation with environmental resilience, particularly in regions vulnerable to the resource curse. The findings contribute to the discourse on global sustainability, offering policymakers evidence-based strategies to enhance GD and climate adaptation through multilateral initiatives like BRI.

1 | Introduction

The escalating population growth exerts immense strain on sustainable natural resources, land, and economic endeavors. As a result, countries face social and environmental challenges, endangering their prospects for sustainable growth and survival. Despite the active involvement of individuals and organizations in addressing these issues and removing obstacles to future development, their efforts still need to be made to create significant change. Numerous reformers and academics now focus on social and environmental development, seeking long-term benefits for society and the planet (Tu et al. 2023). The 17 Sustainable Development Goals (SDGs) are the most ambitious goals that humanity has set for itself. During the UN General Assembly in September 2015, 193 nations adopted these objectives, and 169 sub-goals were included in the 2030 Agenda. The international community is dedicated to achieving these goals by 2030, demonstrating a shared commitment to address global challenges and promote SD globally (Al Mamun et al. 2021; Sadiq et al. 2023). SDGs are universal principles guiding the global community to address worldwide issues, ensuring a future of peace, prosperity, and dignity while preserving the planet's biodiversity. They encompass social, environmental, and financial development, promoting inclusivity, sustainability, peace, and cooperation among nations (Sadiq et al. 2023).

In order to solve environmental problems and unite economic growth and ecological protection, green development has become a common theme and needs to be emphasized (Chaudhry and Hussain 2023). Green development leads to social and economic development sustainability because this approach harmonizes human beings with the natural environment; however, in a similar vein, green development is a complex concept linked with sustainable development goals and is uncertain because the factors that influence green development may have different levels or regional differences. Therefore, research on green development is limited. In this view, it is essential to explore and understand the concept of green development from a regional perspective. Recently, as research on green development has deepened, the assessment of regional green development has become a hot and prevailing topic, and only a few studies have been relatively found on regional green development, emphasizing the city level of individual countries (Zhao et al. 2024).

Nevertheless, attaining these goals will necessitate action on multiple fronts, including implementing a multilateral regional transition. Adopting multilateral regional transition practices significantly contributes to achieving the green SDGs across three crucial dimensions: social, environmental, and economic; these contribute to green development. Multilateral regional transition is the harmonious combination of regional policy alignment and regional economic cooperation (Defraigne 2021; Indset 2023). Multilateral regional transition results in the establishment of robust economic connections among urban areas, whether government initiatives influence them or emerge organically from market dynamics (Wang, Derudder, Kunaka, Liu, et al. 2022, Wang, Zhang, Zhang, Yang, et al. 2022). On one side of the spectrum, when a region becomes increasingly interconnected, it tends to experience greater levels of economic advancement and an increased likelihood of local disturbances rippling throughout the entire economy (Bloise and Tancioni 2021; Lv et al. 2022).

Furthermore, Selvarajan and Ab-Rahim (2020) posited that there is a progression of regional transition initiatives at the multilateral levels before policymakers pursue economic growth objectives. The conceptual framework for advancing multilateral transition might encompass additional strategies to foster the expansion of the financial sector and trade connections while mitigating disparities in knowledge by enhancing financial transparency and elevating reporting standards. Abbas et al. (2024) articulated the necessity of further research into the green Belt and Road Initiative's (BRI) influence from the perspective of multilateral regional transition, while Abbas et al. (2024) recommended the adoption of a multilateral comparative analysis approach concerning Asia or alternative geographical areas to investigate the progress of global green development sustainability as a highly commendable avenue for future research endeavors. Huh and Park (2021) quantified regional integration's influence on income disparities and economic development in Asia. They accomplished this by employing a multidimensional index for integration, subsequently disentangling it into components related to regional and non-regional integration aspects. The study holds significance in assessing multilateral integration within the broader context of national development strategies. It systematically investigates multilateral integration's impacts on income inequality and economic development. Multilateral integration is a multifaceted concept encompassing more than just openness to trade and capital flows; it also encompasses cross-border communication among citizens of different nations, the exchange of ideas and information, and governments collaborating to address globally significant economic, environmental, and political challenges. Hence, therefore, investigating multilateral regional transition is vital in the context of BRI green development.

According to Chaisse (2018), China's BRI, also referred to as One Belt, One Road (OBOR), is a comprehensive infrastructure and development project proclaimed by Chinese President Xi Jinping in 2013. The initiative seeks to revive the historic Silk Road by establishing a land and maritime network connecting China to Europe. The BRI comprises two principal components: the Silk Road Economic Belt (land routes) and the 21st Century Maritime Road (sea routes). BRI project involves the construction of infrastructure such as roads, railways, ports, and energy facilities in more than 60 countries, accounting for approximately 63% of the global population and 30% of the world's GDP. The initiative is financially supported by institutions such as the Asian Infrastructure Investment Bank (AIIB) and the Silk Road Fund. Chaisse (2018) assesses the economic incentives driving the BRI, which include the internationalization of the Chinese currency, the efficient use of foreign currency reserves, the mitigation of surplus production capacities in China, and the development of the western provinces of China. Additionally, it evaluates prospects for key sectors such as infrastructure, transportation, and energy. The authors investigated the BRI framework's market access conditions and competitive environment, addressing challenges such as institutional management, climate risk management, investment, financing, and environmental considerations. A distinct revelation is that the BRI signifies an innovative paradigm of international trade and investment, divergent from conventional Free Trade Agreements (FTAs) or entities like the WTO. Unlike FTAs, which traditionally start with forming a legal framework, the BRI begins with an array of projects endorsed by governmental and public authorities, concomitantly advancing rule-making and development. This methodology allows for enhanced flexibility and inclusivity since the BRI is not a closed consortium but an open-ended construct that welcomes participation from all interested entities. Chaisse (2018) and later Chaisse and Kirkwood (2020) posit that the BRI may ultimately progress into a novel form of economic cooperation model, potentially redefining global trade structures over the next half-century.

China introduced BRI, intending to connect regions spanning Asia, Europe, and the Middle East, as well as Africa. The overarching goals of this initiative encompass the enhancement of multilateral regional transition, the elevation of trade volume, and the promotion of development, which recently focused on green development. China's BRI represents a comprehensive amalgamation of international projects, presenting significant opportunities for emerging economies to engage in deeper regional transition and foster economic cooperation. The BRI is a massive infrastructure and economic development project led by China, aiming to connect Asia, Europe, and Africa through a transportation, energy, and communication corridor network. It involves numerous countries along these routes, making it an extensive multilateral collaboration that is important to investigate (Hsueh 2023; Khanal and Zhang 2024; Li et al. 2024; Liu and Ding 2024; Rehman et al. 2024; Wang and Liu 2024).

The study aims to examine how regional transition and its components, multilateral cooperations, and its mechanism influence green development based on triple bottom rules consisting of social, economic, and environmental factors to achieve integrated SDGs by addressing climate change in Belt and Road Countries, including a comparison of Asia, Europe, and the Africa–Middle East region. It is imperative to establish an effective multilateral framework and conduct research into regional transition as a means to advance integrated green development objectives in BRI countries. So, multilateral cooperation's as the regional transition fostered by the BRI and across regions has acted as a catalyst for green development and the achievement of SDGs. It is characterized as an efficacious trajectory for greening the low-carbon shared economy future in 64 BRI nations and across Asia, Europe, and the Africa–Middle East regions from 2006 to 2021. This study also seeks to understand the level of economic, trade, investment, and financial cooperations among the participating countries. Therefore, the realm of development, the transition of regional finance, value chains, infrastructure, mobility, institutions, and social integration facilitated by the BRI presents a significant contribution to the engagement of multilateral collaborating nations and concerted efforts to tackle potential global challenges.

This study has multiple notable contributions. Therefore, the estimation of green development considering green-adjustednetsavings, including particulate emissions, is computed as follows: subtracting fixed capital usage from gross national savings yields net national savings. Consequently, green-adjusted net savings are calculated by adding public educational expenditures while deducting energy depletion, net forest degradation, carbon dioxide emission damage, and particulate emission damage from net national savings (Afshan et al. 2023; Koirala and Pradhan 2020; Lange et al. 2018; McGrath et al. 2024; Pardi et al. 2015). The recent green-adjusted net saving, including particulate emissions, is briefly characterized as a comprehensive gage of a nation's green savings rate, considering factors such as environmental degradation and depletion, depreciation of produced assets, and the incorporation of investments in human capital. Enhancing green development frameworks necessitates those regional initiatives to transcend sovereign borders, thereby influencing global geo-economic dynamics. Tokimatsu et al. (2019) demonstrated that a green development index can serve as a benchmark for evaluating the effects of climate policies aimed at mitigating environmental degradation, specifically CO_2 emissions, in the context of future well-being. Employing a green savings-based approach to assess climate change implications led to re-examining the costs and outcomes of various policies related to climate change.

The study contributes to the existing literature on the regional transition of multilateral cooperations and green development, potentially advancing theoretical frameworks and providing empirical evidence in this context. Positive outcomes of multilateral cooperations serve to mitigate state fragility and amplify local development in tandem with regional advancement. In light of the pressing global challenges posed by population growth and resource depletion, the study seeks to investigate and contribute to the role of the regional transition of multilateral cooperations, particularly within the framework of the BRI and across Asia, Europe, and the Africa–Middle East regions in advancing green development to achieve SDGs. The study suggests that regional transition (RT) significantly influences green development across various regions, with differing impacts. Furthermore, the study suggests that strengthening multilateral, regional transition might still be a viable development strategy and suggests that the advantages of global green economy transition might be greater for emerging nations. By examining the multilateral aspects of the regional transition composite and its sub-indexes, the study aims to provide insights into how collaborative transition efforts among integrated BRI countries influence green development outcomes across social, economic, and environmental dimensions. Furthermore, by analyzing factors such as the transition of economic trade, investment, and financial cooperation, the study aims to contribute to a deeper understanding of the mechanisms through which regional initiatives can foster green development on a global scale. The study's focus on green development objectives within the BRI context fills a crucial gap in the existing literature, offering both theoretical advancements and empirical evidence.

This section has a detailed introduction to the study. The second section addresses the literature study and development of hypotheses, followed by a description of the data and methodologies aligned with the model framework. The subsequent section presents the model results with in-depth discussions. Finally, concluding remarks and the study's contributions are provided at the end.

2 | Literature Review and Conceptual Framework

Integrated green development has turned into a global development paradigm, and this concept has taken much attention and seems poised to be the universal development paradigm for a long time. The concept of green development is limited to resources that can be natural, social, economic, or technological and maintains future generations' concern with development and functioning. This study describes the application of the triple bottom line principle, a framework associated with integrated green development. It assesses its appropriateness, particularly in the light of the use of indices like adjusted net savings. The "Triple Bottom Line" concept, initially introduced by Elkington (1998), emphasizes the pursuit of quantifiable goals spanning the social, economic, and environmental dimensions to foster green development sustainability within society.

This three-pillar conception linked to green development is a prevailing and widely accepted interpretation in academic literature. It has garnered attention from both the business and executive communities, as well as from scholars like Rogers and Ryan (2001), Witjes and Lozano (2016), Goh et al. (2020), Janjua et al. (2020), Nara et al. (2021), and Feng et al. (2023) have further enriched our understanding and application of this principle through additional insights and details. Recently, scholars such as Koirala and Pradhan (2020), Islam et al. (2023), Afshan et al. (2024) and McGrath et al. (2024) have advocated for the adoption of green savings, known as adjusted-net-savings which is rooted in the World Bank's index.

Green development is a complex concept which encompasses various social, economic, and environmental dimensions. Green development entails the transition from a resource-intensive growth paradigm to a more sustainable and ecologically sound model, encompassing significant advancements in production methods, industrial frameworks, technological innovation, governance, and lifestyles. Numerous nations and regions are presently shifting from high-speed to green development as a sustainable future, confronting the principal problem of reconciling economic expansion with environmental conservation (Cheba et al. 2022; Ren and Liu 2024). Green development entails attaining economic progress while ensuring environmentally resilient sustainability and has long been seen as a vital component of sustainable and green development (Zhu et al. 2024).

This study is linked with the theory of regionalism and regionalization, with an integrated focus on the multilateral transition concept. Regionalization is described as a rise in the cross-border flow of resources, planning, and persons contained by a particular geographical zone. Regionalization is a bottom-up procedure that starts with individuals/organizations. It progresses through societal-driven procedures originating from private trade, marketplaces, and investments, which governments do not rigorously control. The growth of regionalization indicates the rise in foreign direct investments, trade, and people. Regionalization helps protect public relations like globalization.

