



# Transition towards the sustainable development: unraveling the effects of mineral markets, Belt & Road Initiative, and the Paris Agreement on green economic growth

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## ABSTRACT

The Agenda 2030 strongly emphasizes implementing effective and equitable measures to address the urgent challenge of global warming, primarily driven by unsustainable fossil-fuel combustion, and one of its core focuses is Sustainable Development Goal (SDG) – 8, among others. In light of this, the recent article aims to explore the dynamic nexus between minerals (MNR), the Belt and Road Initiative (BRI), the Paris Agreement (PA), green technologies (GT), and green growth, with a specific focus on developing a policy framework for advancing SDG – 8. The study utilizes daily data and advanced econometric tools such as QVAR, Cross-quantilegram, and wavelet-quantile correlation to examine the diverse effects of these factors on green growth across various time horizons. The short-run analysis reveals that MNR, BRI, and GT discourage green growth under most market conditions, except for a few quantiles that exhibit positive or insignificant relationships. In the medium run, impacts are mixed, with both positive and negative effects observed. However, in the long run, MNR, BRI, and GT consistently demonstrate favorable effects on green growth. For PA, short and medium-run effects are mixed, but medium-run results indicate a predominantly positive impact on green growth. In the long run, PA significantly benefits green growth across the majority of market conditions. Overall, the diversified results suggest that minerals, BRI, the Paris Agreement, and green technologies play a crucial role in stimulating green growth to achieve SDG - 8 in the long term.

## 1. Introduction

The fundamental vision of global economies is intrinsically bound to the noble objective of pursuing sustainable development. In light of this, international authorities have consistently and resolutely mobilized their efforts, playing a crucial role in contributing to the multifaceted tapestry of economic growth observed over the past six decades. For instance, in 1960, the global GDP was \$459 (per capita), which increased by 2705% and became \$12875 (per capita) in 2022, as documented by the IMF (2023). Also, it is projected by the IMF (2023) that global per-capita GDP will reach \$14,550 in 2025. The enhancement in global income, living standard, and basic necessities of life apart, the pacy GDP growth is continuously provoking environmental catastrophes (The Economist, 2022) on account of deploying a massive amount of fossil fuel-based energy. Therefore, the United Nations (2023) reported that most global economies suffer from environmental

degradation and face significant challenges to achieving SDG-13 (green environment), as Fig. 1 visualizes the overall scenario. Since environmental catastrophes lead to climate change, cultural and spiritual losses, habitat destruction, soil degradation, and the loss of biodiversity, global environmentalists call on global authorities and policymakers to take serious measures to obtain SDG-13 and minimize the environmental degradation ratio.

The policymakers engaged in discussions regarding the detrimental environmental situation can be broadly categorized into two doctrines: the 'Green Growth Advocates' and the 'No Growth Advocates' (Fouquet, 2019, p. 21). Although the scholars of both bunches admit the various detrimental repercussions of environmental degradation, they proposed different methods in order to deal with the environmental exigencies. For example, the doctrine of green growth advocators (GGA) argues that the current global economic and environmental systems can be revamped by promoting green economic growth. To this end, GGA counsels

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the authorities to promote green energy sources (viz., geothermal, solar, wind, and hydrogen) by subsidizing green technologies through green finance and rejecting the deployment of fossil fuel-based energy through levying carbon taxes. This process, ultimately, can promote green economic growth, disrupting the harmful effects of environmental contamination.

Contrarily, the doctrine of no growth advocates (NGA) heatedly contradicts the GGA and contends to retard the GDP growth by hampering economic activities. It will decrease the use of fossil fuel-based energy and, eventually, enhance the environmental quality by impeding carbon emissions and other greenhouse gases (Fouquet, 2019, p. 21–27). Comparing both doctrines, it can be conjectured that GGA lodges a suitable and comprehensive path to bring off sustainable and green development by promoting green economic growth and suggesting viable strategies. However, the NGA doctrine is equivocal due to not providing the feasible and proper planning to handle the issue of environmental contamination.

Also, reinforcing the GGA's stance, the United Nations (UN) took a significant step in 2015 by introducing SDG – 8 (green economic growth), aiming to drive an effective shift towards green growth to achieve SDG-13 (green environment) by enhancing economic along with disrupting the greenhouse gases (GHGs). In alignment with the UN's suggested SDGs, global economies tended to take several measures to obtain SDG-8 and eventually achieve SDG-13. However, most of the world's economies suffer from significant and major challenges related to green growth. A recent report by the UN (2023) documents that approximately all global economies are far from achieving SDG-8, as Fig. 2 depicts the contemporary scenario.

The preceding discourse plainly indicates that targeting SDG – 8 is imperative in order to acquire SDG – 13. The subtleties of this discourse were evident in the recent discussions at the COP27 Summit, where all countries were encouraged to reaffirm their commitment to restricting the global temperature increase to 1.5 °C above pre-industrial levels (The United Nations Climate Change Conference, 2023). Thus, the recent study endorses the adoption of the GGA stance and further advocates that green economic growth presents an auspicious approach to attaining green development and ultimately realizing a cleaner environment. Hence, the recent study aims to explore the vital drivers of green economic growth in order to draw the appropriate policy recommendations to the global authorities for global sustainable development and environment.

Attaining green economic growth is a crucial requirement for accomplishing the objectives of SDG 8, which will further aid in achieving the goals of SDG 13. The green growth process can assist not only in shifting the production pattern from fossil fuel-based energy to green energy but also in disrupting the GHG ratio. Based on the scholarly discourse documented in the United Nations' Sustainable Development

Goals Report, 2023, it can be surmised that global economies demonstrated a substantial policy lacuna in accomplishing the SDGs – 8 and 13 objectives. In the COP27 summit, global leaders also emphasized divulging viable policy solutions to boost the green growth process to acquire sustainable development and a green environment (Sustainable Development Goals Report, 2023). In addition, the report stipulates the *Breakthrough Agenda* that prioritizes replacing conventional energy-based production systems with cleaner technology-based energy sources to promote green growth. This replacement might lead to obtaining the SDG – 13. However, such a transition to green growth necessitates clean technologies, a favorable policy environment, and global economic prosperity initiatives. The *International Renewable Energy Agency* suggests a *multi-stakeholder approach* that outlines the essential requirements for achieving global economic growth (IRENA, 2023).

The *Breakthrough Agenda* accentuates the diffusion of green technologies for green growth by injecting them into agriculture, electricity, hydrogen, steel, and transport sectors (Chen et al., 2023). Such measures may generate green jobs by initiating green development projects and attracting investment in sustainable initiatives. Now, in order to effectively disseminate green technologies, these projects will necessitate access to technological advancements, green funds, and a favorable policy environment, as highlighted in the COP27 summit (The United Nations Climate Change Conference, 2023).

The utilization of green technologies necessitates the acquisition of minerals for the production of fundamental materials (Irfan et al., 2023). To expedite the process of green technologies through technological advancements, the mineral market can play a fundamental role as it provides crucial raw materials for their development. A report by the World Bank (2019) indicated that the production of minerals such as graphite, lithium, and cobalt increase by roughly 500% by 2050 in order to green technologies' demand. Further, it is highlighted in the report that nearly 3 billion tons of minerals and metals will be needed to deploy wind, solar, geothermal, and energy storage for a below-2°C future. Further, neodymium, dysprosium, and terbium are essential to make wind turbines and electric car motor magnets. Rechargeable electric vehicles and energy storage batteries use lithium, cobalt, and nickel. Solar panels generate energy from silicon. Tungsten, platinum, and palladium reduce energy consumption and emissions in catalytic converters and lighting (Burton et al., 2024; Singh and Chaudhary, 2023; Shao et al., 2024). To recapitulate, mineral markets might be a vital pillar for obtaining a green and sustainable future by providing essential raw materials for producing various eco-friendly technologies.

Realizing the full potential of innovation and financialization in driving green growth requires a favorable policy environment. Such policy tools may be in the form of environmental taxes, environmental subsidies, and environmental awareness and these tools might be called

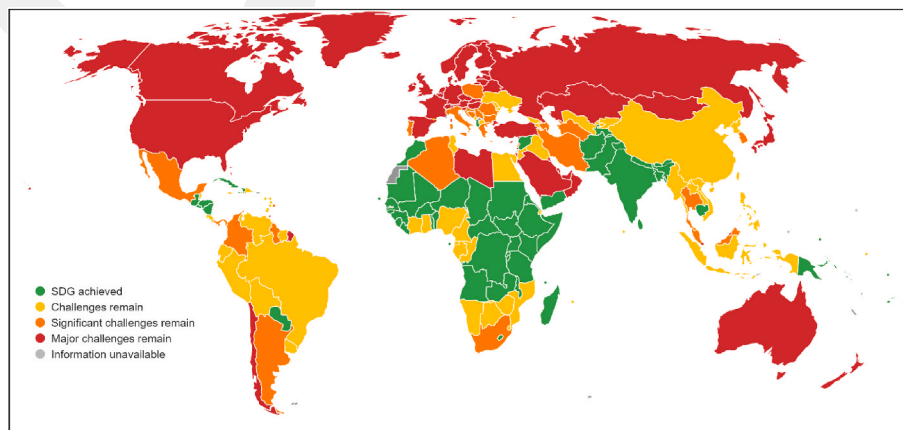


Fig. 1. Global scenario of SDG-13. Source: SDG Dashboard (2023).

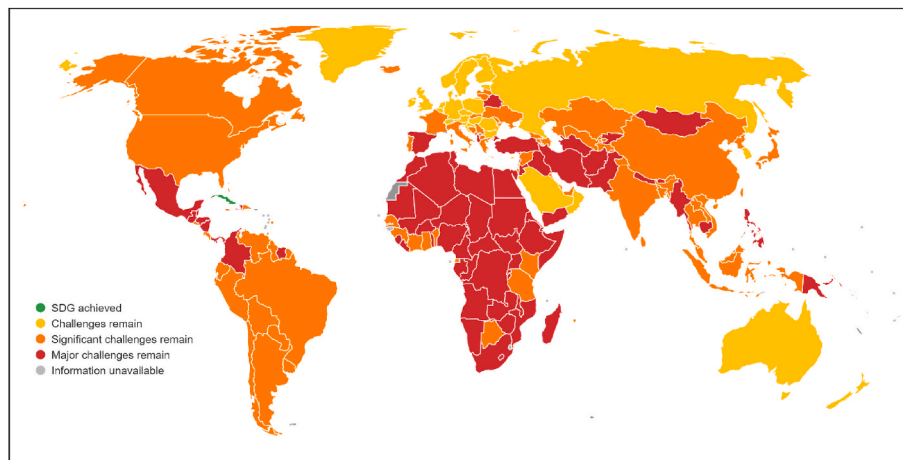


Fig. 2. Global scenario of SDG-8. Source: SDG Dashboard (2023).

“environmental policies.” These environmental policies might play a critical role in achieving green growth by supporting green technologies through green subsidies and discouraging fossil-fuel-based energy sources through environmental taxes. In this context, a global accord, the “Paris Agreement”, was signed in 2015 (The United Nations Climate Change Conference, 2023) in order to obtain SDGs 8 and 13 by triggering green development and curtailing the GHGs. The Paris Agreement, as global environmental policy, might contribute towards achieving the SDGs through the *International Financial Mechanism* (which allows green financing to developing nations) and the *Clean Development Mechanism* (which encourages developed nations to enhance green investment in developing nations) (Pata and Ertugrul, 2023). From both financial and developmental mechanisms standpoints, the Paris Agreement can be an indispensable tool for achieving successful global green growth.