In comparison, regionalism is a top-down process described as an administrative determination to build an official agreement among countries, as its key contributors are governments (Hoshiro 2019). Regionalism is a normative conception denoting collective values, identity, rules, and objectives like globalism. In contrast, regionalization denotes the market-driven integration processes instead of pre-determined plans of national governments, which is like globalization (Kim 2004). Regionalism can be differentiated from regionalization as it involves collaboration at the intergovernmental level. Therefore, regionalism is for regional intergovernmental cooperation to solve numerous issues, although regionalization denotes a continuing progression of financial integration. Therefore, regionalization can breed regionalism (Kim 2004). Regionalism defines regional integration as a theory-driven concept of integration procedures with countries. However, regionalization is a political, social, and economic interaction between two or additional neighboring countries. It also provides a theory-driven concept of integration processes with an analytical emphasis on multinational enterprises and civil societies' (other than government) inducements for regional integration (Giessen et al. 2016).

"During this era of globalization, regional transition aspects are motivating business cycles". Regional aspects' significance has augmented significantly since the 1980s; however, regional transition at the multilateral level aspects recently gained attention, particularly in those states that experienced rapid development in monetary flows and intra-regional businesses, e.g., European, Oceanian, North American, and Asian regions, as per the 2013 reports of IMF. Hence, the regional transition composite is comprised of regionalism and regionalization viewpoints and focuses on the shared economy, which is a vital concept to explore the perspective of greening future development.

Regional transition as multilateral cross-country cooperation is a dynamic process in which neighboring nations work together to achieve shared goals for mutual benefits. Regional transition at multilateral cooperations can be done in different forms, such as developing infrastructure, endorsing trade and investment, increasing people's movement, improving imports/exports, and providing the authorized and institutional foundation for collaboration on international policy (Park and Claveria 2018b). Regional transition viewed through a multidimensional lens represents a pivotal consideration in the contemporary landscape. However, existing empirical research on the intersection of multilateral regional transition and green development presents two notable challenges. Firstly, certain prior empirical investigations have concentrated primarily on variables like foreign direct investment and trade openness, as exemplified by studies such as Çetin et al. (2015). Secondly, this research focuses on the newly introduced "regional transition" composite, which operates on a multidimensional scale, incorporating six additional dimensions. It is worth noting that limited studies have leveraged this comprehensive composite. For instance, (Park and Claveria 2018b) investigated the influence of regional integration on income inequality and economic growth in the Asian context, while Huh and Park (2021) explored the repercussions of globalization on income inequality and economic development in Asia. However, the regional transition concept is ignored, which focuses on the use of resources in greening development and a sustainable future by accomplishing SDGs targets.

It is worth emphasizing that literature has thus far overlooked the association between regional transition at multilateral cooperations and green development. For example, Dhahri and Omri (2018) advocated the exploration of regional business transition mechanisms, encompassing alliances, partnerships, and networks, as a means to propel green development. Furthermore, the significance of multilateral cooperations within the context of the BRI for the pursuit of development objectives is highlighted (Khanal and Zhang 2024; Li et al. 2024; Rehman et al. 2024; Wang and Liu 2024). Naeher and Narayanan (2020) also concluded that empirical evidence still needs to be provided, posing challenges for policymakers in assessing and aligning multilateral cooperation levels across diverse regions to gage progress achieved in alignment with predefined sustainable development targets. Abbas et al. (2024) and Xu et al. (2021) recommend that it is essential to study the role of determinants in promoting sustainable green development by exploring insights from the integrated regional transitions of BRI. Raza et al. (2021) articulated that the influence of integrated regional transition on development sustainability warrants investigation within a multilateral comparative transition framework, with particular attention to economic and governance aspects and considerations that are required to be explored. Meanwhile, Ahmad et al. (2021) highlighted the importance of addressing challenges from a multilateral transition perspective as a valuable avenue for future research endeavors.

The green transformation multidimensionality necessitates the examination of the rate of transition to a green economy in various nations, which varies significantly based on their economic development levels (Cheba et al. 2022). A comprehensive investigation of the collaborative impacts on regional invention networks and the enduring sustainability of green development of these policies is crucial for thoroughly examining the mechanisms propelling the green transformation across various contexts. This would yield a more thorough comprehension of the repercussions and share more successful regional development initiatives (Ren and Liu 2024). A multitude of studies has investigated the influence of regional policy on sustainable development. Nevertheless, research seldom addresses the spillover consequences of multilateral transition and green development. This deficiency may result in weak policy assessments (Ren and Liu 2024; Zhao et al. 2024; Zhu et al. 2024). This study is significant in examining the spillover effects of the BRI and regional transition with multidimensional components on green development.

According to Chaisse and Kirkwood (2020), the study focuses in a keen way on the intricate dynamics of China's investment treaty network embedded within the BRI. The BRI is heralded as a monumental economic endeavor seamlessly weaving through a tapestry of nations and regions. By emphasizing China's extensive web of bilateral investment treaties (BITs) with BRI countries, the study astutely observes that BRI underpins a robust framework for regional economic integration fueled by investment protection. It compellingly argues that the Most Favorite nation (MFN) clauses within China's BITs ignite the flames of an “invisible” multilateral investment treaty for the BRI, illuminating an informal regional integration concerning investment protection standards. Despite the conspicuous absence of new BITs since the inception of the BRI in 2013, the authors argue that an efficient multilateral investment treaty for the BRI is inherently established through the formidable expansion of China's BIT network with the BRI nations. This ‘hidden’ multilateral treaty is resourcefully facilitated by the global MFN clauses infused in nearly all of China's BITs with BRI countries. The comprehensive analysis of China's Bilateral Investment Treaty (BIT) network encompasses 68 BRI jurisdictions, categorizing them according to their signing timelines and the delineation of protection levels offered. It is posited that through strategic utilization of Most-Favored-Nation (MFN) clauses, investors can secure more advantageous terms from third-party BITs, thereby enhancing the protections afforded by earlier treaties. This proposition is substantiated by an array of legal precedents wherein tribunals have illustrated using MFN clauses to incorporate substantive and procedural safeguards from other agreements. This study presents a unique perspective by challenging the traditional static analysis of Chinese BITs, which spans three generations. It highlights the critical potential of MFN clauses to establish a dynamic and robust treaty network, offering a new framework for examining Chinese investment agreements. Moreover, the study emphasizes China's growing significance in the field of international investment law, as it transitions from being predominantly a recipient of Foreign Direct Investment (FDI) to becoming a significant exporter of capital. This transition is reflected in China's evolving approach to investor-state dispute settlement (ISDS) provisions embedded in its BITs, which may result in increased ISDS participation by Chinese investors in upcoming BRI investments.

The scholarly discourse surrounding the BRI highlights its significant potential to address pressing environmental challenges, particularly in developing nations. However, a substantial segment of the current research does not adequately explore the complexities of regional transition mechanisms, such as infrastructure development, governance configurations, and multilateral cooperation, which are critical for shaping environmental and social outcomes. Although the BRI's substantial contributions to economic growth and infrastructure development have been meticulously documented, a significant gap remains in understanding how these transitional dynamics influence long-term sustainability and climate aspirations in developing countries. Numerous scholars, such as Liu (2018) and later Shan and Wang (2019), have emphasized the vast diversity in environmental governance and the spectrum of institutional frameworks within BRI nations, underscoring the critical influence of local governance structures in directing the implementation and success of green development strategies. Liu (2018) posits that the heterogeneous nature of institutions in BRI nations substantially affects the execution of environmental policies and the achievement of sustainability goals. This disparity in institutional strength and policy frameworks across regions necessitates a deeper and more nuanced understanding of regional transition mechanisms that can facilitate or impede green progress. Besides that, a thorough examination of these regional contrasts and policy design is crucial for understanding the effectiveness of the BRI's green development strategies, given that multilateral cooperation may be insufficient without robust, coherent regional transition mechanisms that synchronize economic growth with environmental stewardship as recommended by (Khanal and Zhang 2024; Ren et al. 2025; Wang and Liu 2024).

This study constructs a theoretical framework based on the foundational principles of environmental economics in conjunction with ecological systems theory, intending to develop a comprehensive model to examine the role of regional transition mechanisms in facilitating green development. This analysis of regional transition mechanisms is situated within the broader theoretical context of sustainable development, where the transition to green development is conceptualized as a multifaceted, region-specific phenomenon influenced by local conditions, governance structures, and geopolitical factors. Grounded in environmental economics, transition economies are used to elucidate how BRI countries transition from fossil fuel-dependent systems to more sustainable green development frameworks. This theoretical approach emphasizes the significance of policy formulation, institutional structures, and market mechanisms as key drivers of green development. With their diverse economic landscapes, the BRI nations face unique challenges in integrating environmental policies into their economic structures to achieve sustainable development.

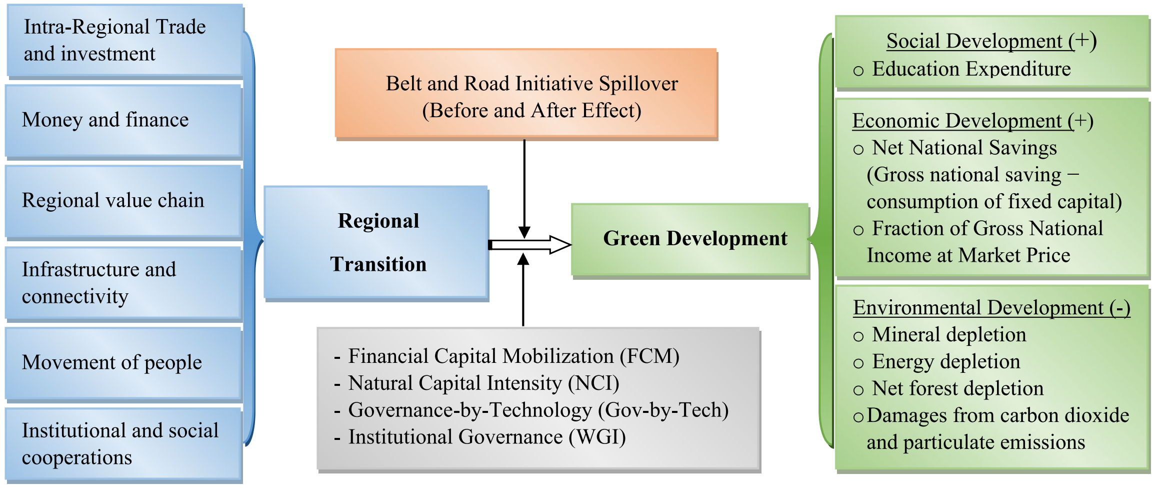

FIGURE 1 | Study Conceptual Framework.

Drawing on insights from Sun et al. (2011), Sarkodie and Strezov (2018), Liu (2018), Wang et al. (2024), Guo and Shahbaz (2024), studies employ the Environmental Kuznets Curve (EKC) hypothesis, which posits that as economies grow, they initially experience environmental degradation but are expected to transition toward sustainable practices eventually. By employing ecological systems theory, this study elucidates how regional transition mechanisms in BRI countries must be assessed within the context of broader environmental systems, where changes in one aspect of the system, including infrastructure, financial resources, investments, regional norms, and institutional integration, can have significant effects across other sectors, such as water resources, biodiversity, and social equity.

The paramount importance of multilateral collaboration is emphasized as a crucial factor in green development; however, achieving its goals is inextricably linked to the institutional architecture within which it operates. By studying the perspectives on institutional variability, this theoretical framework elucidates the critical role of regional institutional strengths or vulnerabilities in determining the efficacy of green development policies. Furthermore, by integrating institutional theory with insights from global governance and regional economics, this study is positioned to conduct a more nuanced and comprehensive analysis of the structuring of multilateral agreements and regional transition mechanisms to advance sustainable development goals and green evolution. At the core, exploring regional transition mechanisms for green development in BRI nations requires a comprehensive theoretical framework that integrates natural resources, governance, institutional dynamics, and multilateral cooperation with climate change mitigation and the pursuit of sustainable green development. Theoretical frameworks grounded in the principles of environmental economics, ecological systems theory, and institutional theory provide essential tools for articulating the complex causal mechanisms by which multilateral cooperation facilitates regional transitions and green development outcomes. By synthesizing insights from relevant sources, this study critically examines how regional transitions, strategic investments, institutional discrepancies, and regional plans either facilitate or impede the realization of carbon neutrality for climate change and the objectives of sustainable green development. By reinforcing the theoretical foundation with these diverse perspectives, this study presents a detailed, regionally tailored analysis of green development in the BRI landscape, thereby contributing to a more significant and transformative addition to the expanding body of literature on climate change, multilateral collaboration, and sustainable green development in the 21st century. This study's conceptual framework is as follows in Figure 1.

3 | Research Methodology

3.1 | Research Design, Data and Measurement of Variables

This paper investigates the effect of comprehensive regional transition on green development. Furthermore, this study explores the integrated regional transition composite sub-index related to intra-regional finance, value chains, infrastructure, mobility, institutions, and social cooperations on green development as a multifaceted analysis of integrated belt and road progress. The study sample consists of 64 BRI countries (including 21 Asia, 22 Europe, and 21 Africa and Middle East) from 2006 to 2021. The sample is based on the panel data of countries considering before and after the BRI period from 2006 to 2021. The comprehensive list of countries is provided below in Appendix A. Large panel datasets are used in this study because of their higher variability, effectiveness in managing individual heterogeneity, and lowering collinearity between variables. The dataset has the capability to identify and quantify precise statistical effects using the panel method, which is not possible with other methods. Further, the dataset normalizes through the Winsor2 normalization process. The data was processed, calculated, and analyzed by utilizing STATA-15 econometric and Origin-Pro 2021 software.