Not only global environmental policies such as the Paris Agreement but also global and regional development projects have the potential to contribute to the SDGs, specifically SDGs 8 and 13. Such projects might be the source of transferring knowledge, innovation, and green investment projects across the nations (Chen et al., 2023); eventually, this process tends to expedite green growth by enhancing energy efficiency. In this context, the Belt and Road Initiative (BRI), as a global grand development project, might be a significant contributor to accelerating the global green growth process. A report by the *Green Belt and Road Initiative Center* (2023) and *The Boston University* (2023) documents that Chinese policymakers have been diligently crafting an *environmental management framework* to govern their outbound investment and finance, with the purpose of “greening” the BRI and assisting countries in obtaining the 2030 Agenda for green growth and environment. Thus, BRI might be a vital global grand project for boosting the green growth to obtain SDG – 13.

The preceding discourse raises some lacunas that might be vital to address for policy recommendation purposes. For instance, the effects of minerals on green growth are less explored and might depend on the structural dynamics of the economy. Therefore, it is important to investigate the time-varying effects. Similarly, when analyzing the dynamic effects of minerals, considering global environmental policies like the Paris Agreement becomes crucial as a novel driver to explore the time-varying influence of environmental regulatory authorities on green development. Additionally, the global economic development initiative, such as the Belt and Road Initiative (BRI), emerges as another new driver of green growth that cannot be overlooked. It serves as an important source for sharing knowledge and technologies. The Paris Agreement and the BRI are global environmental and economic development projects; therefore, it would be more meaningful to conduct a global-level analysis for drawing policy recommendations. This is unlike prior

literature, which did not explore the impacts of the BRI and the Paris Agreement on green growth. Furthermore, the effects stemming from minerals, the Paris Agreement, and the BRI might be nonlinear in nature. However, the pertinent literature could not provide plain insights regarding these thrust areas. Given the potential significance of mineral markets, the Paris Agreement, and the BRI in achieving sustainable and green growth, it is crucial to disseminate research in these areas to propose appropriate policies for the urgent task of promoting green economic growth. Thus, the recent article posits the following query:

Research Question: *How do the minerals, Paris Agreement, and BRI influence green economic growth over-time?*

In order to address the above query for assessing the future of green growth, the recent study extends the pertinent literature in the following ways: First, this is the first study, to the best of our humble knowledge, that seeks the nonlinear and time-varying effects of minerals on green growth. A few studies endeavor to explore the influence of mineral markets; however, they focus on the indirect effects and over-look the nonlinearities that could impede the accurate formulation of policy recommendations. Second, again, this is the first research document that explores the time-varying effects of BRI on green growth. To this end, the study erects an index to measure the influence of BRI rather than relying on the dummy variable approach to avoid the likely biasness. Third, again, this is the first study that explores the dynamic effects of the Paris Agreement on green growth, and to this end, the study deploys a new index to measure the Paris Agreement’s influence. Fourth, this is the first research document that analyzes the impacts exerted by minerals with consort of BRI and the Paris Agreement on green growth at the global level in order to draw policy recommendations for global authorities.

Fifth, an appropriate econometric methodology is necessary to drive suitable policy recommendations by considering the likely nonlinear and time-varying nexus. The nexus among the modeled series might be nonlinear and subject to change over time. In this situation, the application of linear methods is inadequate for handling both the characteristics of the variables, and as a result, the outcomes may be inconsistent and biased (Sun et al., 2023a,b). Thus, the study tends to deploy advanced econometric tools such as Quantile Var (QVAR), Cross-quantilogram (CQ), and Wavelet Quantile Correlation (WQC) methods in order to attain robust and detailed results that can then be employed to draw suitable policy recommendations.

The remainder of the study is organized as follows. The second section reviews the pertinent studies to highlight the literature gap, followed by the third section that underpins the theoretical channels to formulate the econometric model. In the fourth section, econometric methods and data are discussed. The fifth section represents the findings and discussion, followed by the section of conclusion.

## 2. Literature review

The prospect of green economic growth in an economy hinges on the policymakers' perception of sustainable development. This realization drives the orientation of policy instruments while aiming at catalyzing green growth. In this regard, numerous catalyzers, including minerals and green technologies, can play a vital role in boosting the green growth process. Beyond these local catalyzers, there may be some global indicators, such as the Paris Agreement and BRI, which can also influence the ratio of green growth. In this context, the present heads to review the pertinent academic literature in order to highlight the logical research gap to be addressed. Thus, this segment is classified into green growth and mineral markets, green growth and the Paris Agreement, green growth and BRI, and green growth and green technologies.

### 2.1. Green growth and green technologies

In every economy, green growth demands a deliberate approach to technological development underpinned by a steadfast commitment to environmental inclusivity. To do so, the academic literature indicates that the innovation process can play a vital role in achieving the solution that paves a robust path toward accomplishing green growth. In this regard, the pertinent literature can be classified into two bunches. The first bunch of literature endorses the development of technological innovation for attaining green growth, while the second bunch emphasizes the development of green technologies.

As for the first bunch, it argues that technological innovation can contribute to green growth through indirect effects. For instance, it can lead to minimum resource combustion and efficient production methods (Wang et al., 2023a,b,c) through increasing the efficiency. This process leads to cutting down on carbon emissions and increases economic growth. Also, technological innovation can assist in enhancing agricultural methods that result in higher yields with fewer inputs (Herman, 2023; Hao et al., 2023), decreasing the environmental effects. In addition, the development in the transportation sector (such as electric and hydrogen-powered vehicles) on account of the innovation process helps in reducing GHGs and boosting economic growth (Wang et al., 2023a,b,c). Besides, Razzaq et al. (2023), Cao et al. (2022), Talebzadehosseini and Garibay (2022), Zhao et al. (2022), Zhou et al. (2022), Su and Fan (2022), Li et al. (2022), and Ma and Zhu (2022) also argue that technological innovation is capable of thriving the green growth by various indirect effects.

However, the second bunch of scholars contradicts and argues that green technological innovation (viz., solar panels, wind turbines, biodegradable materials, water-saving technologies, and efficient waste management systems) more efficiently contributes to empowering the green growth process by affecting it directly. Since green technologies are specifically designed with environmental sustainability in mind, these technologies can enhance green growth more effectively (Information Technology and Innovation Foundation, 2023). Thus, the most pragmatic approach to drive green growth is by advancing clean technologies, as suggested by the policymakers belonging to the second bunch. In this context, Ahakwa et al. (2023) take the sample of Asian economies to explore the dynamic effects of green technological innovation on green growth. The outcome-based on the advanced econometric methods plainly determines that the contribution of green technologies in expediting green growth is remarkable. The same results are documented by Wang et al. (2023a,b,c) for the various provinces of China. Additionally, Ullah et al. (2023), Sun et al. (2023a,b), She and Mabrouk (2023), Tian and Feng (2023), Li (2023), and Wu et al. (2022) analyze the influence of green technologies on green growth for various nations and deduce the direct significant association.

The preceding critical review exhibits that the scholars of both bunches have numerous anecdotal empirical evidence to support their stance. However, it can be inferred that the effects of green technological innovation on green growth might be more effective and logical.

Thus, the focus on the development of green technologies might assist in acquiring green growth in a more effective way as compared to technological innovation. This discourse encourages the study to develop the following hypothesis.

**Hypothesis 1.** Green technologies can support green growth progress over time.

### 2.2. Green growth and mineral markets

The adoption of environmentally friendly technologies requires the procurement of minerals for the manufacturing of essential materials (Irfan et al., 2023). The mineral market, which is crucial in supplying the essential raw materials required for their development, can facilitate the acceleration of green technologies through technological advancements. Consequently, this process accelerates the green growth. Further, the exploration of the nexus between green growth and minerals is not an old discourse, as the majority of the research documents focus on how economic performance responds to the mineral markets. Also, the majority of the studies rely on natural resources while investigating their effects on economic growth.

For instance, Yu et al. (2023a,b) utilized a sample of the top ten green energy-deploying nations in order to check the effects of natural resources. The results suggest that most of the selected economies gain significant economic benefits on account of their natural resources. The same results are documented by Hasan and Du (2023) for the province-level study of China. The results of studies by Zhao and Rasoulinezhad (2023), Li et al. (2022), and Vu et al. (2023) are also aligned with the aforementioned research documents. Contrarily, some scholars argue for the adverse effects of natural resources and minerals on economic growth. For example, Khan et al. (2023) take a sample of G-7 nations to explore the effects of natural resources and minerals. The study finds adverse effects exerted by minerals and natural resources on economic growth. Also, the same findings are inferred by Ahmad et al. (2023) and Mumuni and Mwimba (2023) for emerging nations and Africa, respectively. Another study by Çetin et al. (2023) observed the indirect adverse impact of natural resources on economic performance via the financial development channel.

Subsequently, some economists reinvestigated the effects of natural resources (including mineral effects) on green growth efficiency and observed positive effects, arguing that the studies reporting the adverse effects of natural resources and minerals may suffer from model misspecification issues. For instance, Zhao and Rasoulinezhad (2023) perform the investigation for BRICS, and similarly, Wang et al. (2023a,b,c) do the investigation for the 30 provinces of China. Both studies determine the favorable effects of natural resources on green growth. In a similar vein, Wei (2024) deploys the daily data and deduces that natural resources can play a vital role in triggering green growth by enhancing green technologies.

The preceding critical review plainly demonstrates that natural resources have the potential to expedite green growth, both directly and indirectly. Also, it can be inferred that the majority of the studies focus on natural resources while analyzing their effects on green growth. Additionally, the pertinent literature does not provide a broad view of the nexus between green growth and mineral markets in order to draw policy recommendations. The minerals might be a pivotal indicator of green growth, calling for exploration in this area. Further, based on the pertinent literature, it is observed that natural resources can play a considerable role in fostering green growth. Since minerals are part of natural resources, the study assumes to formulate the following hypothesis.

**Hypothesis 2.** The mineral markets are capable of fostering green growth.

### 2.3. Green growth and the Paris Agreement

It is tacit that the availability of resources and finance might play an essential role in expediting green growth by accelerating green technologies and green energy. However, this process requires an appropriate regulatory system to ensure the green growth process is effective. In this context, the recent academic literature indicated the critical importance of environmental regulations and policies in fostering sustainable economic growth. These policies encompass various approaches, such as command-and-control environmental regulation, carbon taxes, green subsidies, market-based environmental regulation, and public awareness initiatives (Sun et al., 2023a,b).

Considering the importance of environmental policies, the scholars analyze their plausible effects on green growth. For instance, Yang et al. (2023) suggest deploying a carbon taxation policy in order to boost the green growth process by disrupting the GHGs. The study utilizes data from 285 cities to investigate the influence of carbon taxation policy on green growth. The same results are also witnessed by Xu et al. (2023) in the case of China, suggesting that carbon taxation as an effective policy. Also, Chou and Liou (2023), Singh and Chaudhary (2023), Ran and Xu (2023), and Konradt and Weder di Mauro (2023) propose carbon taxation policy as an appropriate tool to attain the SDG – 8.

Subsequently to this, some scholars endorse the global authorities' adoption of the green innovation policy for green development. For example, Hao et al. (2023) recommend that green innovation policy can be an effective instrument to target clean growth as the study finds favorable impacts in the case of China. Additionally, Binh An et al. (2023) assess the influence of green innovation strategy on green development for advanced economies and the results support the stance proposed by Hao et al. (2023). Sadiq et al. (2023) and Yu et al. (2023a,b) also report the same results and advocate the enormous importance of green innovation policy. In a similar vein, some scholars suggest Pigouvian taxation (Debia et al., 2019), environmental governance (Hu et al., 2022), and Carbon Peak Policy (Chen et al., 2022) as sound tools to head to green development.

The above critical review provides circumstantial evidence indicating that environmental policies might assist global nations in achieving sustainable development through the various channels. In this context, the “Paris Agreement”, a significant global environmental policy established on December 12, 2015, stands out as a crucial catalyst for fostering green growth (Dogar et al., 2022). This international accord aims to unite nations worldwide in addressing global environmental challenges, fostering a collective effort towards sustainable development and a greener future. Thus, it is crucial to explore the effects of the Paris Agreement on green growth. However, the available literature could not provide any insight in order to analyze its influence on the green growth process. Just like other environmental policies, the Paris accord is adopted to accelerate the endeavors to minimize the detrimental repercussions of GHGs. It is assumed the positive externalities exerted from the accord on the green growth. Hence, the study tends to develop the following hypothesis.

**Hypothesis 3.** The Paris Agreement can trigger the progress of green growth over time.

### 2.4. Green growth and BRI

In addition to global environmental policies such as the Kyoto Protocol, both global and regional development projects possess the potential to make significant contributions towards achieving the Sustainable Development Goals (SDGs), particularly SDG-8 and SDG-13. These types of projects have the potential to facilitate the transfer of knowledge, innovation, and green investment projects between nations (Chen et al., 2023), accelerating green growth by improving energy efficiency. In this particular context, the Belt and Road Initiative (BRI), being a global-level development project, might play a significant role in

expediting the progress of global green growth.

In order to analyze the plausible effects of the BRI project, many scholars investigate how green growth responds to the various determinants in the BRI nations. To this end, the pertinent articles deploy several proxies, viz., green total factor productivity (GTFP), carbon emissions, ecological footprint, greenhouse gases, and carbon footprints, to quantify green economic growth. For example, Wang et al. (2023a,b,c) examine how natural resources and institutional quality affect GTFP in 48 BRI economies. The threshold panel technique shows that GTFP positively correlates with both independent variables' rising trajectories, benefiting BRI nations. Also, Hu et al. (2023) use GTFP to analyze the effects of BRI on green growth in 238 Chinese cities. BRI was established using the dummy variable method. BRI boosts green growth according to DID coefficients.

In a similar vein, Li et al. (2022) also examine BRI green growth over time. The study uses DID technique and data from 121 nations. The BRI project boosts sampled nations' green growth over time. Further, Jin et al. (2022) claim that BRI nations' green growth depends on public expenditures, technical innovation, and financial development. Yang et al. (2023) use GTFP to measure green growth in 51 BRI economies and suggest that financial development, industrialization, natural resources, and institutional quality can help the modeled nations achieve green development. Another study by Xin and Wang (2022) investigates the determinants of green growth for selected 64 BRI nations. It is suggested that technological innovation and industrialization reduce carbon intensity, promoting green growth. Green growth in BRI economies is also influenced by energy price variations, economic freedom, market size, green bonds, capital investment, political stability, manufacturing, governance quality, and government control (Zhao et al., 2022; Chen and Bian, 2023; Luo and Zhang, 2022).

The antecedent discourse indicates that numerous studies strive to divulge the various indicators of green growth for the global territories involved in the BRI project. Based on the reported findings, it can be inferred that the BRI nations have attained considerable advantages by boosting their economic performance, which can help in targeting the SDGs. Therefore, it is rational to expect a vital role exerted by BRI on green growth. However, the academic literature does not provide any academic document that analyzes the effects of the BRI project on green growth. A report by the Green Belt and Road Initiative Center (2023) and The Boston University (2023) documents that Chinese policymakers have been diligently crafting an environmental management framework to govern their outbound investment and finance, with the purpose of “greening” the BRI and assisting countries in obtaining the 2030 Agenda for green growth and environment. Thus, BRI might be a vital global grand project for boosting green growth. Recognizing the potential significance of the Belt and Road Initiative (BRI) in promoting green growth, the study postulates a policy-oriented correlation between BRI and environmentally sustainable development and hypothesizes it as.

**Hypothesis 4.** The BRI has the potential to foster the global green growth

### 2.5. Refreshing the literature gap

The prior brief review plainly exhibits that minerals, the Paris Agreement, BRI, and green technologies might have a pivotal role in shaping sustainable growth in the future for global economies. Despite the immense importance of the aforementioned indicators, the current body of literature falls short of providing sufficient empirical evidence to construct a comprehensive policy framework for global economies. This highlights the critical research gaps that demand immediate exploration. The literature gaps can be classified into economic literature-based gap and econometric methods-based gaps.

As for the economic literature-based gap, less attention is paid to how minerals influence green growth. Further, a few studies strive to scrutinize the effects of minerals; however, they focus on small samples,

and their findings cannot be generalized to draw global-level policy recommendations. Also, a few studies inspect the effects of BRI and the Paris Agreement on energy transition while using the dummy variable approach to quantify their effects. However, not a single study assesses how BRI and the Paris Agreement influence green growth despite the fact that both indicators have the potential to contribute to sustainable development. Whereas the econometric methods-based gaps are concerned, the majority of the studies focus on measuring the average effects while utilizing linear estimators. However, recent literature confirms the time-varying nature of economic variables, and the application of conventional methods to measure their nexus may be inconsistent (Zeng et al., 2024). It necessitates the deployment of appropriate econometric methods to obtain robust results for recommending suitable policies. Also, the linear estimators are not capable of dealing with the likely nonlinearities in the economic series. In addition, most of the previous papers rely on the aggregated (annual) data for analysis, which may hinder the detailed information, causing biased findings. It demands the utilization of disaggregated data for more informative results.

To address the aforementioned gaps in the literature, the recent study aims to explore dynamic connectedness between minerals, BRI, the Paris Agreement, green technologies, and green growth and deploy advanced econometric tools to deal with the advanced econometric issues in the economic variables.

### 3. Theoretical underpinning

Green economic growth can be referred to as a process in which an economy's GDP growth thrives while GHGs tend to fall over time. Thus, the process to move from GDP growth with the rise in GHGs to GDP growth with a decline in GHGs can be referred to as green growth. This concept of green growth is aligned with the definition published in a report by the OECD (2011). Attaining green economic growth is a crucial requirement for accomplishing the objectives of SDG 8, which will further aid in achieving the objectives of SDG 13. The green growth process can assist not only in shifting the production pattern from fossil fuel-based energy to green energy but also in disrupting the GHG ratio.

The movement towards the green growth process demands a conducive policy environment. Such a policy environment endorses the global authorities on the use of clean technologies, a favorable policy environment, and global economic prosperity initiatives. The scientists and policy makers accentuate the diffusion of green technologies for green growth by injecting them into agriculture, electricity, hydrogen, steel, and transport sectors (Sun et al., 2023a,b). Such measures might generate green jobs by initiating green development projects and attracting investment in sustainable initiatives. This process might escalate the production of clean energy to trigger the green economic production, and expedite the process of green growth by disrupting the GHGs. Thus, the importance of green technologies for green growth can be mathematically modeled as:

$$GG_t = f(GT_t) \quad (1)$$

In the above expression, GG and GT are the representatives of green growth and green technologies, respectively. Further,  $f()$  indicates function form. Now, in order to effectively disseminate green technologies, green technologies-based projects will necessitate access to technological advancements, green funds, and a favorable policy environment, as highlighted in the COP27 summit (The United Nations Climate Change Conference, 2023). Further, the utilization of green technologies necessitates the acquisition of minerals for the production of fundamental materials. The production of magnets used in wind turbines and electric car motors demands the utilization of neodymium, dysprosium, and terbium. Lithium, cobalt, and nickel are the primary materials utilized in rechargeable batteries designed for electric vehicles and energy storage applications. Solar panels harness energy through the utilization of silicon. Tungsten, platinum, and palladium have been

found to effectively mitigate energy consumption and emissions in catalytic converters and lighting systems (Avantgarde International, 2022). The promotion of a green and sustainable future can be facilitated through the responsible utilization of these minerals. Summing up, the utilization of minerals might contribute to boosting green growth by assisting in generating green technologies and tools to generate and store green energy. Thus, the importance of minerals to encourage the process of green growth can be expressed mathematically as:

$$GG_t = f(GT_t, MNR_t) \quad (2)$$

where MNR in the above expression signifies the minerals resources, implying that these resources might be the vital indicator of green growth.

The deployment of green technologies and mineral resources in driving green growth requires a favorable policy environment. Such policy tools might be in the form of environmental taxes, environmental subsidies, and environmental awareness and these tools might be called "environmental policies". These environmental policies might play a critical role in achieving green growth by supporting green technologies through green subsidies and discouraging fossil-fuel-based energy sources through environmental taxes. In this context, a global accord, the "Paris Agreement", was signed in 2015 (The United Nations Climate Change Conference, 2023) in order to obtain SDGs 8 and 13 by triggering green development and curtailing the GHGs. The Paris Agreement, as a global environmental policy, can be expected to contribute towards achieving green growth. For instance, the Paris Agreement possesses the *International Financial Mechanism* that allows the movement of green financing from the developed world to the developing nations. Also, it endorses the *Clean Development Mechanism* which encourages developed nations to enhance green investment in developing nations (Pata and Ertugrul, 2023). Both mechanisms under the accord of the Paris Agreement might significantly enhance green production by improving green technologies. From both financial and developmental mechanisms standpoints, the Paris Agreement might be an indispensable tool for achieving successful global green growth. Hence, it is rational to include the Paris Agreement as an indicator in the following mathematical expression:

$$GG_t = f(GT_t, MNR_t, PA_t) \quad (3)$$

where PA shows the accord of the Paris Agreement as a global grand environmental policy. Not only the global environmental policies such as the Paris Agreement, but global and regional development projects have the potential to contribute to the SDGs, specifically, SDGs – 8 and 13. Such projects might be the source of transferring knowledge, innovation, and green investment projects across the nations (Chen et al., 2023); eventually, this process tends to expedite green growth by enhancing energy efficiency. In this context, the Belt and Road Initiative (BRI), as a global grand development project, might be a significant contributor to accelerating the global green growth process. A report by the *Green Belt and Road Initiative Center* (2023) and *The Boston University* (2023) documents that Chinese policymakers have been diligently crafting an environmental management framework to govern their outbound investment and finance, with the purpose of "greening" the BRI and assisting countries in obtaining the 2030 Agenda for green growth and environment. Thus, BRI might be a vital global grand project for boosting the green growth to obtain SDG – 13. Hence, Eq. (3) can be extended by including the BRI in the model as:

$$GG_t = f(GT_t, MNR_t, PA_t, BRI_t) \quad (4)$$

The above represents the proposed econometric model of the recent study for analysis. Based on the above discourse, the study expects the following effects exerted from GT, MNR, PA, and BRI on the GG as depicted in Fig. 3.

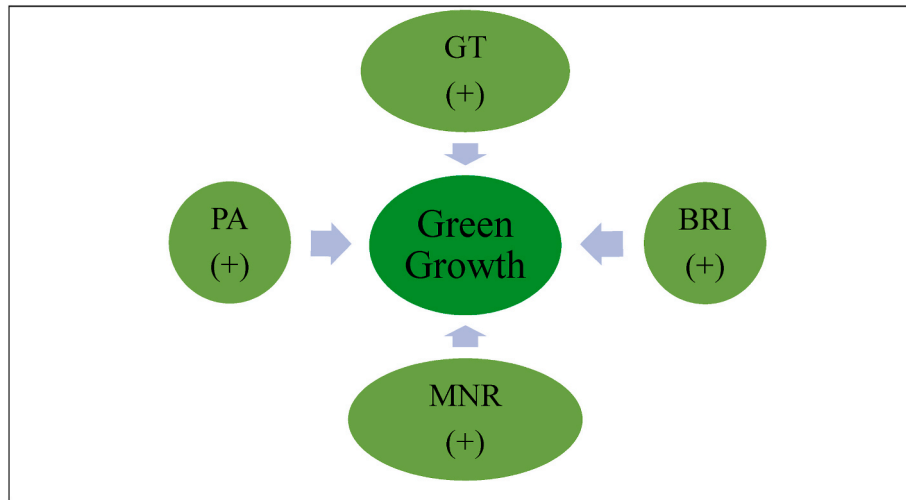


Fig. 3. Theory-based influence of selected series on green growth. Source: Authors' erection.