Consequently, this study has opted to employ the World Bank's proposed green-adjusted net saving rate, including the particulate emissions index, for assessing green development. This concept has fundamentally reshaped the significance of incorporating considerations related to natural resource depreciation or degradation into the calculations of the gross net national production (Hamilton and Clemens 1999; Hess 2010). Green-adjusted net savings are widely recognized within academic discourse as comprehensive indicators of sustainable green development, as evidenced by the works of (Afshan et al. 2024; Gnegne 2009; Greasley et al. 2014; Koirala and Pradhan 2020; McGrath et al. 2024; Qasim and Grimes 2022). Furthermore, Koirala and Pradhan (2020) and McGrath et al. (2024) investigated the factors affecting development sustainability by endorsing green savings. Their findings shed light on intergenerational trade-offs concerning current and potential demand levels and endorse green development for the concepts of a sustainable future.

Green development is a vital and recently prevailing concept (Luukkanen et al. 2019). However, measuring green development is complex and one of the critical challenges (Zhu et al. 2024). Therefore, this study's dependent variable is predicated on the optimal index for assessing green development, which takes the form of a green-adjusted net savings index. Notably, this index incorporates the impact of particulate emissions damage, rendering it a robust measure. The World Bank has introduced an alternative indicator, the green-adjusted net savings rate (GANSR), including and excluding particulate emissions damage, to gage sustainable and green development (Afshan et al. 2024; Feng et al. 2023; Koirala and Pradhan 2020; McGrath et al. 2024). The green-adjusted net savings index, commonly referred to as the Genuine Savings Index (GSI), stands as a recognized index for green development. It is noteworthy that while a variety of green development indicators exist, the green-adjusted net savings index proposed by the World Bank emerges as the prevailing choice. This preference is rooted in its wide acceptance as an all-encompassing measure that comprehensively addresses the three fundamental dimensions of green development sustainability, namely economic, social, and environmental aspects, all at once (Afshan et al. 2024; Arrow et al. 2012; Ferreira et al. 2008; Greasley et al. 2014; Hess 2010; Kaimuri and Kosimbei 2017; Koirala and Pradhan 2020; McGrath et al. 2024).

The adjusted net savings rate (ANSR) concept aligns with the reformation of the Hartwick Rule (Larissa et al. 2020) and better captures the green development path (Cheba et al. 2022; Tariq et al. 2024; Zhao et al. 2024). Subsequently, the World Bank put forth a comprehensive ANSR index for assessing green development. This index has been recently updated, drawing on the findings presented in the Changing Wealth of Nations 2018, to contribute to the construction of a sustainable future, as exemplified by Lange et al. (2018) in the table provided below (Appendix B). Notably, recent research by Koirala and Pradhan (2020), Afshan et al. (2024) and McGrath et al. (2024) has recommended and employed green-adjusted net savings as the most suitable index for appraising sustainable development, which is the broader context of green development transition. Further elucidation of the dependent variable, inclusive details regarding data sources, and the formulation of hypotheses, all grounded in previous scholarly investigations, are presented in Appendix B.

The study's independent variable is the regional transition, which comprises six multilateral sub-indices: intra-regional trade and investment, money and finance, value chain, infrastructure and connectivity, movement of people, and social and institutional institutions integrated transition. This variable is derived from a recently developed and unexplored metric that measures the extent of regional transition for multidimensional integration at a comprehensive level (Appendix B). The alternate hypothesis H_1 is that regional transition at a multidimensional level positively impacts green development. Our methodology builds on Huh and Park (2017), extended by Park and Claveria (2018b) and Huh and Park (2021) for panel data analysis. RT indicators are supported by (Abbas et al. 2024; Alvarez et al. 2024; Feng et al. 2023; Naeher and Narayanan 2020). Figure 2 presents a flow chart illustrating the proposed regional transition at a multi-dimensional level, which aims to enhance comprehension of its composite characteristics.

Furthermore, additional determinants are considered as controlling factors in this study. Indicators include financial capital mobilization, natural capital intensity as resource rent, governance-by-technology, and institutional governance index. In addition, the integration of the BRI is accounted for, both 7 years before and 7 years after the introduction of a dummy variable. Appendix B, demonstrated at the end, has a comprehensive explanation of the control variables and the data sources used based on prior research.

3.2 | Econometric Strategy

This study employed the most robust econometric estimation techniques, i.e., principal component analysis (PCA), Cross-Sectional Dependence tests (CSD), second-generation panel unit root, and two-step system Generalized Method of Moments (sys-GMM). The results were authenticated through two-stage least squares (2SLS) and a dynamic fixed effect to increase the reliability of the outcomes. This study used the latest and longest available panel dataset from 2006 to 2021. Simultaneously, a different strategy involves replacing similar variables; for example, a version of green-adjusted savings that does not include particle emission was used in place of the dependent variable of green-adjusted savings, which accounted for particulate emission. Furthermore, a composite measure of institutional quality, which is constructed from six alternative governance indicators identified in the ICRG database, was used in place of the composite measure of governance from the WGI database (Kutan et al. 2017). Primary models incorporated macroeconomic conditions, whereas robust models excluded inflation in the PCA but used it as an instrument. The 2013 BRI policy functioned as a positive instrumental time effect shock and contributed to the sustainable green development trajectory of the partner countries. In addition, the Variance inflation factors (VIFs) test provides an effective way to quantify the degree of collinearity between the regressors in the equation. The VIF, correlation matrix, and descriptive values suggest no multicollinearity among variables, and the data exhibit a normal distribution. Thus, overall, these tests would determine the quality of the results. Also, this study made an effort to enlarge the existing literature by employing the origin-pro graphical trend of variables to understand the variables' nature and relationship better.

FIGURE 2 | Regional transition at the multilateral level used indicators chart [*Source:* prepared by authors].

3.2.1 | Cross-Sectional Dependence and Second-Generation Unit Root Tests

Before examining the data stationarity, conducting the cross-dependence test is crucial for a panel-based cross-sectional study. Hence, this study uses the cross-sectional Pesaran (2004) suggestion equation as follows.

$$\mathrm{CD} = \sqrt{\frac{2T}{N(N-1)}\left(\sum_{i=0}^{N-1}\sum_{j=i+1}^{N}\rho ij\right)} \quad (1)$$

Equation (1) denotes CD as a measure of cross-sectional dependence, where "n" represents the number of cross-sections and "t" signifies time. Moreover, the relationship between the errors in the cross-sectional data of "j" and "i" is represented by the symbol ρij. This equation is used to analyze cross-sectional dependence in the following manner:

$$y_{it} = \alpha_{it} + \beta_i x_{it} + \mu_{it} \quad (2)$$

The variables "i" and "t" in Equation (2) stand for cross-section (CS) as well as period, respectively. Moreover, the alternative hypothesis suggests a dependency across the variable's CS, whereas the null hypothesis asserts independence across them.

To evaluate the order of integration of the variables, this study uses the CIPS known as Cross-sectional Augmented Im-Pesaran-Shin and CADF, which are known as Cross-sectional Augmented Dickey-Fuller, as the indicators for unit root tests, which were proposed by Pesaran in 2007. To ascertain the stationarity at level $I(0)$ or at the first difference $I(1)$ of the variables, these unit root tests are essential. In order to address cross-sectional dependencies in the study of the variables' unit root qualities, the formulas for estimating the CADF and CIPS unit root tests are applied. The following is the CIPS test equation:

$$y_{it} = \alpha_{it} + \beta_i x_{it-1}\rho_i T + \sum_{j=0}^{n}\theta_{it} \triangle x_{i,t-j} + \mu_{it} \quad (3)$$

$$CIPS = \frac{1}{N}\sum_{i=1}^{N} CADFi \quad (4)$$

here, variables and residuals are denoted by x_{it} and μ_{it} whereas i and t represent cross-country groups and period in the panel data. The CIPS test is estimated to use the CADF in this way.

The CSD diagnostic tests indicated that the data lacked cross-sectional dependence. Unit root analysis suggests that the data are stationary at the level of the first difference, demonstrating model accuracy and indicating dynamic panel analysis.

3.2.2 | Two-Step System GMM

Dynamic effects are associated with long-term and intertemporal relationships between variables, which are essential in the analysis of sustainability as current decisions can have lasting future impacts. Factors such as resource depletion, population growth, technological advancement, and policy modifications can initiate dynamic patterns, necessitating their modeling consideration. The analysis utilized sequential estimation (two-step system GMM), as Kripfganz and Schwarz (2019) recommended for regional analysis. The two-step system-GMM approach effectively addresses endogeneity issues by employing instrumental variables and leveraging moment conditions to estimate parameters in a consistent and efficient manner. Its advantages include the capacity to control for measurement errors and unobserved panel heterogeneity (Abbas et al. 2024; Adeleye and Eboagu 2019). This two-step procedure first estimates the moment conditions via instrumental variables and then derives parameters using these estimates. The primary step computes the moment conditions using instrumental variables, whereas the secondary step calculates parameters using the established moment conditions. Sys-GMM is valuable for analyzing panel data across multiple nations and addressing unobserved heterogeneity. Its computational efficiency, data utilization, ability to address endogeneity and measurement errors, and accommodation of heterogeneity and nonlinearity forms (Bond and Windmeijer 2002; Ghannouchi 2023; Hayakawa and Qi 2020; Roodman 2009; Windmeijer 2005) underscore its utility.

The two-step post-analysis system Generalized Method of Moments (GMM) corroborates the model's significance. The AR(1) p-value was observed to be 5%, suggesting the absence of first-order serial correlation, whereas the AR(2) p-value was similarly 5%, thereby affirming the moment conditions met the prescribed benchmark, as proposed by Roodman (2009). This was achieved using the two-step orthogonal command xtabond2 with the collapse option and a lag specification of 2. Additionally, Hansen's p-value, ranging between 0.10 and 0.25, indicates the model's accuracy (Roodman 2009). The Sargan test p-value was insignificant, confirming the validity of over-identifying restrictions and instrument reliability. The Sargan test values imply the consistency and fitness of the model instruments and variables. The number of J-statistics instruments is less than the total number of countries, validating the sys-GMM instruments. The Wald test specifies that all the variables are significant, asserting that the two-step system GMM is a reliable instrumental method.

Sys-GMM is best when we do not know the dependent variable distribution; therefore, in this case, sys-GMM is the most appropriate strategy. Therefore, the inclusion of a lagged dependent variable within a dynamic panel model effectively addresses endogeneity issues that arise due to the correlation between the error term and the explanatory variable. This methodological approach employs instrumental variables to appropriately manage endogeneity and ensure that parameter estimates remain unbiased (Abbas et al. 2024). Hence, considering the relevance, importance, and literature gaps, this study employed the first two-step sys-GMM as a key estimation technique, and the results were robust and validated through the 2SLS estimator as the best alternate and suitable solution to counter the problem of endogeneity in the entire study (Abbas et al. 2024; Roodman 2009; Ahmad et al. 2021; Geng and He 2021).

The influence of regional transition (RT) on green development is investigated for BRI countries. To test the hypothesis stating RI and its sub-indexes, which can impact green development (GD), the Sys-GMM system was applied. Recalling the Cobb–Douglas function through the extended version of the Solow growth theoretical framework and the econometric two-step system GMM function by following Hess (2010) and Koirala and Pradhan (2020), the equation is expressed as follows:

$$GD_{i,t} = \alpha_i + \lambda(GD)_{i,t-1} + \beta_1(RT)_{i,t} + \sum_{j=1}^{k} \delta_j Z_{jit} + \varphi_t + \varepsilon_{it} \quad (5)$$

The RT sub-indexes extension dynamic models can be written as follows:

$$GD_{i,t} = \alpha_i + \lambda(GD)_{i,t-1} + \beta_1(TII)_{i,t} + \beta_2(MFI)_{i,t} + \beta_3(RVCI)_{i,t} + \beta_4(ICI)_{i,t} + \beta_5(MOPI)_{i,t} + \beta_6(ISI)_{i,t} + \sum_{j=1}^{k} \delta_j Z_{jit} + \varphi_t + \varepsilon_{it} \quad (6)$$

where the dependent variable GD is green development, RT is regional transition comprehensive index comprised on the indices of trade and investment (TII), money and finance (MFI), regional value chains (RVCI), infrastructure and connectivity (ICI), movement of people (MOPI), institutional and social (ISI). $\sum_{j=1}^{k} \delta_j Z_{jit}$ represent the control variables and ε_{it} is error term.