4. Econometric methods and data

For empirical analysis, the recent article adopts the following econometric strategy to obtain robust findings. Firstly, the quantile connectedness is confirmed by applying the QVAR method to ensure that all modeled series are interconnected. Secondly, the Cross-quantilogram (CQ) method is utilized to measure the marginal effects of independent series on green growth. Thirdly, the wavelet quantile correlation (WQC) method is deployed to affirm the reliability of the results. Finally, all the analyses are performed for various time horizons in order to assess the response of green growth to recommend suitable policy recommendations. Also, the estimation scheme for empirical analysis is depicted in Fig. 4a.

4.1. Quantile VAR method

The study intends to deploy the quantile VAR (QVAR) method in order to ensure whether the dynamic connectedness among the modeled series exists or not. The QVAR by Chatziantoniou et al. (2022) is an extended form of the conventional VAR model that can produce the outcome while incorporating the quantiles to expose the maximum information. Unlike the traditional VAR model, the QVAR method offers several notable advantages. For instance, it provides connectedness for various time horizons, such as the short and long run, enabling the exploration of dynamics among the selected series. Additionally, it takes into account the timing when computing connectedness level, addressing the effects arising from different economic shocks. Moreover, the

QVAR method can capture the inherent uncertainty in the modeled series by reporting interconnectedness across various quantiles. This approach also has the benefit of capturing potential nonlinearities among the modeled series. Furthermore, it facilitates the measurement of h-step-ahead prediction error variance decomposition. In order to compute the total quantile connectedness, Ando et al. (2022) suggest the following equation:

$$y_t = \alpha + \sum_{j=1}^p \theta_j y_{t-j} + u_t \tag{5}$$

The above expression is utilized to erect the total connectedness among the opted series for various quantiles. Further,  $y_t$  and its lag exhibits the dependent side and  $\theta_j$  demonstrate the computed parameters while taking the  $j$ th lags. The model employs the Schwarz Information Criterion to determine the optimal lag selection and address potential serial correlation issues. It specifically emphasizes the analysis of idiosyncratic oscillations while controlling for systematic variations and examining spillover effects among the modeled variables. Besides, total connectedness demonstrates the interconnectedness degree among the opted series such that a higher interconnectedness degree depicts the high rate of interconnectedness (Chatziantoniou et al., 2022).

4.2. Cross-quantilogram method

Next, the study tends to deploy the cross-quantilogram (CQ) techniques by Han et al. (2016). Essentially, the CQ method is erected in order to quantile-wise bidirectional nexus between the modeled series.

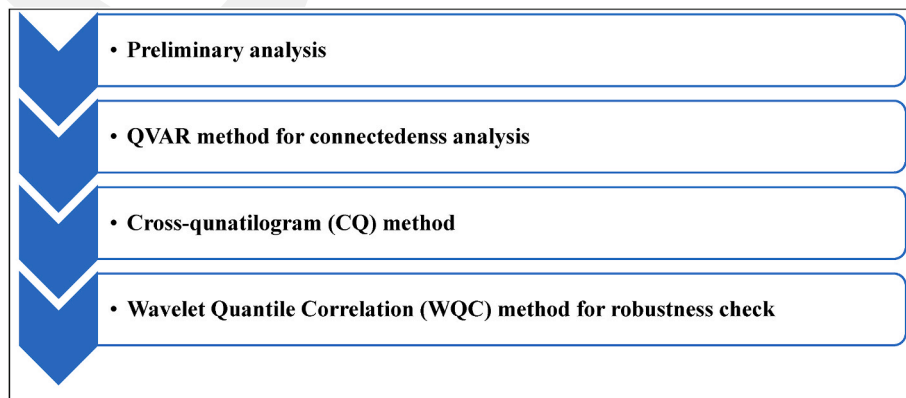


Fig. 4a. Estimation scheme for empirical analysis.

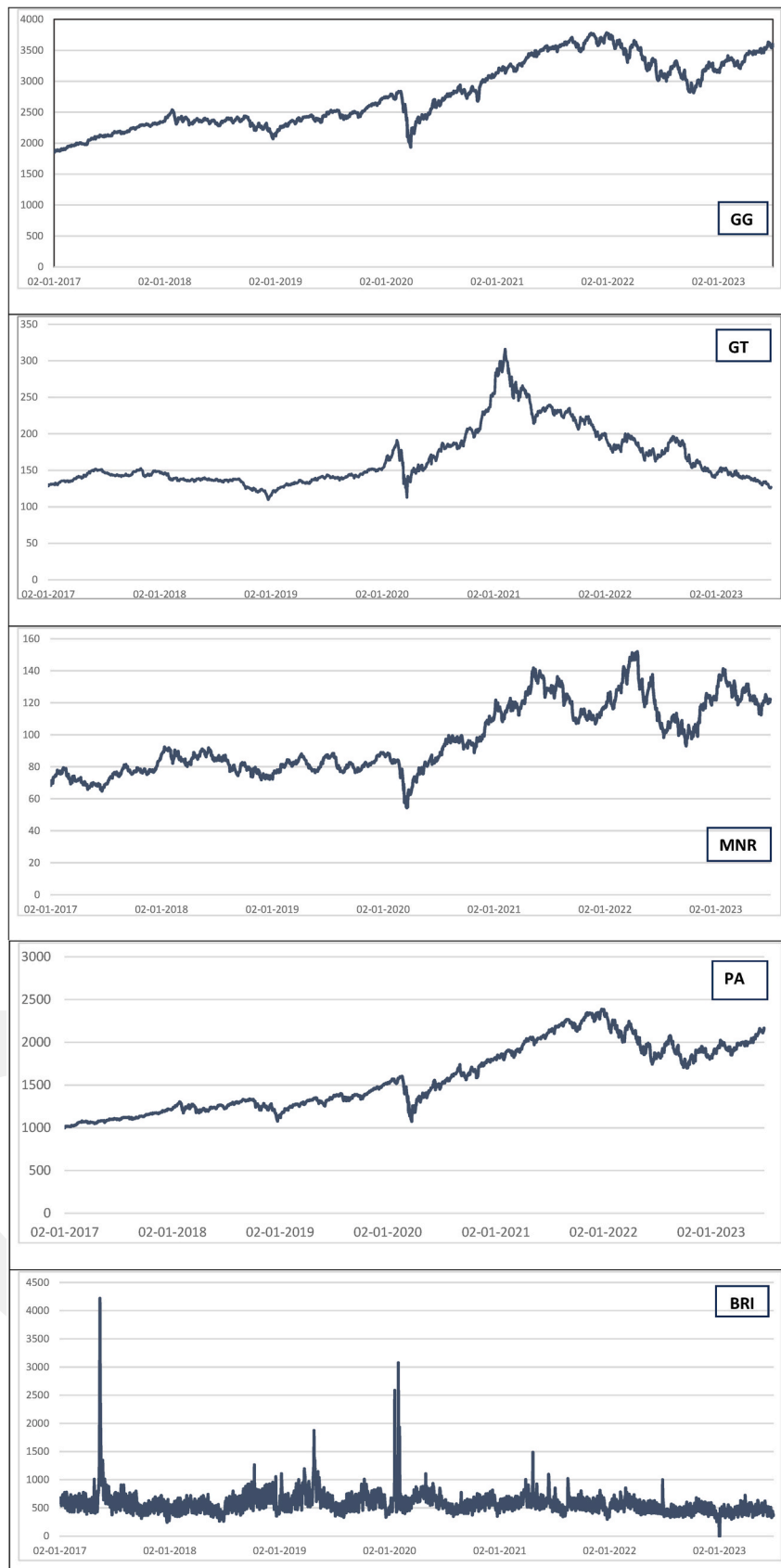


Fig. 4b. Overall trends in the selected series.

Mechanically, Han et al. (2016) assume  $y_t = (y_{1t}, y_{2t})^T \in \mathbb{R}^2$  and  $x_t = (x_{1t}, x_{2t}) \in \mathbb{R}^{d_1} \times \mathbb{R}^{d_2}$  in order to formulate CQ between the two opted series, viz.,  $\{(y_t, x_t) : t \in \mathbb{Z}\}$ . Further,  $x_{it} = [x_{it}^1 \dots x_{it}^{d_i}]^T \in \mathbb{R}^{d_i}$  with  $d_i \in \mathbb{N}$ . Additionally, the function " $F_{y_{it}|x_{it}}(\cdot | x_{it})$ " is utilized to explain the conditional distribution between two-time series, indicating the directional predictability in the both series. Further, it is deemed that  $\mathcal{F}$  is a Cartesian product of two closed intervals in  $(0, 1)$ , that is,  $\mathcal{F} \equiv \mathcal{F}_1 \times \mathcal{F}_2$ , where  $\mathcal{F}_i = [\tau_i, \bar{\tau}_i]$  for some  $0 < \tau_i < \bar{\tau}_i < 1$ .

In order to assume the serial dependence between two series (viz.,  $y_1$ , and  $y_2$ ), the CQ method use to take  $k$  lags for specific pairs like  $(\tau_1, \tau_2)^T \in \mathcal{F}$ . Hence, Han et al. (2016) suggest the following expression to model the CQ:

$$\rho_{\tau}(k) = \frac{E[\Psi_{\tau_1}(y_{1t} \leq q_{1t}(\tau_1))\Psi_{\tau_2}(y_{2t-k} \leq q_{2t-k}(\tau_2))]}{\sqrt{E[\Psi_{\tau_1}^2(y_{1t} \leq q_{1t}(\tau_1))]} \sqrt{E[\Psi_{\tau_2}^2(y_{2t-k} \leq q_{2t-k}(\tau_2))]}} \quad (6)$$

where In  $y_{it}$ ,  $Y$  represents a series with no unit root,  $i$  represents 1, ..., 5 to show the number of opted variables, and  $t$  indicates time ( $t = 1, 2, \dots, T$ ). Further, the functions  $F_i(\cdot)$  and  $f_i(\cdot)$  capture the distribution and density functions of  $y_{it}$ ,  $i = 1, 2$ , respectively. Besides, in order to ensure the statistical significance of  $\rho_{\tau}(k)$ , the Ljung-Box test is suggested by Han et al. (2016) that can be expressed as:

$$Q_{\tau}^*(p) = T(T+2) \sum_{k=1}^p \hat{\rho}_{\tau}^2(k) / (T-k) \quad (7)$$

As per indications of Han et al. (2016), the CQ method can handle several econometric exigencies to provide robust outcomes. For instance, the CQ technique, unlike the traditional methods, can offset the influence of outliers implying that it can produce reliable outcomes while handling the uncertain shocks in the series. It can handle the nonlinear series, indicating that the CQ method is more suitable for daily data that are suspected of nonlinearities. It can measure the marginal effects without moment conditions, implying that the CQ model is compatible with dealing with the market and financial data series. Besides, it can take various lags to assess the likely asymmetric information (Cheng et al. (2023), and curb the plausible model misspecification. Based on the preceding several benefits of the CQ method, it can be an appropriate choice to handle the daily data series (Sohag et al., 2022). Besides, the study relies on the WQC method for robustness checks. The WQC method can handle the likely nonlinearities, and provide detailed results by incorporating the quantiles along with handling the outliers, it suitable to deploy for daily data analysis (Wang et al., 2023b); it is suitable to apply it for robustness check of the results.

### 4.3. Data and preliminary analysis

The study proposes to explore the dynamic associations between minerals (MNR), the Belt & Road Initiative (BRI), the Paris Agreement (PA), green technologies (GT), and green growth in order to draw suitable policies for SDG – 8. To this end, the study utilizes the daily data from different authentic sources. For instance, the All Metals Index (a proxy for MNR), Clean Technology Index (a proxy for green technologies), Net Zero 2050 Paris-Aligned ESG Index (a proxy for the Paris Agreement), and World Sustainability Index (a proxy for green growth) are retrieved from S&P Dow Jones Indices (<https://www.spglobal.com/spdji/en/>). Further, the study erects the indices of BRI in order to measure these series, unlike the prior literature that relies on the dummy variable approach. To do so, the study follows Boungou and Yatie (2022) and collects the different relevant and trending words from public interest sites, such as google trends, twitter trends, and Reddit for formulating the indices. For example, the words “Belt & Road Initiative”, “China Project”, “Trade”, “Financial Integration”, and “Sustainable Development” are opted for measuring the BRI index. It is important to note that the words utilized to erect the index of BRI stem from the core

agenda of the project.

Moreover, the data for the modeled series spans from July 2, 2017, to June 30, 2023, based on the availability of data. The chosen data range encompasses various global economic events and shocks, such as the COVID-19 pandemic and the Ukraine-Russia War. It is crucial to take into account these events and shocks when assessing the nexus to derive an appropriate policy recommendation. Additionally, Fig. 4b illustrates the overall trends of the selected series.

Table 1 depicts the descriptive statistics and preliminary analysis, indicating the important information regarding the selected variables. For instance, the high variance of the variables plainly indicates the non-normal distribution of the series. Also, the significance of the skewness implies the same characteristics of the series. Looking at the JB values, it can be again inferred that the modeled series possesses a non-normal distribution. The preceding pre-estimations tests demonstrate that the series are non-normally distributed, implying that the application of linear and average estimators cannot deal with such series; hence, the results may be biased. Therefore, the study, as per the suggestion of Sun et al. (2023a,b), tends to deploy advanced econometric tools to deal with nonlinearities by incorporating the quantiles for various time horizons. Besides, the ERS test conforms that all series are stationary at the 1% level of significance.

## 5. Results and discussion

In this section, the study presents the findings of the connectedness between green growth and its proposed indicators. To this end, the study assesses the time-varying symmetric or asymmetric connectedness among the modeled series while utilizing the QVAR model. Subsequently, the study heads towards measuring the marginal effects of minerals (MNR), BRI, the Paris Agreement (PA), and green technologies (GT) on green growth. Econometrically, it is imperative to evaluate whether the modeled series exhibits interconnectedness to measure the marginal effect. In this pursuit, the study adheres to the methodology proposed by Chatziantoniou et al. (2022) and scrutinizes the dynamic connectedness levels across different time horizons. Once the time-varying connectedness among the series is confirmed, it becomes significant to calculate the marginal effects, which constitute the central objective of the study for formulating policy recommendations. Consequently, the study employs the CQ and WQC methods to investigate the dynamic effects across various periods. In succession to this, quantile Granger causality (QGC) is utilized for robustness check.

### 5.1. Time-varying connectedness analysis

This subpart tends to exhibit the time-varying quantile connectedness among the selected series, deploying the heatmap-based QVAR technique put forth by Chatziantoniou et al. (2022). For capturing the connectedness, the QVAR method uses quantile transmission channels. Further, it relies on the 10-step forecast horizon and 200-day rolling window to erect the quantile connectedness. In order to analyze the connectedness across the various time horizons, the study measures the total, short-run, and long-run connectedness. For instance, Fig. 5 visualizes the total quantile connectedness while Figs. 6 and 7 depict the short and long-run quantile connectedness, respectively. The outcome based on the QVAR method is presented in 3D heatmaps. Before, delving into the discussion, it is worth noting that hot shade implies a high degree of connectedness while cold shade implies a low degree. Further, the color bar apprehended along with right-side of each heatmap also exhibits the intensity of the connectedness among the selected markets. Besides, the quantiles given along with left-side of each heatmap indicate the low and high extremes.

As for the total time-varying quantile connectedness, the hot and cold shades can be observed across time. Along the horizontal axis, a high level of interconnectedness among the selected markets can be witnessed at the lowest and highest quantiles. More specifically, after

**Table 1**  
Descriptive statistics and preliminary tests.

	GG	MNR	BRI	PA	GT
Mean	-1.078	-0.038	0.33	0.222	0.001
Variance	705.539	3.679	23216.64	6623.826	13.98
Skewness	-0.386***	-0.910***	-0.079	-0.585***	4.053***
	0.000	0.000	-0.181	0.000	0.000
Ex.Kurtosis	26.601***	20.190***	102.085***	1.999***	208.231***
	0.000	0.000	0.000	0.000	0.000
JB	50372.720***	29229.748***	741220.797***	381.718***	3088674.946***
	0.000	0.000	0.000	0.000	0.000
ERS	-17.641***	-13.276***	-8.069***	-7.288***	-18.888***
	0.000	0.000	0.000	0.000	0.000
Q (10)	21.667***	20.138***	253.015***	725.783***	38.860***
	0.000	0.000	0.000	0.000	0.000
Q2 (10)	324.747***	126.076***	453.462***	145.944***	257.999***
	0.000	0.000	0.000	0.000	0.000

Note: \*\*\*, \*\*, and \* signify the significance level at 1%, 5%, and 10%, respectively.

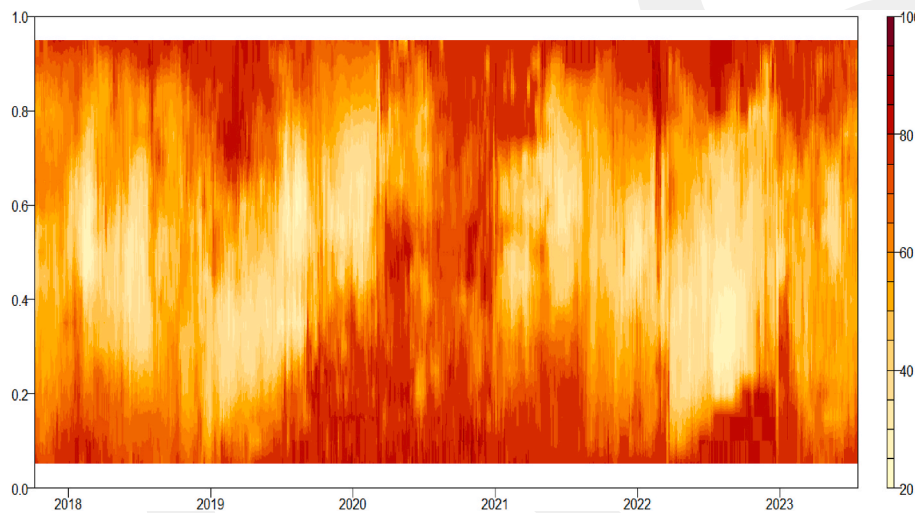


Fig. 5. Overall QVAR-based dynamic total connectedness for various quantiles.

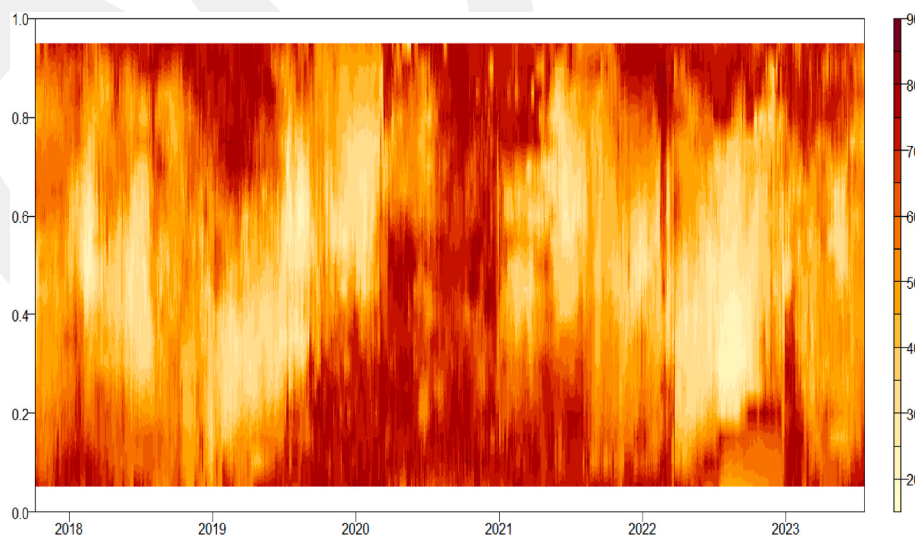


Fig. 6. Short-run QVAR-based dynamic total connectedness for various quantiles.

2020 and 2022, a very high degree of connectedness can be seen, covering approximately all lower and higher quantiles. Possibly, these extreme periods are due to the effects exerted from recent economic shocks, viz., COVID-19 and Ukraine-Russia War as noted by [Li et al.](#)

(2022) and [Chen et al. \(2023\)](#). Also, it indicates that market uncertainty during the period of economic shocks is higher than the period when economic improvement (such as technological innovations) occurs. In addition, the variation in connectedness tends to vary across the various

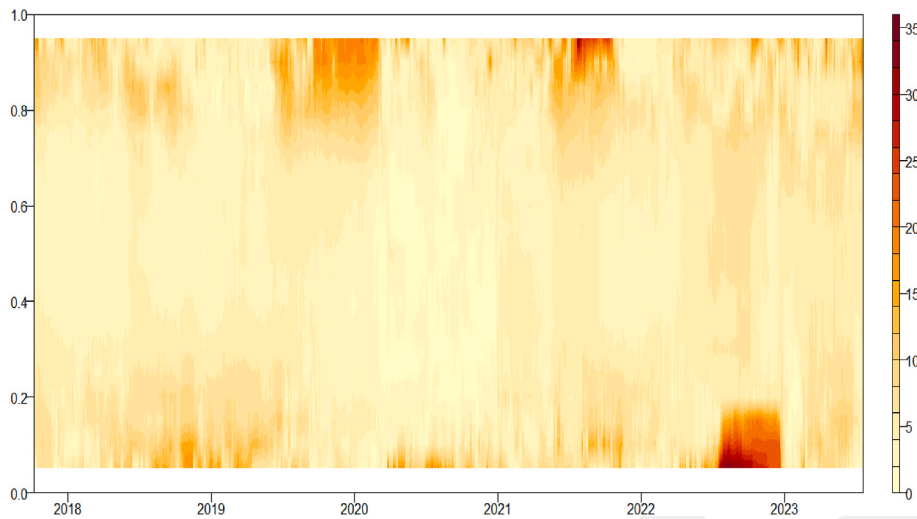


Fig. 7. Long-run QVAR-based dynamic total connectedness for various quantiles.

quantiles over time, implying the asymmetric quantile connectedness over time. Summing up, Fig. 5 of total connectedness demonstrates a significant level of connectedness among the opted series across the various quantiles over time.

As for the short-run total quantile connectedness, Fig. 6 visualizes it across the various quantiles. Interestingly, the short-run connectedness-

based heatmap supports the total connectedness. It means that the total connectedness might depict the short-run connectedness among the modeled markets. Also, it can be inferred that, in the short-run, the selected markets had to endure significant uncertainty, specifically, during periods of economic shocks.