3.2.3 | Robustness Check Through 2SLS and Dynamic Fixed Effects Methods

The 2SLS instrumental variables (IV) procedure is the most effective method of dealing with endogeneity concerns. Therefore, the present study employed the two-stage least squares (2SLS) estimation method as a robustness assessment to address endogeneity concerns and validate the Sys-GMM results. Previous studies used 2SLS for alternative specification tests (Tao et al. 2022; Zhou et al. 2022). The 2SLS estimation determines the parameters of the structural equation model with endogenous variables. When a regression model has endogeneity issues, the 2SLS is often advantageous. In 2SLS, independent variables correlated with the error term are excluded and regressed on instrumental variables, severing the association between the independent variables and the error term. The 2SLS estimation involves regressing endogenous variables against instrumental variables (IV) and generating predicted values for each variable. IVs lack the influence of endogenous variables but maintain a correlation with them.

Two different methods were employed to authenticate the study findings robustness, which were generated from the core sys-GMM method. The first approach to endogeneity was to use 2SLS estimation using instrumental variables, as mentioned above.

The equations of robustness check 2SLS models, as quantified by Zahid et al. (2020), can be described as Equation (3.26). The direct channel model equation is as follows.

$$\gamma_{it} = \alpha_1 + \beta_{1it} + \gamma_1 x_{it} + \delta_t + \varepsilon_{1it} \text{ (1ststage)} \tag{7}$$

$$\beta_{1it} = \alpha_2 + \theta Z_{it} + \gamma_2 x_{it} + \delta_t + \varepsilon_{2it} \text{ (2ndstage)}$$

where, γ_{it} is represents the dependent variable of a specific country "i" at a given time "t". While α_1 and α_2 represent constants for the first and second stages. β_{1it} denote endogenous independent variables in the models of a specific country "i" at the time-period "t". Moreover, $\gamma_1 x_{it}$ and $\gamma_2 x_{it}$ are the other control determinant variables. The instrument variables represent θZ_{it} in the models of a specific country "i" at a given time "t". ε_{1it} and ε_{2it} describes the composite, residual, or disturbance error. Using the 2SLS model estimates the second stage so that the first stage equation is achieved and gets fitted values for the endogenous independent variable(s). The fitted values are subsequently employed to estimate the equation of the initial stage. Therefore, the coefficient of β_{1it} can be interrelated as the marginal impact of a one-unit change in independent variables on the dependent variables of the models (Wooldridge 2015; Zahid et al. 2020).

$$\Delta z_{it} = \propto_i d_i + \vartheta\left(z_{i(t-1)} + \acute{\pi}_i y_{i(t-i)}\right) + \sum_{j=1}^{m} \phi_{ij} \Delta z_{i(t-1)} + \sum_{j=1}^{m} \varphi_{ij} \Delta z_{i(t-1)} + \sum_{j-1}^{J} \lambda_j^i y_{i(t-j)} + \mu_{it} \tag{8}$$

3.2.4 | Instruments Used in the Models

Models' instruments are globalization index indicators, currency exchange rate volatility, and interest rate. Moreover, the second model additionally added cultural globalization factors in cultural exchange agreements as instruments, global capital mobility, and global trade openness. The selection of instrumental variables (IVs) for this research is based on their strong theoretical and empirical links with endogenous explanatory variables while ensuring exogeneity from green development outcomes. Principal instruments include globalization indices, currency exchange rate volatility, and interest rates, as they significantly influence intra-regional finance, value chain integration, and institutional development. Globalization indicators reflect regional economic connectivity, affecting financial flows and trade links while remaining detached from the immediate effects of green development policy. Currency exchange rate volatility influences cross-border investments and trade balance adjustments without directly affecting environmental sustainability policies. Interest rates affect capital mobility and financial market stability, influencing infrastructure investments and institutional cooperation without directly affecting the green development results. To strengthen the identification strategy, the secondary model incorporates the cultural factors of globalization, global capital mobility, and global trade openness as additional instruments. Cultural exchange agreements foster regional cooperation and institutional conformity, impacting governance and investment environments while remaining independent of green development trajectories. Global capital mobility affects financial accessibility and influences intraregional finance and infrastructure investment but does not directly define environmental policies. Trade openness is integral to regional supply chain dynamics, influencing value chain integration and economic development without immediately catalyzing green outcomes. The BRI policy of 2013 is employed as a natural experiment in time-fixed effects, serving as a significant exogenous shock. To ensure robustness, diagnostic tests such as the Hansen J-test for over-identification, Sargan, and J-stat instrument tests were administered to validate the instruments' legitimacy. These instruments address endogeneity issues and increase the credibility of the empirical findings on the impact of regional transitions on sustainable green development.

3.2.5 | Test for co-Integration Models

The co-integration models from works by McCoskey and Kao (1998), Pedroni (2004), and Westerlund (2007) analyze and confirm the co-integration between the variables. The functions of the Westerlund-ECT-based key test for cointegration can be as follows.

Equation (8) models dynamic panel data, addressing persistence and endogeneity through lagged dependent and independent variables. The dependent variable Δz_{it} eliminates fixed effects, while $\propto_i d_i$ controls for unit-specific heterogeneity. The lagged dependent variable $z_{i(t-1)}$, scaled by ϑ, captures past influences, and $\acute{\pi}_i y_{i(t-i)}$ accounts for the delayed effects of independent variables. Momentum effects are modeled via $\sum_{j=1}^{m} \phi_{ij} \Delta z_{i(t-1)}$ and $\sum_{j=1}^{m} \varphi_{ij} \Delta z_{i(t-1)}$, while $\sum_{j-1}^{J} \lambda_j^i y_{i(t-j)}$ incorporates long-term dependencies. The error term μ_{it} captures unexplained variations.

$$G_\tau = \frac{1}{N} \sum_{i=1}^{N} \frac{\vartheta_i}{SE(\acute{\vartheta}_i)} \tag{9}$$

$$G_\alpha = \frac{1}{N} \sum_{i=1}^{N} \frac{T\vartheta_i}{\acute{\vartheta}_i(1)} \tag{10}$$

$$P_\tau = \frac{\hat{\vartheta}_i}{SE\left(\hat{\vartheta}_i\right)} \tag{11}$$

$$G_\alpha = T\hat{\vartheta}_i \tag{12}$$

where, d_i represents the vector of deterministic components and other parameters introduce the nuisance in variables of interest, ϑ_i is the adjustment term. To judge the null hypothesis G_τ

and G_α are the group mean statistics that state that there is no cointegration in the cross-sectional panel. If this hypothesis is rejected, then cointegration must exist for at least one-panel cross-sectional unit.

This formulation, designed for application within the Generalized Method of Moments (GMM), facilitates rigorous inferences regarding regional transition and green development. The Westerlund error correction test (ECT) is necessary to substantiate the existence of a long-term equilibrium. This test evaluates the extent to which deviations from equilibrium are rectified over time, thereby confirming cointegration. Unlike residual-based methodologies, the Westerlund–ECT test directly estimates the error correction term (ECT), allowing heterogeneous adjustment speeds across panel units. Upon confirmation of cointegration, an error correction model (ECM) can be employed to reconcile short-term fluctuations (Equations 8–12) with long-term adjustments, providing a comprehensive analytical framework for the study of regional transition and green development.

TABLE 1 | Pesaran cross-sectional dependence test.

Tests	Fixed effect	Decision
Model 1		Refers to the second-generation unit root estimation
Pesaran's test of cross-sectional independence	1.701**	
Model 2		
Pesaran's test of cross-sectional independence	1.686**	

4 | Results and Discussion

4.1 | Pesaran Cross-Sectional Dependence Test and Second-Generation Unit Root

The outcomes of CSD tests in Table 1 show that the alternative hypothesis (H1) indicates that there is cross-sectional dependence. Detailed results can be found in Table 1.

All variables are considered stationary at the level or in the first difference, according to Table 1, combined results from the CIPS and CADF unit root tests. This implies that the dynamic two-step system model is suitable for further analysis. In Table 2, the outcomes of CIPS and CADF are shown.

4.2 | Results of Descriptive and Correlation Analysis

An overview of the descriptive statistics for the independent, dependent, and control variables is shown in Table 3, which includes the standard deviation, mean, minimum, maximum, and number of observations. Table 3 highlights that the dataset includes 1024 observations spanning from 2006 to 2021, originating from a sample of 64 countries. The descriptive statistics affirm that all data values fall within the expected range.

Table 4 displays the pairwise correlations (Overall Study Models) between the variables. The findings in Table 4 depict that regional transition (RT), trade and investment index (TII), regional value chain index (RVCI), and financial capital mobilization (FCM) have statistically significant and positive relationships with green development (GD) at the 1% significance level. Moreover, intuitional governance (WGI) is also positively correlated with GD at the 5% level and infrastructure and connectivity index (ICI) at the 10%

TABLE 2 | Results of CIPS and CADF (second-generation unit root) tests.

CPIS with no trend				Pesaran's CADF test Constant & no trend		
Variables	**Level**	**First difference**	**Decision order**	**Level**	**First difference**	**Decision order**
GD	−2.261	−2.744***	I(1)	−2.029	−2.635***	I(1)
RT	−1.593	−4.343***	I(1)	−1.155	−2.421***	I(1)
TII	−2.005	−3.977***	I(1)	−1.340	−2.405***	I(1)
MFI	−2.734**	—	I(0)	−1.538	−3.061***	I(1)
RVCI	−1.650	−3.557***	I(1)	−1.322	−2.115**	I(1)
ICI	−1.571	−3.119***	I(1)	−1.667	−2.821	I(1)
MOPI	−1.887	−3.825***	I(1)	−1.748	−2.367***	I(1)
ISII	−2.365***	—	I(0)	−1.927*	−2.161***	I(0)
FCM	−2.389	—	I(0)	−1.713	−3.246	I(1)
NCI	−2.220 ***	—	I(0)	2.147**	−2.685***	I(0)
Gov-by-Tech.	−1.784	−2.862***	I(1)	−1.713	−3.246	I(1)
IG (WGI)	−2.309***	—	I(0)	−2.168***	—	I(0)
IQ (ICRG)	−1.395	−2.813***	I(1)	−1.656	−2.624***	I(1)

Note: C and CT represent constant and constant trends, ***, ** and * indicate significance levels at 1%, 5%, and 10%.

TABLE 3 | Descriptive statistics.

Variables	Obs.	Mean	Standard deviation	Min	Max
GD	1024	2.280	1.014	−3.096	3.643
RT	1024	−0.722	0.244	−1.287	−0.345
TII	1024	−0.900	0.978	−4.213	3.600
MFI	1024	−0.808	0.519	−1.738	2.277
RVCI	1024	−0.714	0.233	−1.279	0.144
ICI	1024	−0.683	0.567	−1.579	3.414
MOPI	1024	−0.669	0.658	−2.245	2.975
ISI	1024	−0.729	0.798	−2.138	4.356
FCM	1024	0.308	0.170	0.076	0.718
NCI	1024	0.761	2.203	−7.561	3.936
Gov-by-Tech.	1024	−0.807	0.402	−1.966	−0.182
IG (WGI)	1024	−0.507	1.121	−5.012	1.225
IQ (ICRG)	1024	2.666	0.348	1.635	3.251
Integrated BRI spillover	1024	0.500	0.500	0.000	1.000

level of significance. However, the institutional and social index (ISI) is negative at the 5% significance level. While other variables, such as the movement of people index (MOPI), governance-by-technology, and natural capital intensity (NCI), are positively correlated with GD but are insignificant. Besides that, the money and finance integration index (MFI) and BRI have negatively insignificant relations with integrated GD.

Table 5 demonstrates the pairwise correlations between variables specific to model 1. Table 5 findings show that regional transition (RT) and FCM are statistically significant and have a positive correlation with GD at a 1% significant level. Moreover, a positive correlation exists between institutional governance (WGI) and GD at a 5% significant level. While other variables such as Gov-by-Tech. and NCI are positively correlated with GD but insignificant. Besides that, BRI is negatively correlated with GD but insignificant.

Table 6 displays the pairwise correlations between variables specific to model 2 based on multilateral integration dimensions. Table 6 findings show that TII, RVCI, and FCM are statistically significant and have a favorable correlation with GD at a 1% significance level. Institutional governance (WGI) is also positively connected with GD at a 5% significance level. However, the ISII and GD have a negative correlation at a 5% significance level. Other variables such as MOPI, Gov-by-Tech., and NCI are positively correlated with GD but are insignificant. Besides that, MFI and BRI have negatively insignificant relations with GD.

The Variance Inflation Factor (VIF) analysis specific to models 1 and 2 is shown in Table 7. We computed the VIF for the model 1 and model 2 variables to ensure and confirm that no multicollinearity exists in our dataset. According to Salmerón-Gómez et al. (2024) if any variable has a VIF greater than five, it suggests the presence of multicollinearity issues. In our case, all the VIF values in Table 7 are below five, indicating that our data is not affected by multicollinearity.

4.3 | Results for the Main Models of Two-Step System GMM: Belt & Road Full Sample

Table 8 displays the influence of the regional transition (RT) and multilateral sub-indices on green development columns (1 and 2). This is predicted on the system-GMM and 2SLS for robust verification. Also, Table 8 is based on the initial results related to the system-GMM standards, and the Wald test supports the output model of the system-GMM to demonstrate the findings in columns (1 and 2). The findings in column (1) of the main model of system-GMM show that RT has a positively significant effect on GD with a *p*-value of less than 5%. An increase of one percentage point in regional transition at the multilateral level will boost green development.