In Fig. 7, the long-run total connectedness for the various quantiles is

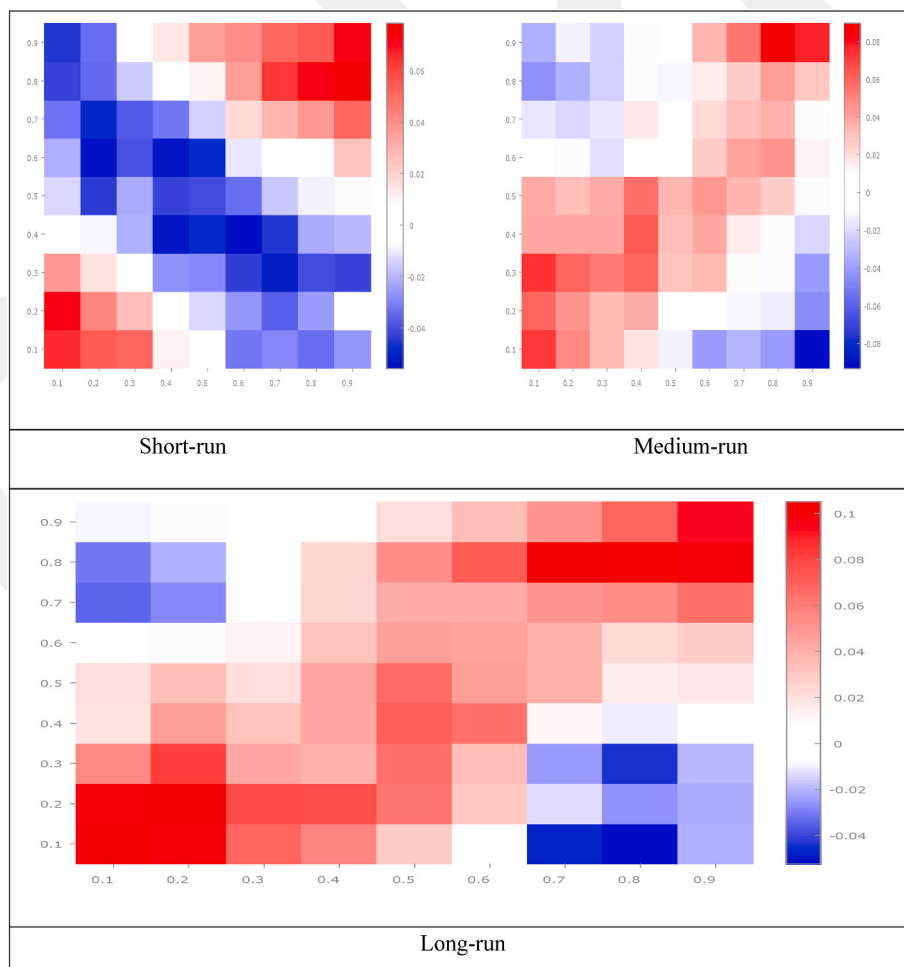


Fig. 8. The CQ-based effects of MNR on GG. Notes: The x-axis represents the independent series while y-axis denotes the dependent series. Also, the 1st lag-based analysis indicates the short-run findings, while the analysis done by taking the 6th and 22nd lags imply the medium and long-run results.

visualized. It can be observed that the total connectedness is dominant during the positive returns periods as compared to the periods having economic shocks as also reported by Jiang et al. (2022). Instinctively, it is tacit that favorable return shocks occur during the period of technological advancement. Besides, the cold shades during the periods of COVID-19 and the Ukraine-Russia War reflect the successful endeavors by the global authorities in order to minimize the adverse repercussions of the negative economic shocks. Overall, a high level of total connectedness for various time horizons across the different quantiles is observed, indicating the significant asymmetric association among the selected markets to draw the policy implications. Hence, the study moves towards analyzing how the selected series influences green growth across the various time horizons.

### 5.2. Cross quantilegram (CQ) analysis

In this subpart, the study deploys the CQ method in order to seek the marginal effects stemming from MNR, BRI, PA, and GT on GG. It is important to note that the study takes different lags to capture the effects across the various time horizons, following Ren et al. (2022). For instance, the 1st lag-based analysis indicates the short-run findings, while the analysis done by taking the 6th and 22nd lags implies the medium and long-run results, correspondingly. Furthermore, an economy having immediate adjustments with fixed factors represents the short-run situation, while in the medium run, an economy an increase

the flexibility in prices and wages. In the long run, all inputs are variable, and the economy has fully adapted, addressing sustained growth and structural changes (Mankiwauthor, 2016). Besides, the 1–3 quantiles imply the bearish market situation while the 4–6, and 7–9 quantiles signify the condition when the markets are normal and bullish, respectively.

Focusing on how minerals (MNR) influence green growth, Fig. 8 depicts the findings. In the short-run, a bearish MNR market is positively associated with green growth during its bearish market condition, while it shows a negative association with green growth during normal and bullish market conditions. Additionally, MNR during normal and bullish market situations is negatively linked to green growth during its normal market condition. However, green growth during its bullish market condition responds positively when MNR market conditions are normal and bullish. Except for a few quantiles of various market conditions which have no significant effects.

In the medium-run, green growth market conditions ranging from bearish to bullish exhibit a significantly positive response to the corresponding market conditions of MNR. However, for the remaining market situations in both series, no negative associations are observed. In the long-run, overall, significant and positive effects exerted from MNR on green growth are witnessed across the various time horizons. For instance, MNR market conditions ranging from bearish to bullish exhibit a significantly positive impact on the corresponding market conditions of green growth. Further, the normal MNR market situation has a

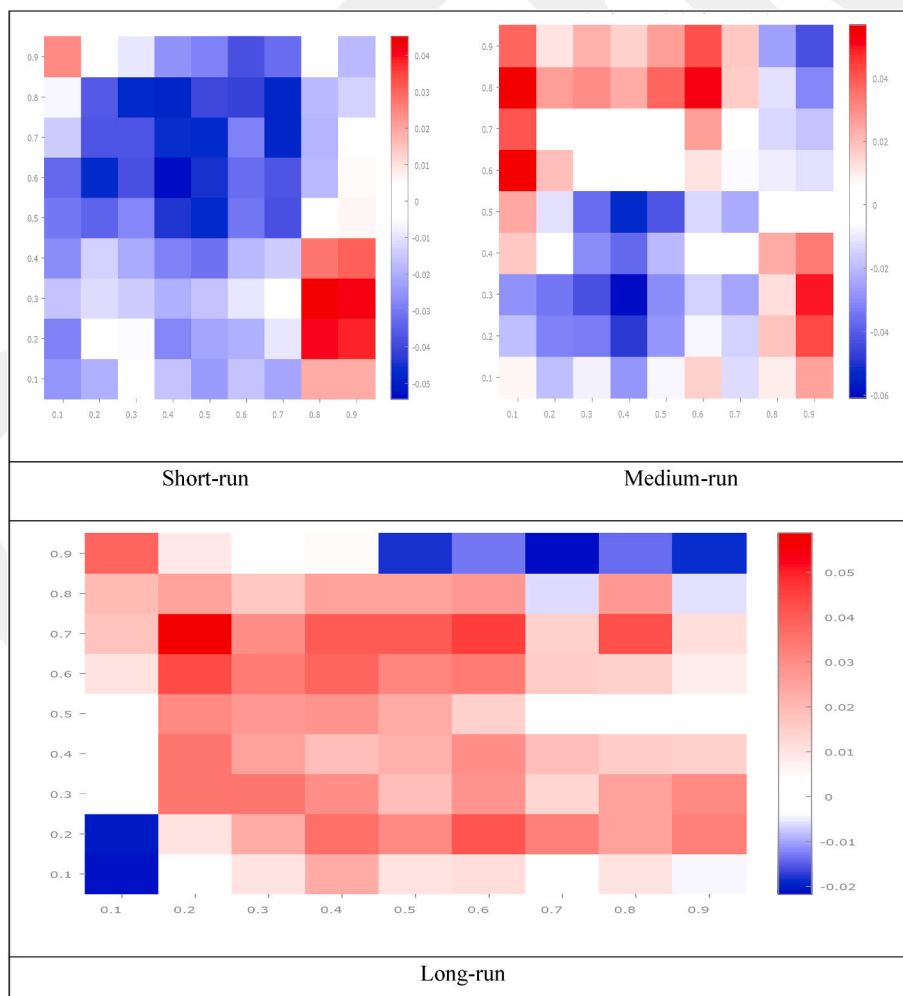


Fig. 9. The CQ-based effects of BRI on GG.

Notes: The x-axis represents the independent series while y-axis denotes the dependent series. Also, the 1st lag-based analysis indicates the short-run findings, while the analysis done by taking the 6th and 22nd lags imply the medium and long-run results.

favorable impact on the green growth during its bearish and bullish market situation. Contrarily, the bearish and bullish green growth markets have to endure adverse effects stemming from the bullish and bearish market situations of MNR. Besides, the remaining market conditions exhibit no significant effects of independent series. Compared to the outcomes presented in prior literature, our study yields distinctive and more detailed results. In contrast to the findings of Wei (2024), Zeng et al. (2024), and Cheng et al. (2023), which primarily reported linear effects of minerals on green growth, our study goes beyond by addressing and acknowledging potential asymmetries in these effects.

As for the impact of BRI on green growth, Fig. 9 visualizes the outcome for the various time horizons. In the short run, the Belt and Road Initiative (BRI) generally demonstrates significant adverse effects on green growth across various market conditions. However, during the 8th and 9th quantiles of BRI's bullish market conditions, there appears to be a positive influence on green growth when the market situation is bearish. Additionally, there are a few quantiles across different market situations that do not demonstrate any considerable linkages between BRI and green growth. Observing the medium-run outcome, the results largely remain the same as witnessed in the short-run with the exception of the bullish green growth market situation. Notably, its response turned from negative to positive response when interacting with the bearish and normal market conditions of BRI. Looking at the long-run effects of BRI on green growth, the BRI's impact on green growth turns significantly positive across most of the time horizons, unlike the short and medium-run findings. On the other hand, the 9th quantile of

BRI's bearish and bullish market conditions exhibits adverse effects on the corresponding quantile of the green growth. Besides, a few quantiles across the different time horizons indicate no significant effects on green growth. These distinctive outcomes emanate from our study, highlighting the substantial contribution of the BRI to global green growth.

Looking at the influence of the Paris Agreement (PA), Fig. 10 reports the response to green growth. In the short and medium-run, the mixed (viz., positive, negative, and insignificant) effects of PA on green growth are observed across the various market conditions. Interestingly, the long-run coefficients of PA exhibit a favorable influence on green growth across the most of time horizons with the exception of a few quantiles which demonstrate the negative and insignificant effects. In sum, the short and medium-run impact of PA on green growth remains mixed while in the long-run, the association becomes significantly positive across the various market situations. This is another notable finding which confirms the PA as the crucial determinant of green growth.