The outcomes in column (2) show the effect of the composite sub-dimensions on green development. Findings depict that the regional business value chain index (RVCI) significantly impacts green development, directing at the significance level of 1%. It suggests that a percentage change in the RVCI increases the GD level. Value chains under the integrated BRI network are productive and contribute to society. Moreover, infrastructure and connectivity (ICI) indicate a significantly positive effect on green development, compelling a 10% significance level. Furthermore, the results demonstrate that trade and investment (TII), together with institutional and social (ISI) factors, exert a significantly detrimental influence on green development (GD) with a significant level of 5%. This occurs predominantly through mechanisms, such as increased environmental degradation, insufficient regulatory frameworks, and social resistance to sustainable practices. Specifically, trade and investment activities can exacerbate pollution and

TABLE 4 | Pairwise correlations (overall study variables).

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
GD	1.000													
RT	0.089***	1.000												
TII	0.107***	0.668***	1.000											
MFI	−0.048	0.525***	0.615***	1.000										
RVCI	0.205***	0.582***	0.563***	0.388***	1.000									
ICI	0.059*	0.131***	0.528***	0.649***	0.240***	1.000								
MOPI	0.053	0.612***	0.639***	0.620***	0.456***	0.622***	1.000							
ISI	−0.079**	0.409***	0.569***	0.606***	0.370***	0.546***	0.662***	1.000						
FCM	0.172***	0.367***	0.053*	−0.012	0.172***	0.004	0.035	0.096***	1.000					
NCI	0.004	−0.157***	−0.160***	−0.108***	−0.032	−0.127***	−0.088***	−0.217***	−0.197***	1.000				
Gov-by-Tech.	0.016	0.576***	0.313***	0.295***	0.354***	0.207***	0.203***	0.311***	0.577***	0.475**	1.000			
IG (WGI)	0.119**	0.182***	0.032	−0.083*	0.001	−0.107**	0.007	−0.148***	0.153***	0.210***	−0.202***	1.000		
IQ (ICRG)	−0.167***	0.113***	−0.020	0.176***	−0.137***	−0.028	0.029	0.130***	0.202***	0.270***	0.016	0.075	1.000	
BRI	−0.002	0.038	0.044	−0.059*	−0.036	0.088***	0.025	0.030	0.047	0.238***	−0.009	−0.028	0.044	1.000

Note: ***$p < 0.01$ is 1%, **$p < 0.05$ is 5%, *$p < 0.1$ is 10% significance levels as parentheses for standard errors.

TABLE 5 | Pairwise correlations (specific to model: 1).

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
GD	1.000							
RT	0.089***	1.000						
FCM	0.172***	0.367***	1.000					
NCI	0.004	−0.157***	−0.197***	−0.256***	1.000			
Gov-by-Tech.	0.016	0.576***	0.577***	0.461***	0.510***	1.000		
IG (WGI)	0.119**	0.182***	0.153***	0.210***	−0.202***	0.121**	1.000	
BRI	−0.002	0.038	0.047	0.238***	−0.009	−0.051*	−0.189***	1.000

Note: ***$p < 0.01$ is 1%, **$p < 0.05$ is 5%, *$p < 0.1$ is 10% significance levels as parentheses for standard errors.

carbon emissions, whereas weak institutions and social inequalities impede the implementation of green policies and practices.

Besides, Table 8, in column (2), shows that the movement of people index (MOPI) has an insignificantly positive influence on GD; however, money and finance integration indicate an insignificantly negative impact on GD in BRI countries from 2006 to 2021. Moreover, controlling factors in both columns (1 and 2), such as financial capital mobilization (FCM), have shown a statistically significant beneficial influence on green development, directing the significance level at 5%. This suggests that a percentage increase in the development of financial capital mobilization will positively improve BRI countries' green development. Meanwhile, governance (WGI composite) significantly and favorably affects GD. At the 1% significance level in column (1) and the 5% significance level in column (2), governance by technology demonstrates a strong, positive influence on green development. It suggests that regional transition enhances technology in taking good governance decision frameworks in BRI member countries. Simultaneously, the results of other determinants like natural capital intensity (NCI) outcomes have a significantly negative influence on GD in both columns (1 and 2) by directing a 10% significance level in column (1) and the significance level of 5% in column (2). It indicates that BRI countries need to utilize their natural resources more efficiently. In addition, the effect of BRI spillover before and after the dummy indicates that BRI significantly contributes toward the green development of the partner countries after the initiative.

Overall, the post-diagnostic test findings demonstrated in Table 8 ensure accurate inference and validate sys-GMM findings. The sys-GMM models diagnostic tests in columns (1 and 2) residual meet the necessary estimation assumptions and pass. The p-value of the Arellano-Bond (AR1) test, which is below 5%, indicates that there is no autocorrelation in the first-order differences of the assessed models. Hence, there is no serial correlation present. Given that there are more N (64) than T (16) in this study, the sys-GMM is a fit estimation technique when it comes to the second-order difference, as indicated by the AR2 p-value of more than 5%. The p-value of the Hansen test statistic falls between the range of 0.10–0.30. In contrast, the Sargan test p-value is insignificant, as Roodman (2009) suggested, which depicts that the over-identifying parameters of the Hansen and Sargan tests are legitimate; they support the instrument's consistency and fall short of rejecting the null hypothesis. In addition, the number of instruments in column (1) model is 49 while 50 in column (2), which is less than the 64 representing the number of groups. Thus, provide further evidence supporting the GMM instruments' validity. The GMM model utilized variables that were selected based on their Chi-square and F-statistics, which demonstrated p-values below 1%. This indicates that the models are suitably fitted for practical use. Furthermore, the Wald-Chi square test verifies the statistical significance of used variables. All post-diagnostic tests from corresponding models of column (1 and 2) results are also reported in Table 8.

4.4 | Robustness Check Through 2SLS and Alternate Variables: Belt & Road Full Sample

The system GMM models findings of Table 8 columns (1 and 2) were validated and confirmed through the 2SLS method, described in columns (1 and 2) of Table 8. In depth, the outcomes of 2SLS and the alternate variables, which are institutional quality and the alternate dependent variable index, verify the legitimacy of the first two column model findings of system GMM. Overall results of regional transition and its multilateral sub-indexes and control factors show consistent outcomes, which signify at different levels. These are further validated through post-diagnostic tests of alternate methods. In addition, alternate replaced dependent variable green development confirms similar outcomes to those of our main model. Furthermore, the alternative institutional quality composite (ICRG), which took the place of the governance composite (WGI), affirms the substantial, favorable influence on green development. Overall, the outcome of the robust examination verifies that there are no endogenous problems in the overall models. Consequently, the conclusions of the robust verification confirm the conclusions of the first system-GMM models.

Table 9 reports the post-analysis findings for all diagnostic tests of 2SLS using the relevant robust models in columns (1 and 2). In addition, the outcomes demonstrate the accuracy of the inference and the dependability of the primary models' consistency. Robust models excluding instruments are globalization index indicators, currency exchange rate volatility, and interest rate. Moreover, the second model additionally adds cultural globalization factors, cultural exchange agreements as instruments, global capital mobility, and global trade openness. Detailed outcomes of the robust examination using the 2SLS are revealed in columns (1–2) in Table 9.

TABLE 6 | Pairwise correlations (specific to model: 2).

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
GD	1.000										
TII	0.107***	1.000									
MFI	−0.048	0.615***	1.000								
RVCI	0.205***	0.563***	0.388***	1.000							
ICI	0.059*	0.528***	0.649***	0.240***	1.000						
MOPI	0.053	0.639***	0.520***	0.456***	0.622***	1.000					
ISII	−0.079**	0.569***	0.606***	0.370***	0.646***	0.662***	1.000				
FCM	0.172***	0.053*	−0.012	0.172***	0.004	0.035	0.096***	1.000			
NCI	0.004	−0.160***	−0.108***	−0.032	−0.127***	−0.088***	−0.217***	−0.197***	1.000		
Gov-by-Tech.	0.016	0.313***	0.295***	0.354***	0.207***	0.203***	0.311***	0.577***	0.512***	1.000	
IG (WGI)	0.119**	0.032	−0.083*	0.001	−0.107**	0.007	−0.148***	0.153***	0.210***	−0.202***	
BRI	−0.002	0.044	−0.059*	−0.036	0.088***	0.025	0.030	0.047	0.238***	−0.009	1.000

Note: ***$p < 0.01$ is 1%, **$p < 0.05$ is 5%, *$p < 0.1$ is 10% significance levels as parentheses for standard errors.

TABLE 7 | Variance inflation factor (specific to models: 1 and 2).

	Model 1		Model 2	
Variables	**VIF**	**1/VIF**	**VIF**	**1/VIF**
RT	2.163	0.462	2.240	0.446
TII			2.579	0.387
MFI			2.257	0.443
RVCI			2.445	0.408
ICI			2.346	0.426
MOPI			3.218	0.310
ISI			4.051	0.247
FCM	4.081	0.245	3.949	0.253
NCI	2.387	0.419	3.410	0.293
Gov-by-Tech.	2.040	0.490	2.273	0.440
IG (WGI)	1.575	0.635	1.771	0.565
BRI	1.267	0.789	1.489	0.671
Mean VIF	2.252		2.669	

4.5 | Regionwide Results

Table 10 shows the regionwide results of Asia, Europe, Africa, and Middle East sample countries. This study indicates that regional transition (RT) significantly influences green development (GD) across various regions, with differing impacts. The effect is most pronounced in Asia and the Africa–Middle East region, where structural changes are actively transforming economic settings and sustainability policies are being implemented to achieve green development. In Asia, Europe, and Africa– Middle East, the notable positive impact suggests that rapid industrial restructuring, urbanization, and policy-driven transitions play crucial roles in enhancing green development. This observation supports the Ecological Modernization Theory (EMT), which posits that economic restructuring, technological innovation, and governance adaptation are essential drivers of sustainable green development. Conversely, Europe exhibits a weaker yet significant effect of regional transition on green development, indicating that established environmental policies and existing green infrastructure have integrated sustainability into the economic framework, resulting in diminishing returns from further regional change.

Among the control variables, financial capital mobilization (FCM) positively influences green development across all regions, with the greatest impact observed in Asia and the African–Middle East. This underscores the significance of financial resources in promoting investment in renewable energy, environmentally friendly industries, and sustainable infrastructure. The relatively lower effect in Europe suggests that the financial mechanisms for green projects are already well developed, resulting in a saturation effect in which additional capital yields diminishing marginal returns. Notably, the influence of natural capital intensity (NCI) on green development

TABLE 8 | Results of multilateral integration and its sub-indexes at multidimensional level on green development: Sys-GMM.

Dependent variable: green development (GD)	(1)	(2)
	Main models	
	Two-step system GMM	
	SD	SD
L. GD	0.739***	0.696***
	(0.030)	(0.098)
RT	17.115**	
	(6.178)	
TII		−10.908**
		(4.694)
MFI		−7.784
		(5.174)
RVCI		0.516***
		(11.326)
ICI		15.541*
		(8.096)
MOPI		0.846
		(0.506)
ISI		−0.131** (5.250)
FCM	6.012**	6.661**
	(1.494)	(10.114)
NCI	−0.032*	−0.175**
	(0.026)	(0.076)
Gov-by-Tech.	9.741***	11.536**
	(2.553)	(5.370)
Institutional Governance (WGI)	0.023**	0.975*
	(0.334)	(1.162)
BRI spillover effect	1.441**	2.481***
	(0.728)	(0.853)
I. Year F.E.	YES	YES
Constant	YES	YES
Observations	832	832
AR 1 (*p*-value)	−3.847 (0.0002)	−3.826 (0.0001)
AR2 (*p*-value)	2.001 (0.454)	2.153 (0.313)
Hansen test (*p*-value)	22.95 (0.247)	23.59 (0.131)
No. of Instruments/*J*-stat.	49	50
Wald/Chi2 test (*p*-value)	7095 (0.000)	2574 (0.000)
Sargan test (*p*-value)	45.88 (0.133)	34.55 (0.713)
BRI sample Countries	64	64

(Continues)

TABLE 8 | (Continued)

Note: Roodman (2009) xtabond2 command used. ***$p < 0.01$ is 1%, **$p < 0.05$ is 5%, *$p < 0.1$ is 10% significance levels, and in parentheses, the values of standard errors are reported.

varies across regions. Asia's negative NCI impact aligns with the resource curse and early-stage Environmental Kuznets Curve (EKC) hypothesis, necessitating stronger environmental governance. Europe's positive impact corresponds to institutional theory, which illustrates that robust governance ensures sustainable resource management. The developing positive impact of the African Middle East indicates a gradual shift toward sustainable resource utilization, consistent with recent investment trends in green infrastructure.

A significant finding is the differential impact of technology-driven governance (Gov-by-Tech) on green development. In Asia and Europe, technology-led governance substantially enhances green development, indicating that advancements in digital governance, smart infrastructure, and AI-driven environmental strategies positively influence the sustainability of green development. Conversely, in Africa and the Middle East, the effect is adverse, suggesting that governance deficiencies, technological limitations, and a lack of institutional capacity may impede the efficacy of technology-based governance in promoting green development in these regions. This underscores the necessity of capacity enhancement and institutional empowerment in developing regions to optimize the beneficial application of technology in environmental governance. Institutional quality (IQ) has a consistently positive and substantial effect on green development across all regions, emphasizing the crucial role of regulatory systems, policy implementation, and institutional stability. The most significant impact is observed in Asia, where enhanced governance frameworks are instrumental in advancing green initiatives. Europe, Africa, and the Middle East also benefit from robust institutional governance, highlighting that clear regulations and stable policies are essential for the sustainability of green development. The BRI involvement in green development yields varied outcomes. Asia experienced a slight positive impact, suggesting that the BRI could support certain green projects. In contrast, Europe exhibited an insignificant, notably positive effect, indicating that the BRI has a minimal influence on sustainability outcomes. However, in Africa and the Middle East, BRI participation has had a negative impact on green development. This suggests that BRI ventures in the

TABLE 9 | Results robustness check: 2SLS.

Dependent variable: green development (GD)	(1)	(2)
	Robustness check	
	2SLS	2SLS
	Model-1	Model-2
RT	0.392***	
	(0.035)	
TII		8.776***
		(1.946)
MFI		−4.503
		(3.034)
RVCI		4.293**
		(3.959)
ICI		11.461**
		(2.040)
MOPI		0.588
		(0.831)
ISI		−0.108 (0.958)
FCM	24.010***	24.382***
	(2.878)	(3.018)
NCI	−0.018**	−0.046***
	(0.046)	(0.047)
Gov-by-Tech.	17.258***	15.971***
	(3.773)	(3.758)
IQ (ICRG)	2.208***	2.318**
	(0.429)	(0.434)
BRI spillover effect	0.104***	0.189**
	(0.018)	(1.923)
I. Year F.E	YES	YES
Constant	YES	YES
Observations	896	896
R-sq.	0.687	0.5912
Sargan test	3.450	14.700
Sargan (*p*-value)	0.1782	0.701
Endogeneity test (*p*-value)	13.011 (0.0003)	11.584 (0.0007)
Wu–Hausman (*p*-value)	12.833 (0.0004)	11.342 (0.0008)
LM under identification statistics (*p*-value)	760.932 (0.0000)	748.947 (0.0000)
Wald F statistic for weak identification	1633.778	2205.292
Weak identification critical criteria	Pass	Pass
Sample BRI countries	64	64

(Continues)

TABLE 9 | (Continued)

Note: ***$p < 0.01$ is 1%, **$p < 0.05$ is 5%, *$p < 0.1$ is 10% significance levels, and in parentheses, the values of standard errors are reported. Used Stata ivreg, ivreg2 commands. Endogeneity test is the difference of two Sargan–Hansen statistics.

region may be associated with environmental degradation, resource misallocation, and unsustainable high-carbon infrastructure and energy projects. These findings necessitate a reevaluation of BRI approaches to ensure that major projects align with sustainability objectives and contribute positively to green development, particularly in Asia and Africa. The region-wise results are shown in Table 10.

Figure 3 indicates the regional comparison of integrated green development among BRI partner countries in Asia consistently exhibits an upward trend, indicating advancements in green development indicators over time. Europe's trajectory exhibits expansion with intermittent fluctuations, signifying times of accelerated and decelerated advancement. The Middle East & Africa region has notable growth with occasional oscillations, which may indicate periods of strong progress as well as encountering hurdles. This map is a visual aid for comparing and contrasting the green development of certain regions within the context of the BRI programmed. Moreover, in recent years, sustainable paths have increased in the regions.

Figure 4 presents a radar chart that illustrates the level of integration among partner countries of the BRI in Asia, Europe, and the Middle East & Africa. Figure 4 uses an index called RT (Multilateral Regional Transition Index) to assess this integration. The data covers the period from 2006 to 2021. The BRI demonstrates a high degree of transition to integration, particularly reaching its highest point in 2019. Asia demonstrates a consistent increase in transition to integration, peaking around the same year, whereas Europe's transition to integration levels vary considerably over time. The Middle East and Africa areas have the highest degree of variation, characterized by a distinct peak in 2013 and subsequent fluctuating levels of transition to

TABLE 10 | Region-wise results of regional transition on green development: Asia, Europe Africa and Middle East.

	(1)	(2)	(3)	(4)	(5)	(6)
	Two-step system GMM main models (1–3)			Dynamic fixed effect robustness check (3–6)		
Variables	Asia	Europe	Africa Middle East	Asia	Europe	Africa Middle East
L. GD	0.611***	0.839***	0.677***	0.632***	0.785***	0.477***
	(0.018)	(0.015)	(0.018)	(0.046)	(0.035)	(0.045)
RT	48.012**	16.144*	37.450***	38.491*	9.449**	7.177**
	(23.696)	(8.645)	(9.221)	(18.720)	(2.532)	(2.018)
FCM	15.841**	0.771*	9.798***	8.931*	0.609**	6.664**
	(6.877)	(0.455)	(1.713)	(2.789)	(0.341)	(1.116)
NCI	−0.198**	0.116***	0.099***	−0.262***	0.204***	0.178***
	(0.077)	(0.017)	(0.022)	(0.068)	(0.073)	(0.043)
Gov-by-Tech.	8.860***	17.531***	−6.034*	12.932*	4.327**	−2.170**
	(2.279)	(4.792)	(3.610)	(6.587)	(1.261)	(0.990)
IQ (ICRG)	3.064***	1.167***	1.474**	6.320***	1.355*	1.136***
	(0.367)	(0.239)	(0.696)	(0.622)	(0.777)	(0.258)
BRI spillover effect	2.665*	0.738	−1.327***	0.652**	0.663	−1.623***
	(1.463)	(1.230)	(0.144)	(0.208)	(0.450)	(0.489)
Year effect	YES	YES	YES	YES	YES	YES
Constant	YES	YES	YES	YES	YES	YES
Observations	315	330	315	315	330	315
R-squared				0.468	0.628	0.535
AR-1	−2.610	−3.311	−2.909			
AR-1 (*p*-value)	0.00906	0.0009	0.00363			
AR-2	2.021	−1.595	1.676			
AR-2 (*p*-value)	0.433	0.111	0.100			
Sargan test	26.66	20.55	13.74			
Sargan *p*-value	0.316	0.152	0.545			
Hansen test	18.41	14.57	17.77			
Hansen *p*-value	0.242	0.248	0.275			
J-statistics	18	20	19			
Wald/CHI2	13,576	52,624	168,057			
Wald/CHI2 *p*-value	0.000	0.000	0.000			
Countries	21	22	21	21	22	21

Note: Roodman (2009) xtabond2 command used. ***$p < 0.01$ is 1%, **$p < 0.05$ is 5%, *$p < 0.1$ is 10% significance levels, and in parentheses, the values of standard errors are reported.

integration. This indicates varying levels of engagement and collaboration with the BRI throughout the time under study.

4.6 | Comparison and Discussion of Findings

The impact of regional transition and its multilateral subindexes at a multidimensional level on green development in BRI is explored. For this investigation, linear cointegration tests present an appropriate initial method for exploring long-term trends and relationships. First, linear models offer analytical simplicity and are more readily interpretable, particularly when the principal aim is to comprehend regional trends. Second, techniques such as the two-step system GMM (sys-GMM), 2SLS with instruments, and dynamic fixed effects are specifically designed to mitigate endogeneity, which is crucial in the intricate

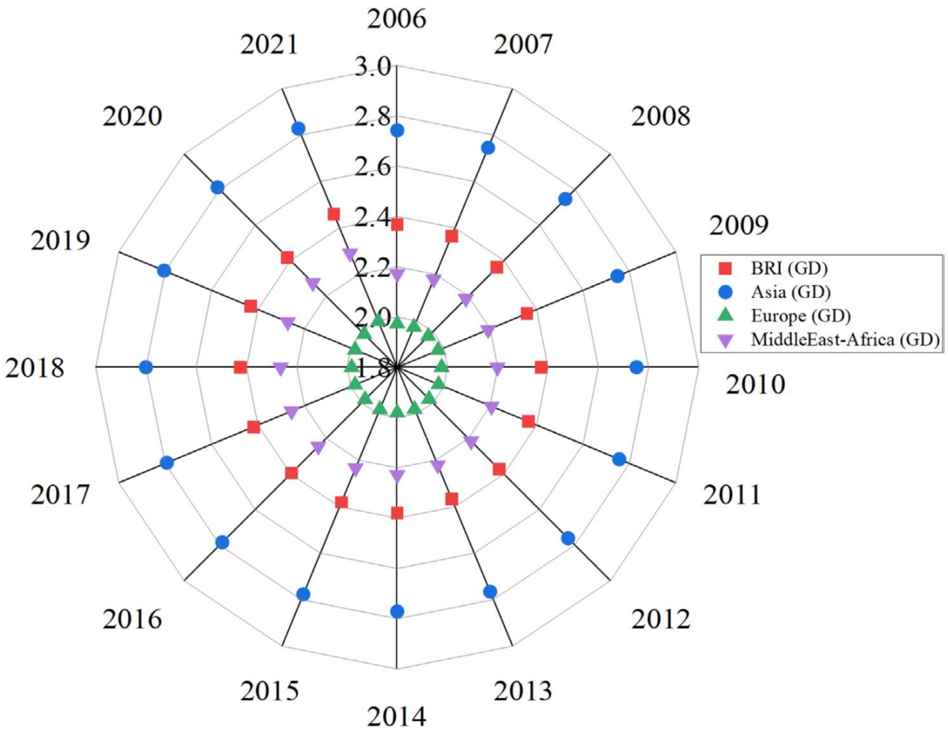

FIGURE 3 | Integrated green development region-wise comparison Radar trends (estimated in Origin Pro 2021 software).

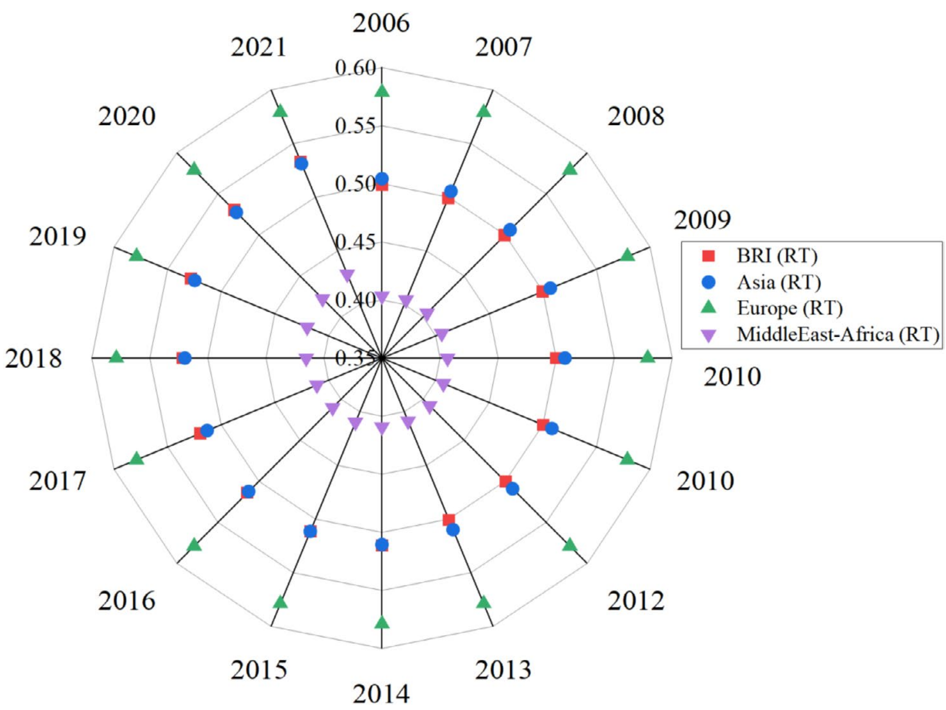

FIGURE 4 | Comparison integrated regional transition radar trends (estimated in Origin Pro 2021 software).

relationships between regional transition and green development. The sys-GMM estimator is frequently utilized in linear models because of its capacity to correct for endogeneity, and it can additionally capture certain indirect nonlinearities if appropriately structured lags and instruments are applied. Dynamic fixed effects models showing the region-wise results robustness check effectively capture system persistence or inertia, such as in regional transitions, where current levels of green development might depend on previous values. This methodology permits the inclusion of lagged dependent variables that assist in accounting for the dynamic effects over time. Although the model is linear, it can address complex time-dependent relationships by including explanatory variables that vary over time. The linearity assumption is a methodological decision that emphasizes capturing long-term dynamics instead of detailed nonlinear interactions. It remains an advantageous tool for estimating the detailed trends within the data. Cointegration tests were used to determine whether there is a long-term equilibrium relationship between regional transitions and green development. Although used, they can still provide valuable information on the long-term relationships between variables. Third, this study models facilitate efficient estimation and are widely employed in empirical research when the intention is to determine average effects rather than model every potential nonlinearity nuance of the short run. In conclusion, adopting a linear framework to represent the impact of regional transition on green development is a rational choice, particularly when employing robust estimation methodologies, such as the Two-Step System GMM, 2SLS, dynamic fixed effects, and cointegration tests. These techniques effectively address endogeneity and dynamic interactions, rendering the linear model a viable starting point for examining broad regional patterns and overarching trends in green development. Consequently, this study model can be considered an advantageous analytical tool that provides meaningful insights and subsequent robustness checks.