In the case of green technologies (GT)-green growth nexus, Fig. 11 visualizes that, in the short-run, green growth has to endure adverse effects exerted by GT across most of the time horizons. While exceptions are bearish and bullish green growth market situations which show the positive link with the corresponding market conditions. The medium-run findings suggest that GT possesses a positive as well as negative influence on green growth across the various time horizons, unlike the short-run results. Further, some quantiles of the different market conditions show no significant linkage between both series. In the long-run, it can be observed that green growth enjoys significant advantages on

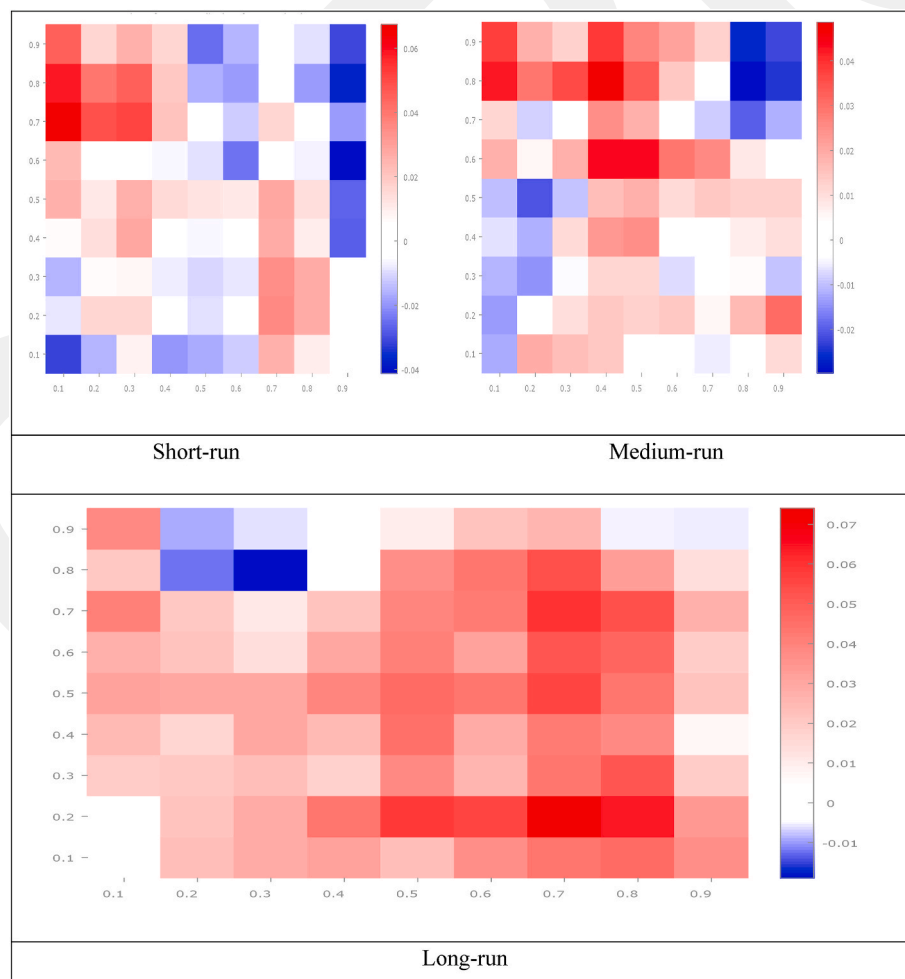
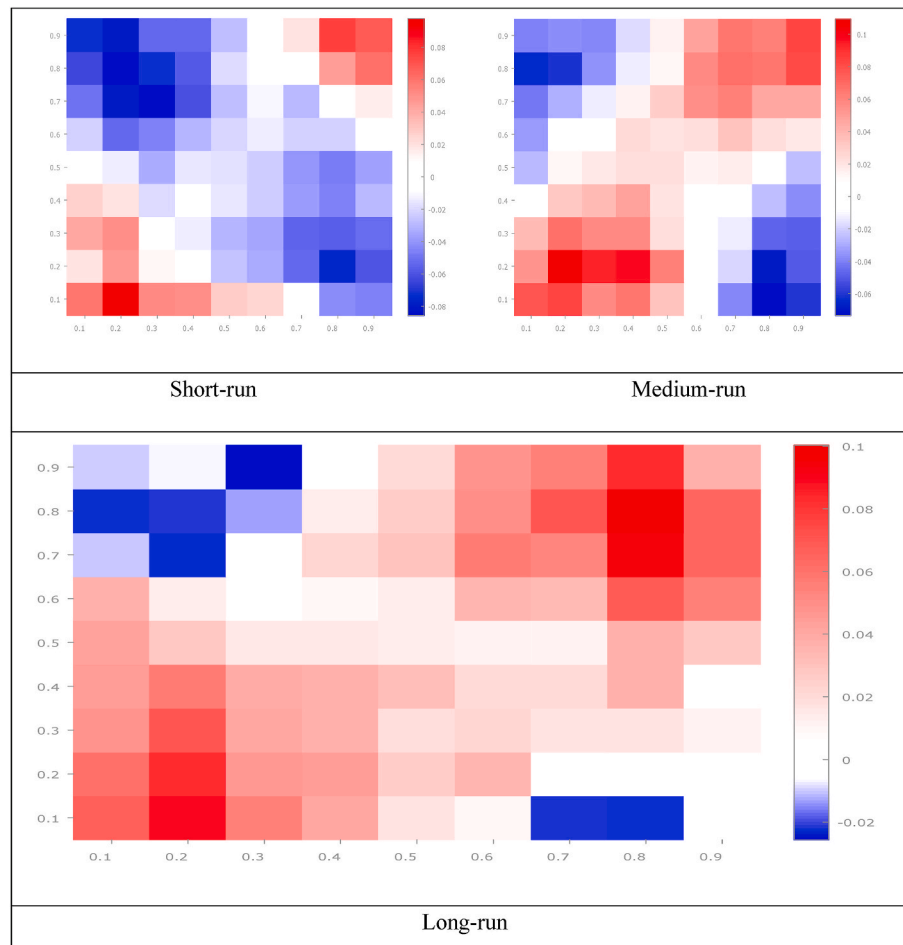


Fig. 10. The CQ-based effects of PA on GG.

Notes: The x-axis represents the independent series while y-axis denotes the dependent series. Also, the 1st lag-based analysis indicates the short-run findings, while the analysis done by taking the 6th and 22nd lags imply the medium and long-run results.



**Fig. 11.** The CQ-based effects of GT on GG.

Notes: The x-axis represents the independent series while y-axis denotes the dependent series. Also, the 1st lag-based analysis indicates the short-run findings, while the analysis done by taking the 6th and 22nd lags imply the medium and long-run results.

account of GT across the various market conditions. However, the exceptions are some quantiles across the various time horizons exhibit the negative and insignificant nexus. Summing up, GT has a favorable influence on green growth in the long-run while in the short and medium-run, the impact is mixed. The same outcome is documented by [Sun et al. \(2023a,b\)](#), [Chen et al. \(2023\)](#), and [Wang et al. \(2023a,b,c\)](#).

### 5.3. Robustness check: wavelet quantile correlation (WQC)

For assessing the reliability of the results, the study deploys the WQC method as a robustness check. Since the WQC method can handle the likely nonlinearities, and provide detailed results by incorporating the quantiles along with handling the outliers, it is suitable to deploy for daily data analysis ([Zeng et al., 2024](#)). Further, the WQC-based results are depicted in [Fig. 12](#). Before explaining the results, it is worth noting that 4–8 days indicate the short-run, 16–32 days indicate the medium-run, and 128–256 days indicate the long-run. Furthermore, 0.01–0.3 quantiles represent the bearish market situation, 0.4–0.6 quantiles show the normal market situation and 0.7–0.95 quantiles exhibit the bullish market condition. Intriguingly, the outcome of the WQC method plainly supports the findings determined by the CQ method, confirming the robustness of the results. For instance, in the case of the green growth – MNR nexus, it is noticed that MNR has a mixed (positive, negative, and insignificant) influence on green growth across the various market conditions during the short and medium run. In the long-run, approximately, all market conditions of green growth gain significant benefits due to MNR. It implies that the green growth's

impact becomes significantly positive in the long-run across the various time horizons, supporting the outcome of the CQ method. In a similar vein, the WQC-based outcome for the influence of BRI, PA, and GT demonstrates the mixed effects during the short and medium run while a favorable impact is observed across most of the market situation during the long-run. In summary, the WQC-based outcome plainly supports the results of the CQ method, signifying the robustness of the results.

### 5.4. Discussion

The findings based on the QVAR method are reported in [Figs. 5–7](#) for total, short, and long-run quantile connectedness. The results visualized in [Figs. 5 and 6](#) demonstrate the high rate of connectedness on account of high market risk specifically during COVID-19 and the Ukraine-Russia war. The high ratio of connectedness among the selected variables across the various time horizons induces an exploration of the marginal effects to draw suitable policy recommendations. To this end, two advanced econometric (CQ and WQC) tools are utilized.

As for the influence of mineral markets (MNR) on green growth as visualized in [Figs. 8 and 12](#), the outcome indicates that, overall, MNR significantly contributed to green growth across the various time horizons, specifically, in the medium and long-run. Economically, MNR assists in developing the smart green technologies used to generate and store green energy. For instance, the production of magnets used in wind turbines and electric car motors demands the utilization of neodymium, dysprosium, and terbium. Lithium, cobalt, and nickel are the primary materials utilized in rechargeable batteries designed for electric vehicles

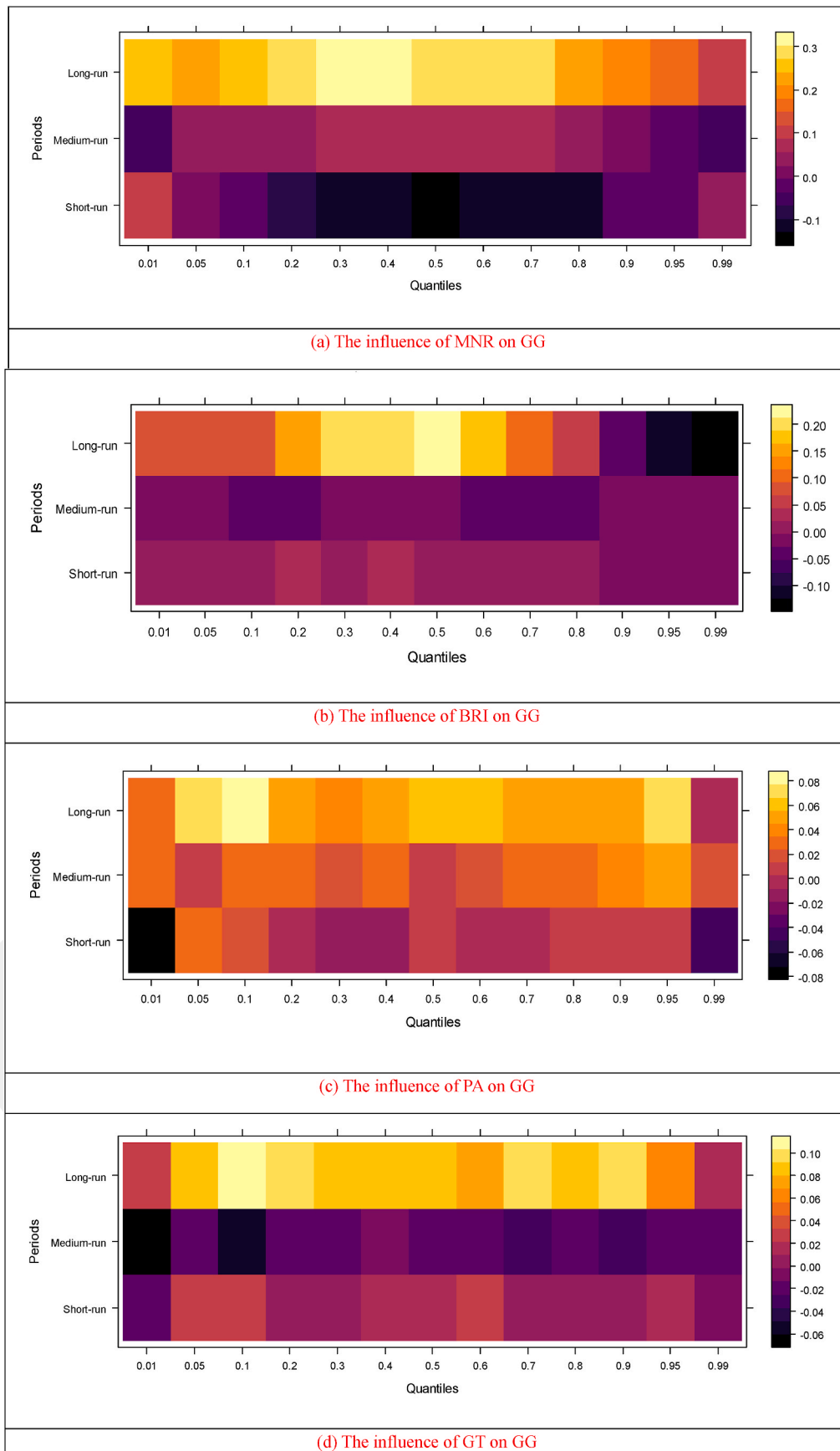


Fig. 12. WQC-based effects of modeled series on green growth. Note: 4–8 days indicate the short-run, 16–32 days indicate the medium-run, and 128–256 days indicate the long-run.

and energy storage applications. Solar panels harness energy through the utilization of silicon. Tungsten, platinum, and palladium have been found to effectively mitigate energy consumption and emissions in catalytic converters and lighting systems (Avantgarde International, 2022). The promotion of a green and sustainable future can be facilitated through the responsible utilization of these minerals. According to a report by the International Energy Agency (2023), the deployment of crucial MNRs such as lithium, copper, and nickel in various green energy technologies has surged by an impressive 30% since 2015. Projections indicate a further substantial increase, with their usage expected to rise by 60–70% by 2040. Summing up, the utilization of minerals significantly contributes to boosting green growth by assisting in generating green technologies and tools to generate and store green energy.

In the case of BRI, as the results are visualized in Figs. 9 and 12, it is observed that green growth has to endure adverse repercussions stemming from BRI across most of the various market conditions during the short and medium run. However, in the long-run, BRI predominantly supports the green growth process across various market horizons. Our findings can be supported by facts and economic logic. In the context of facts, the global BRI project, initiated in 2013, invested approximately 65% of total investment in fossil fuel-based (oil, gas, and coal) energy markets till 2019. In 2020, the Chinese authorities endorsed targeting the SDGs, specifically, SDG – 8, and therefore, decided to develop the green BRI center. As a result, the investment to trigger the green energy markets including solar, wind, and hydropower was increased by 50% in 2020 as compared to last year (China BRI Investment Report, 2022). Thus, the findings plainly depict the effects of green BRI investment that is increased and demonstrate the favorable influence of green investment on green growth, supporting the long-run result. However, in the short and medium-run, the adverse effects were on account of the dominant investment of BRI in cheap energy projects. In the context of economic logic, BRI as a global grand project can be the source of transferring knowledge, innovation, and green investment projects across the nations (Chen et al., 2023); eventually, this process tends to expedite green growth by enhancing energy efficiency. Hence, BRI can be a significant contributor to accelerating the global green growth process.

Looking at the influence of the Paris Agreement (PA) in Figs. 10 and 12, it can be witnessed that green growth shows a mixed response to the PA across the various market conditions during the short and medium-run. However, the long-run outcome asserts the supportive role of PA in enhancing the global green growth ratio. Possibly, the transition from cheap energy to green energy, as mandated by the Paris Agreement accord, presents challenges to global economies and may result in short and medium-term losses. This transition involves a significant cost, often referred to as the “carbon bubble.” This situation highlights the adverse effects experienced during the initial stages of adopting the Paris Agreement. However, in the long run, the majority of nations have committed to the Paris Agreement and have shown support for developing nations through the International Financial Mechanism. This mechanism facilitates the flow of green financing from developed countries to developing nations. Additionally, the Clean Development Mechanism encourages developed nations to increase their green investments in developing countries (Pata and Ertugrul, 2023). Therefore, the positive influence exerted by PA accord on green growth is observed across most of the market conditions during the long-run.

Finally, green technologies (GT), as reported in Figs. 11 and 12, disrupt the green growth process across most of the market conditions during the short and medium run. Possibly, the diffusion of green technologies was costly due to having no advancements in the field of green markets. Therefore, high costs of green techs’ diffusion tend to deteriorate green growth by hindering green economic activities. However, in the long-run, the influence of GT turned into a positive impact. It can be due to achieving the economies of scale in the production and diffusion of GT which ultimately trigger the green growth ratio. To recapitulate, the diversified effects exerted from the

independent series on green growth are observed across the various market conditions during different time horizons. Besides, the summary of the results is reported in Table 2.

## 6. Conclusion and policy recommendations

So far, the recent study explores the dynamic connectedness between minerals (MNR), the Belt and Road Initiative (BRI), the Paris Agreement (PA), green technologies (GT), and green growth. To do so, the recent article utilizes the daily data and deploys advanced econometric (QVAR, Cross-quantilogram, and Wavelet Quantile Correlation) tools. Unlike the prior literature, the results confirm the diversified effects of the modeled on the green growth series across the various time horizons. For instance, In the short-run, MNR, BRI, and GT discourage green growth across most of the various market conditions with the exceptions of a few quantiles in the different market situations which show positive or insignificant nexus. Further, the medium-run time horizon indicates the mixed (positive, negative, and insignificant) impacts. However, in the long, most of the market conditions depict the favorable effects exerted by MNR, BRI, and GT on green growth. Moreover, in the case of PA, the results suggest mixed effects on green growth across the various market conditions during the short and medium-run; however, the positive effects stemming from PA on green growth remain predominant in the medium-run. In the long-run, green growth significantly enjoys the benefits on account of PA across the majority of the market conditions. Based on the medium and long-term results, it can be inferred that the hypotheses supporting the roles of MNR, BRI, the Paris Agreement, and GT in fostering green growth are identified, except for the short run, which could not support these hypotheses. Summing up, despite the divergence in results, our overall findings suggest that minerals, the Belt and Road Initiative (BRI), the Paris Agreement, and green technologies collectively possess significant potential to catalyze green growth, aligning with the long-term objectives of SDG – 8.

### 6.1. Policy recommendations

The recent study’s findings demonstrate the diversification in the results, implying the effects of the modeled series vary while responding to the different market conditions over time. Thus, the study tends to recommend time-horizon-wise policies in order to trigger the green growth for SDG – 8.

First, the study suggests the following time-horizon-wise policies for minerals in order to enhance the process of green growth.

#### (i) Short-term measures

In the short run, since the effects of minerals (MNR) on green growth are mostly discouraging, policymakers should focus on promoting and

**Table 2**  
Summary of the results.

Series	Short-run	Medium-Run	Long-run	Support to SDG-8
MNR	Mixed but predominantly negative	Mixed but predominantly positive	Predominantly positive	✓
BRI	Mixed but predominantly negative	Mixed but predominantly positive	Predominantly positive	✓
PA	Mixed	Mixed	Predominantly positive	✓
GT	Mixed but predominantly negative	Mixed but predominantly positive	Predominantly positive	✓

Note: MNR, BRI, PA, and GT exhibit the minerals, the Belt and Road Initiative, the Paris Agreement, and green technologies, respectively. Note: The dependent variable is green growth.

incentivizing green growth initiatives while providing the green subsidy to users of MNR for green projects and imposing the green tax on other users. This could include encouraging the adoption of MNR for green economic activities. Also, policymakers should closely analyze the specific market conditions where MNR shows positive or insignificant effects on green growth. Understanding these conditions can help identify potential opportunities to align MNR activities with sustainable development objectives.

#### (ii) Medium-term measures

Given the mixed impacts of MNR on green growth in the medium run, it is important to carefully monitor the effects and consider implementing measures to mitigate any negative impacts. This might involve implementing stricter regulations or standards for MNR activities to ensure they align with environmental goals. As the positive effects of MNR on green growth remain predominant in the medium run, policymakers should encourage the adoption of green technologies within the minerals sector. This could involve providing incentives for sustainable practices, promoting eco-friendly mining methods, and investing in research and development of green technologies for the minerals industry.

#### (iii) Long-run term measures

With most market conditions showing favorable effects of MNR on green growth in the long run, policymakers should integrate sustainable practices and green growth principles into the core strategies of the minerals sector. This might include developing long-term sustainability plans for mining and resource extraction, promoting responsible mining practices, and investing in eco-friendly infrastructure. Also, the study suggests that minerals have the significant capability to trigger green growth to target Sustainable Development Goal 8 (SDG - 8), which focuses on promoting economic growth and decent work while ensuring environmental sustainability. Policymakers should actively work towards aligning the minerals sector with SDG - 8 by prioritizing green growth and sustainable practices in resource extraction and utilization.

*Second*, the study suggests the following time-horizon-wise policies for BRI projects in order to enhance the process of green growth.

#### (i) Short-run term measures

In the short run, the BRI seems to have a discouraging effect on green growth in most market conditions. Therefore, to promote green growth in the short term, policymakers should focus on implementing targeted environmental policies and regulations that encourage the adoption of green technologies and sustainable practices. This could include providing incentives and subsidies for green projects and industries, imposing stricter environmental standards, and promoting green innovation through research and development grants.

#### (ii) Medium-term measures

The medium-run shows mixed impacts of the BRI on green growth, with some positive, negative, and insignificant effects. In this scenario, policymakers should adopt a balanced approach. They should continue to promote and support green initiatives while also addressing any negative impacts that might arise from the BRI projects. This could involve conducting thorough environmental impact assessments for BRI projects and ensuring that adequate safeguards and mitigation measures are in place to minimize any adverse effects on the environment.

#### (iii) Long-run term measures

In the long run, the BRI seems to have favorable effects on green growth in most market conditions. To leverage these positive effects and

ensure sustainable development, policymakers should strengthen and expand the integration of green technologies and sustainable practices in BRI projects. They should prioritize investments in green infrastructure, renewable energy, and environmentally friendly technologies. Additionally, collaboration and knowledge-sharing among BRI countries on green growth strategies can be encouraged to maximize the benefits.

*Third*, the study suggests the following time-horizon-wise policies for the Paris Agreement in order to enhance the process of green growth.

#### (i) Short-run term measures

Given the mixed effects of the Paris Agreement (PA) on green growth in the short run, policymakers should closely monitor the market conditions and the specific factors that influence the positive, negative, and insignificant impacts. This monitoring will allow for timely interventions and adjustments to ensure a more consistent positive impact on green growth. Since the study explores the dynamic connectedness between green technologies and green growth, policymakers should focus on incentivizing the adoption and development of green technologies in the short-run. This can be done through tax breaks, subsidies, and research grants to promote the implementation of environmentally friendly technologies.

#### (ii) Medium-term measures

As the medium-run time horizon indicates predominantly positive effects of PA on green growth, policymakers should focus on strengthening the implementation of the Paris Agreement measures. This may involve enhancing international cooperation and coordination to ensure effective emission reduction and sustainable practices. In addition, the study does not provide specific results for BRI's impact on green growth, policymakers should explore how BRI projects can align with green growth objectives. By integrating environmental sustainability criteria into BRI projects, countries can enhance their commitment to green development.

#### (iii) Long-run term measures

As the study suggests that minerals have a significant capability to trigger green growth, policymakers should devise strategies for sustainable mineral exploitation. This may involve establishing responsible mining practices, promoting recycling, and reducing environmental impacts associated with mining activities. Given the favorable effects exerted by PA on green growth in the long-run, countries should strengthen their long-term climate commitments and strive to exceed their emission reduction targets under the Paris Agreement. This could involve setting more ambitious climate goals and adopting policies to transition to low-carbon economies.

## 6.2. Limitations

The indirect purpose of social science-based research is to open new insights for further research. In this context, the recent study also has some limitations to encourage future studies in this area. For instance, the study explores the time-varying influence of modeled series while ignoring the recent economic shocks. The incorporation of economic shocks such as COVID-19 and the Ukraine-Russia war in the model may provide more interesting findings. Also, the recent document focuses on the global level analysis to explore the determinants of green growth. In the future, region-wise analysis may produce more directional findings for suitable policy recommendations. Besides, future studies can enrich the model by including blockchain, artificial intelligence, and fintech technologies for more interesting findings.

## Ethics approval and consent to participate

Not applicable.

## Consent for publication

Not applicable.

## Compliance with ethical standards

- Disclosure of potential conflicts of interest
- Research involving Human Participants and/or Animals
- Informed consent

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## Data availability statement

Data available on request due to privacy/ethical restrictions.

## CRediT authorship contribution statement

**Xiqiang Xia:** Supervision, Writing – original draft, Writing – review & editing. **Muhammad Zubair Chishti:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Eyup Dogan:** Methodology, Writing – original draft, Writing – review & editing.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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