Employing a two-step sys-GMM method commanded by Windmeijer (2005) and Roodman (2009) calculated the influence of substitutability and interdependence on green development. Overall, the results indicate the reliability of the GMM two-step process, that it satisfies all model assumptions, and that it is robust. Further, the various diagnostic tests—AR1, AR2, Hansen's value, instruments (*J*-statistics), and Wald examination of the residual of assessed models—account for the necessary inference assumptions and are sufficient to guarantee reliable inference and validation outcomes. The first-order difference in the estimated models shows no serial correlation and no autocorrelation since the AR1 *p*-value is directed below 5%. In contrast, the AR2 *p*-value's second-order fluctuations are significantly greater than 5%. The over-identifying restrictions are real, as shown by Hansen's and Sargan's tests, which support instrument reliability but do not successfully decline the null hypothesis. Analytical post-tests further demonstrate the legitimacy of system-GMM instruments since fewer instruments are used than the number of groups. The Wald test (also called the Hausman) establishes a FE model in the panel regressions, suggesting that panel heterogeneity is acknowledged. The Wald–Chi square test demonstrates the significant level of each variable by demonstrating a *p*-value of less than 1%, which was used in the models; it reveals that the model is appropriate for use. Thus, system GMM is the most suitable and appropriate estimation technique for the current studies. 2SLS also confirms and leads toward the system-GMM validation. Overall, robust checks 2SLS results confirm the consistency of outcomes and conclude that the study models do not exhibit any endogenous problems.

The results of green development as a dependent variable using green-adjusted net savings also confirm the positive dynamic nature directing at 1% the significance level consistent in BRI full, Asia, Europe, Africa, and the Middle East. This signifies that green-adjusted saving as green development is positive and BRI countries are on a sustainable path with the help of regional transition at a multilateral level. Overall, green development is favorable as adjusted net saving patterns are correlated with expanding physical and human capital stocks instead of depleting natural resources. Hence, natural resources are converted into industrial products domestically. In other words, green development implies that green-adjusted net savings are not harmful in BRI full, Asia, Europe, Africa, and Middle East countries. A decreasing green-adjusted saving, especially over a period of years, suggests that a country is headed in an unsustainable direction since it reduces the constructive potential necessary to ensure the welfare of future generations of green wealth. By comparison, negative or decreasing patterns suggest unsustainable paths in that natural resource depletion is fueling economies without turning those natural resources into other types of capital. Therefore, BRI full, Asia, Europe, Africa, and Middle East countries should maintain positive green savings for the green development path. Moreover, findings endorse that China has addressed the issue of green development in Eurasia by the BRI intention as the key to succeeding mutual goals (Brautigam and Tang 2014). As a means of achieving prosperity and green development, BRI regional transition at multilateral cooperations can be seen as a doorway to escalating green economic activities. Interestingly, the overall findings align with the Ecological Modernization Theory (EMT), Institutional Theory, resource curse, and early-stage Environmental Kuznets Curve (EKC) hypothesis, with empirical evidence supporting the observed regional differences.

The System GMM findings are robust with 2SLS and indicate that multilateral integration regional transition has a significant positive effect on GD at a significant level of 5% in the overall BRI full sample, while in region-wise regional transition also shows a positive and significant effect but varies at the significance level. Therefore, a percentage increase in multilateral integration leads to a corresponding improvement in green development and its underlying elements in BRI full, Asia, Europe, Africa, and Middle East countries. Therefore, its findings are consistent with (Huh and Park 2021; Naeher and Narayanan 2020; Park and Claveria 2018b); they claimed that multilateral integration can facilitate the expansion of markets, improve the allocation of resources, and create more chances for investment and output. Also, it shows that multilateral integration of regional transition is the primary engine of economic growth and that multilateral integration greatly enhances it. Results imply that multilateral integration might promote economic growth more successfully. We accept the alternate hypothesis that the regional transition of multilateral integration at multiple levels has a significant positive influence on GD. Hence, Huh and Park (2021) concluding remarks suggest that multilateral integration attempts to reduce poverty through the development of financial resources and a rise in income per capita level may still be a good development strategy stepping stone for global integration. Our findings endorse the Shan and Wang (2019) discourse by rigorously examining energy governance within BRI projects, scrutinizing the alignment of energy infrastructure with enduring sustainability objectives, and noting that many BRI energy projects, despite their economic advantages, may intensify reliance on fossil fuels instead of promoting renewable energy alternatives. This issue is central to the debate on green progress, as energy investments, which are a key facet of the regional transition index, play an essential role in advancing or hindering the transition to low-carbon economies. By integrating this critique, this study can more effectively address the environmental consequences of BRI energy investments and the extent to which these initiatives have advanced global carbon neutrality and climate change. Furthermore, endorse the scholarly work (Khanal and Zhang 2024; Ren et al. 2025; Wang and Liu 2024) on multilateral cooperation within the BRI framework has yielded mixed findings. Although certain studies indicate the significant positive potential of cooperative efforts in fulfilling climate-change goals, they highlight the obstacles posed by conflicting national priorities and institutional deficiencies.

Further sub-indexes of multilateral regional transition findings depict that the regional business value chain index (RVCI) significantly impacts GD at a 1% significance level. Many nations, especially the smaller emerging ones, want business value chains in order to minimize any potential bad consequences of globalization while maintaining their profit from multilateral commerce. This takes place when nations involved in regular supply chains split apart from regional trade accords more frequently. In comparison, the infrastructure and connectivity index (ICI) indicates a significantly positive influence on GD. Therefore, infrastructure-driven development theory suggests that technological innovation growth should be stimulated in the areas that lag in socio-economic development in BRI countries. Further, outcomes show that TII and ISI have a significantly negative influence on green development. Trade and investment activities have the potential to enhance industrial activity; however, in the absence of stringent regulations, they may contribute to pollution, the overexploitation of natural resources, and environmental degradation. For instance, foreign investments in sectors such as manufacturing and resource extraction can precipitate increased emissions or ecosystem depletion when environmental protection is insufficient. The expansion of international trade can lead to an increase in transportation-related emissions (e.g., carbon emissions from shipping or air transport), thereby undermining green development objectives such as reducing carbon emissions and promoting sustainability. The primary objective of trade and investment is economic growth, which frequently neglects sustainable practices. This prioritization of short-term economic gains may jeopardize the achievement of long-term environmental sustainability objectives. In circumstances where institutions tasked with enforcing environmental regulations are weak or ineffective, the amplified influence of institutional and social dynamics could result in the inadequate enforcement of environmental standards. Consequently, this would allow businesses to circumvent environmental obligations, adversely affecting green development. Social factors, including resistance to environmental regulations, insufficient public awareness, and support for environmentally friendly initiatives, can impede the implementation of sustainable practices. A disconnect between social infrastructure and sustainability goals, such as inadequate education or a lack of incentives for eco-friendly behavior, can obstruct progress toward green development. Social inequality may exacerbate environmental justice issues. When particular social groups or regions suffer disproportionately from environmental burdens such as pollution, they can lead to social unrest or reduced public support for green development policies. Results imply that institutional frameworks, connectivity, and intraregional infrastructure integration affect economic performance (Huh and Park 2021).

Besides that, the movement of people index (MOPI) has an insignificantly positive influence on GD. However, money and finance integration (MFI) indicates insignificantly negative impacts on BRI countries' green development from 2006 to 2021. Our outcomes endorse Huh and Park (2017) concluding remarks that increasing people's mobility, supporting regional public goods, developing infrastructure, based on green investments, and financing policy collaboration can do multilateral transition. Therefore, findings imply that trade and investment should not receive more emphasis than other aspects on the green perspective of development; therefore, countries should invest in green projects. Also, multilateral regional transition cannot proceed without institutional and social transition. Moreover, as suggested by Huh and Park (2021), there are numerous ways in which economic integrated transition should be implemented, such as promoting green investment and trade, developing infrastructure, improving human mobility, increasing the supply of global public green products, and providing the institutional and legal framework for cooperation in international affairs for the net-zero path. As a first step toward greening a sustainable future, this study proposes that strengthening multilateral regional transition might still be a viable development strategy and suggests that the advantages of global green economy transition might be greater for emerging nations. Developing nations engage in greater trade and investment with their extra-regional partners than they do with other nations. Therefore, green development and sustainable opportunities are impossible without green initiatives such as shared green economy, green investment, trade, green finance, business, value chains, and institutional relations with neighboring and other countries.

Other factors outcomes indicate that financial capital mobilization has a significantly positive influence on GD, which shows that an increase in financial capital mobilization for green projects will positively improve BRI countries' green development. The results support the alternative hypothesis that has been put forth and are consistent with earlier findings (Hess 2010; Kaimuri and Kosimbei 2017; Koirala and Pradhan 2020); they discovered that there was a notable favorable influence of financial proxy on green development. The conclusions are established by the finding of Ali et al. (2021), as they also observed that financial institutions' inclusion as a component of financial capital has a considerable favorable effect on economic development. Also, the results align with Usman et al. (2021), which validated that financial institutions' inclusion boosts ecological sustainability. Simultaneously, natural capital intensity as resource rent outcomes has a significantly negative effect on GD. It shows that BRI countries are utilizing their natural resources inefficiently. Hence, zero-carbon projects should focus on improving energy efficiency. The results align with the study conducted by Koirala and Pradhan (2020) and Ahmad et al. (2024); their findings endorsed concluding remarks that sustainability entails preserving a reasonable balance of natural resources. They contend that bridging the present and future requires the rental of natural resources. Therefore, BRI countries must concentrate on balanced consumption without harming natural resources while protecting against environmental degradation in BRI countries. The differential impacts of BRI participation in Africa and the Middle East raise concerns regarding the environmental implications of large-scale infrastructure investments. Trade openness is integral to regional supply chain dynamics, influencing value chain integration and economic development without immediately catalyzing environmentally sustainable outcomes.

Notably, the results imply that BRI projects in the region may in fact coincide with environmental degradation, ineffective resource allocation, and the expansion of unsustainable high-carbon infrastructure and energy projects. In this context, the necessity for green finance, advanced technological governance, and strong institutional reinforcement becomes increasingly vital—to ensure that regional transitions truly promote green development on a global scale. Furthermore, trade openness is a crucial factor in regional supply chain dynamics, influencing value chain integration and economic development, albeit without immediately triggering green outcomes. Governance by technology has a significant positive influence on green development. It suggests that multilateral regional transition enhances the e-government framework in BRI nations. The outcomes support the concept that governments should take preventive measures and provide technology-enabled services to raise local healthcare and living conditions. Besides that, institutional governance (WGI composite) demonstrates a strongly favorable effect on green development.

The study posits the Environmental Kuznets Curve (EKC) hypothesis as suggested by Sun et al. (2011), Sarkodie and Strezov (2018), Liu (2018), Wang et al. (2024), Guo and Shahbaz (2024) that transformation is driven by regional transition and reforms in institutional and governance structures, necessitating a comprehensive examination of regional transition mechanisms to understand the trajectory of green development in BRI countries. Moreover, findings endorse the ecological systems theory, which posits that human-environment interactions are characterized by complexity, interconnection, and dynamic interplay, providing an additional perspective for evaluating the impact of BRI projects on green development outcomes. This theoretical framework emphasizes the intricate interdependencies among social, economic, and environmental systems, suggesting that sustainable development requires a holistic approach encompassing the full spectrum of ecological, economic, and social dynamics. Institutional theory, which examines the dynamic ways in which institutions shape behavior and outcomes, serves as an essential framework for understanding the varying success rates of multilateral green development initiatives within the BRI.

The pivotal findings concerning RT align significantly with the theories underlying regional integration, suggesting that a complex, multidimensional approach to regional cooperation that encompasses economic, political, and technological domains is essential for advancing green development. The assertion that regional integration substantially promotes sustainable development is strongly supported, particularly in the dynamic context of Asia and Africa, where the integration of diverse sectors significantly enhances green development. Regional variations indicate that while technology-enabling and economic factors are universally significant, governance and competitive dynamics vary considerably across regions, underscoring the necessity for meticulously crafted, tailored policies for green development in each distinct region. These findings emphasize the substantial value of regional integration theory, highlighting the critical nature of transnational collaboration and resource sharing in promoting green initiatives, especially in dynamic regions such as Asia and Africa. Concurrently, the regionalization theory elucidates the potential constraints or advantageous features inherent to unique regional identities and governance structures, as exemplified in the Middle East. Global integration functions as the primary catalyst for disseminating green technologies and policies, influencing regions to varying degrees, as evidenced by Europe's slightly diminished impact on RT, potentially reflecting its profound entrenchment in global green development frameworks. Lastly, global integration theory intricately interweaves global currents of technology, finance, and policy into regional developments, demonstrating how global interconnectedness can significantly shape local green development outcomes. The dynamic interplay between these theories provides a comprehensive understanding of how both intrinsic regional dynamics and overarching global factors influence regional transitions to green development.

In addition, the effect of BRI spillover before and after the dummy indicates that BRI significantly contributes toward the green development of the partner countries. The BRI policy of 2013 was a positive instrumental shock as a time effect and contributed substantially to partner countries' sustainable green development path. Therefore, concerning the BRI multilateral transition to green and sustainable future outcomes of BRI before and after effect, Tambo et al. (2019) conclude that BRI has developmental effects. This policy change has altered infrastructure development, trade partnerships, and financial collaboration between participating countries, influencing economic transitions without directly steering sustainability policies. Its inclusion reinforces the econometric strategy by providing a quasi-exogenous source of variation in regional transition dynamics. Hence, the BRI is a multilateral initiative that aims to promote green development in the 21st century. This global initiative promotes environmentally sustainable green development internationally. BRI helps the global reach of technology and information, facilitating trade and commerce as well as human capital. It increases energy resources and moves the world closer to development driven by planetary health, which will lead to long-term economic growth. In fact, multilateral integration has accelerated and grown alongside globalization by BRI integration.

5 | Conclusions

This study delves into the effect of regional transition and its multilateral sub-indexes on green development across 64 nations (21 Asia, 22 Europe, and 21 Africa and Middle East countries) including participation in the integrated BRI spillover from 2006 to 2021. Employing two robust econometric methods, namely the two-step system GMM and the 2SLS estimation method, the Sargan and Hansen tests confirmed the instruments' validity and reliability. The AR-1 and AR-2 values indicated no autocorrelation, underscoring model consistency. This research reveals insightful dynamics within integrated green development pathways, aligning with sustainable development theory. The estimations indicate a significantly positive relationship between regional transition and green development. This supports the notion that as nations within the Belt and Road region deepen economic transition, they tend to bolster integrated green development, thus affirming regionalization development theory.

However, the study also uncovers nuanced nuances within specific sub-indexes of multilateral cooperation. While intra-regional trade and investment, as well as institutional and social factors, exhibit significant impacts on integrated green development, these effects lean toward the negative side. Conversely, the study identifies a strong and favorable correlation between infrastructure and connectivity and green development outcomes. Moreover, the movement of people within the Belt and Road countries shows a marginally significant yet positive effect on green development. This study significantly advances our comprehension of economic cooperation and green development by furnishing empirical evidence of the positive impact of regional transition on green development. Nevertheless, the mixed effects observed within the sub-indexes of regional transition at the multilateral level necessitate nuanced policy considerations. These findings can inform theoretical frameworks and provide valuable insights for policymakers and stakeholders involved in multilateral cooperation initiatives.

The findings of regions underscore that regional transition is a fundamental driver of green development, particularly in developing regions where economic changes are directly correlated with sustainability outcomes. However, the efficacy of regional transition efforts is influenced by several key factors, including governance quality, financial mobilization, natural capital intensity, and the role of international economic initiatives such as BRI. Noteworthy findings from the control variables shed light on additional dimensions. The mobilization of financial capital, governance-by-technology, and institutional governance all positively influence green development in BRI nations. Conversely, the study highlights the detrimental impact of inefficient utilization of natural resources in the BRI region, as indicated by the significant yet adverse effect of green resource productivity on green development. Furthermore, the research underscores the substantial contribution of the BRI to green development in partner countries, both pre-d post-introduction of the BRI spillover variable, emphasizing its positive impact on the green development of the sustainability landscape.

In Asia, policymakers must prioritize integrating the sustainability of the green transition into competitiveness strategies to ensure that economic growth does not compromise environmental progress. In Europe, efforts should be directed toward enhancing financial incentives for green transitions as existing policies may have reached saturation. Meanwhile, Africa and the Middle East must prioritize institutional and governance reforms to better leverage technological governance and financial capital for the sustainability of green development.

Our results are consistent with the Ecological Modernization Theory (EMT), Institutional Theory, resource curse, and early-stage EKC hypothesis, while empirical assessments confirm the observed regional differences. The varying impacts of BRI involvement underscore the necessity of enhanced environmental governance frameworks in international development initiatives. By addressing these institutional and financial issues, regions can enhance the sustainability of their transition and expedite global green development. Ecological Modernization Theory (EMT) suggests that advancements in the economy and technology, and institutional reform can lead to environmental enhancement, where regional transition supports green development by advancing industrial restructuring, technological innovation, and policy changes. Hence, the carbon neutrality effect, while simultaneously promoting host countries' industrialization.

To mitigate climate risks, countries participating in the BRI focus on integrating natural resource management into institutional reforms to ensure sustainable and green development. Regions in different developmental stages require customized sustainability policies: Asia needs stronger governance, Europe must maintain leadership, and Africa and the Middle East must enhance institutional capacity. Global collaboration is essential to ensure resource-rich economies avoid resource curses and leverage their natural capital for long-term green growth. The negative impact of BRI participation in Africa and the Middle East raises concerns about the environmental consequences of large-scale infrastructure investments. To address this, BRI projects should incorporate stronger environmental governance mechanisms and adhere to global sustainability standards to mitigate negative ecological impacts. Green finance, technological governance, and institutional strengthening are critical to ensure that regional transitions foster green development worldwide.

While this research provides significant insights, it is not without limitations. The study's scope is confined to the 64 countries participating in the BRI and adheres to the triple bottom rule, potentially limiting generalizability. The focus of the industrial economy shifts toward green and low-carbon sectors. Therefore, future research endeavors could enrich our understanding by exploring the role of innovation, considering finance-enabling technologies, digital transformation, and technological innovation while also incorporating a time-varying dimension at global and regional income group levels on green development and low-carbon sectors. Although the interaction effects between regional transition and green development have the potential to be nonlinear, the linearity of the 2SLS models often simplifies the analyzes, making relationships easier to interpret. However, exploring nonlinear models in future research could determine whether the linearity assumption imposes excessive constraints.

Moreover, the operationalization of key variables, particularly "green development" as measured through adjusted net savings, is both innovative and a limitation. While the study's reliance on the adjusted net savings index aligns with recognized academic standards and provides a consistent framework for cross-national comparisons, it does so at the expense of a broader understanding of sustainability outcomes. Adjusted net savings, though comprehensive in integrating economic, social, and environmental factors, may underrepresent certain critical dimensions of green development, such as ecosystem health, carbon neutrality, and biodiversity preservation. Incorporating alternative metrics, such as carbon footprint reduction, renewable energy adoption rates, or biodiversity indices, could offer a more holistic view of green development. These metrics capture diverse aspects of sustainability that adjusted net savings might overlook. For instance, biodiversity indices would provide insights into ecological resilience, while carbon metrics would highlight progress in mitigating climate change; a critical element given the paper's focus on sustainability within BRI. However, it is important to acknowledge practical constraints that prevent such revisions from being fully realized within the scope of this study. The paper's reliance on existing datasets and econometric methods imposes limitations on the inclusion of these alternative measures, as many of the suggested metrics are unavailable or incomplete across countries over the long-term panel data. This constraint is particularly significant in cross-national studies, where data standardization and availability are perennial challenges. Similarly, modifying the dataset to incorporate new variables would necessitate substantial methodological adjustments and potentially undermine the study's econometric rigor. To address these limitations within the scope, future research could provide supplementary discussion on sector index construction work by acknowledging the trade-offs inherent in their chosen measurement approach worldwide and comparing them with regions.

Author Contributions

Atta Ullah: conceptualization, data curation, formal analysis, investigation, methodology, software, roles/writing – original draft, visualization, writing – review and editing. **Haitham Nobanee:** conceptualization, funding acquisition, supervision, validation, visualization, writing – review and editing, project administration, resources. **Saif Ullah:** methodology, investigation, roles/writing – original draft, visualization. **Saba Khan:** conceptualization, investigation, roles/writing – original draft, visualization.

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Conflicts of Interest

The authors declare no conflicts of interest.

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Appendix A

List of Countries

#	Country	#	Country	#	Country
1	Mainland China	23	Armenia	45	Egypt
2	Mongolia MNG	24	Azerbaijan	46	Israel
3	Pakistan	25	Belarus	47	Jordan
4	Bangladesh	26	Bulgaria	48	Kuwait
5	Bhutan	27	Croatia	49	Lebanon
6	India	28	Czech Republic Czechia	50	Oman
7	Nepal	29	Estonia	51	Qatar
8	Sri Lanka	30	Georgia	52	Saudi Arabia
9	Brunei	31	Hungary	53	Algeria
10	Cambodia	32	Latvia	54	Burkina Faso
11	Indonesia	33	Lithuania	55	Djibouti
12	Laos Lao PDR	34	Macedonia	56	Ethiopia
13	Malaysia	35	Moldova	57	Gambia, The
14	Myanmar	36	Poland	58	Mali
15	Philippines	37	Romania	59	Mauritius
16	Singapore	38	Russian Federation	60	Morocco
17	Thailand	39	Serbia	61	Rwanda
18	Vietnam	40	Slovakia/Slovak Republic	62	Senegal
19	Kazakhstan	41	Slovenia	63	South Africa
20	Kyrgyzstan Kyrgyz Republic	42	Turkey	64	Kenya
21	Tajikistan	43	Ukraine		
22	Albania	44	Bahrain		

Appendix B

Measurement of Variables

Indicator	Data description, measurement, and followed studies	Data website
Integrated green development	$\text{ANSR} = \frac{\text{NNS} + \text{CSE} - \sum R_{n,\ i} - \text{CD}}{\text{GNI}}$ Where, GANS = Green-Adjusted Net Saving Rate, NNS = Net National Savings, CSE = expenditure on education, $R_{n,i}$ = Damages of natural capital I (mineral depletion + energy depletion + net forest depletion), CD = Damages from carbon dioxide and particulate emissions, GNI = Gross National Income at Market Prices. GANSR is the fraction of GNI and is found by dividing adjusted net savings (ANS) by GNI. Where, Net national savings (NNS) = (Gross national saving − consumption of fixed capital). The World Bank staff, based on the Changing Wealth of Nations 2018: Building a Sustainable Future, described sources and methods (Lange et al. 2018). Green development measured through ANS (adjusted net saving) proxy followed (Hess 2010; Kaimuri and Kosimbei 2017; Koirala and Pradhan 2020; Pardi et al. 2015) and (Afshan et al. 2024; Feng et al. 2023; McGrath et al. 2024).	World Development Indicators-WDI, World Bank
Regional transition	Regional Transition at Multilateral level index based on the six sub-indexes PCA which emphasized by several studies (Huh and Park, 2018, 2021; Naeher and Narayanan 2020; Park and Claveria 2018a, 2018b). (1) Intra-regional trade and investment index. (2) Money and finance index. (3) Regional value chain index. (4) Infrastructure and connectivity index. (5) Movement of people index. (6) Institutional and social index.	Asian Development Bank; World Bank; IMF; Bloomberg; United Nations
Financial capital mobilization (FCM)	Proxied IMF's recent composite comprised of financial markets and institutions development, depth, access, and efficiency were used. Proxy followed (Ahmad et al. 2024; Antwi et al. 2024; Koirala and Pradhan 2020; Svirydzenka 2016).	International Monetary Fund (IMF)
Natural capital intensity (NCI)	Total natural resources rent (TNNR). This proxy measured for the richness of the resources as a percentage of GDP (Koirala and Pradhan 2020). TNRR, as a percentage of GDP, is the sum of rents from natural gas, oil, minerals, coal (hard and soft), and forest rents.	World Bank
Governance-by-technology (Gov-by-Tech)	Governance-by-Technology (Gov-by-Tech) is based on the E-government development index, which is comprised of the three most noteworthy components: Online Service Index (OSI), online participation, human capital, and telecommunication infrastructure (TII). Recent studies suggested this proxy (Faid et al. 2020; Máchová et al. 2018; Rehman et al. 2018).	UN E-Government Knowledge Database
Institutional Governance (WGI)	PCA Index of Governance is comprised of the rule of law, government effectiveness, voice and accountability, political stability and absence of terrorism, regulatory quality, and control of corruption (Fluckiger et al. 2019; Pardi et al. 2015; Stojanovic et al. 2016).	World Bank, World Governance Indicators-WDI
Institutional quality (ICRG)	Institutional quality is a PCA composite of alternate six governance indicators: quality of the bureaucracy, stability in government, investment profile, corruption, law and order with democratic accountability (Kutan et al. 2017).	International Country Guide Risk-ICRG Data
BRI spillover	BRI Spillover effect is measured before and after the initiative dummy period. From (2006–2012) counted zero while in the start year, and after that, 2023–2021 was given one.	Authors estimations