Evaluating the Environmental Impact of Supply Chain Innovations across the Belt and Road Initiative: A Comparative Study of Pakistan, Russia, China, Kazakhstan, and Vietnam

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Abstract

In the contemporary epoch, China's Belt and Road Initiative (BRI) has disrupted the cross-border trade and logistics encapsulating Asia and Europe. However, its environmental impact is controversial and remains to be a great concern. This study is having an aim to address the prominent research gaps by scrutinizing the environmental implications of supply chain innovations among the five selected BRI countries. These countries include Pakistan, Russia, China, Kazakhstan, and Vietnam. The study incorporates the panel data analysis and respective environmental indicators in order to analyze the impacts of logistics efficiency, regulatory quality, and infrastructure on emissions and energy use. The study has unearthed that the improved logistics performance result sin the reduced levels of emissions, however, the regulatory differences remain a challenge for the creation of a unified environmental standard across the member countries. Deep insights have been crafted for the policy makers to help them balance the trade growth without compromising the environmental sustainability, by developing improved governance frameworks. Future researchers are recommended to further explore the regional collaboration to harmonize the environmental standards. Only achieving the said harmony will result in fostering the sustainable practices across diverse regulatory landscapes. The study offers a comprehensive approach towards development of understanding of environmental outcomes in terms of trade and infrastructure development in BRI nations. Hence, the study opens the endeavors for the sustainable international trade.

Keywords: *Logistics Performance; Environmental Sustainability; Belt and Road Initiative (BRI); Supply Chain Innovations; Regulatory Quality*

1.0. Introduction

1.1. Background and Context

The Belt and Road Initiative, known as BRI is a strategic project initiated by China (Carmody & Wainwright, 2022). BRI has disrupted the conventional means of business through creation of an extensive transportation and logistics infrastructure aimed at facilitating trade connectivity across Asia, Europe and Africa (Komakech & Ombati, 2023; Torun, 2023). The current growth in BRI has been beginning to boost the respective economies of the partner countries as mentioned by Ooi et al. (2011) and Wu and Han (2022) that include Pakistan, Russia, China, Kazakhstan and Vietnam. BRI is poised to catalyse economic opportunity yet brings with it environmental challenges including carbon emissions from large scale infrastructure development as well as higher resource consumption and ecosystem disruption (Bharti, 2023; Hussain et al., 2023).

Arguing that trade and logistics in cross border initiatives has gained significant interest in this frame of reference, Khanal and Zhang (2024) and Yu et al. (2024) depict that the environmental impact of trade and logistics in such initiatives is a hot topic.t. Nevertheless, recent technological trends such as digitalized logistics and green transportation are seen as indispensable tools against the environmental burden of the economic growth (Li et al., 2022; Sattar et al., 2022). Overall, the current understanding of the environmental performance of the said innovations in the diverse regulatory contexts remains underexplored.

1.2. Problem Statement

Despite the economic hopes and promises attached to the BRI, its rapid infrastructure has generated environmental challenges including but not limited to carbon emissions, pollution and resource overuse (Ali et al., 2022; Du et al., 2022). These challenges are particularly pronounced in cross-country initiatives where there is an existence of diverse and contradictory environmental standards and respective policies. Taidong (2022) and Zhang et al. (2022) explained that the diverse nature of the problem has further complicated the required efforts to implement consistent sustainability efforts and practices. Different countries in BRI have their own peculiarities in terms of logistics, environmental regulations as well and governance structures, which as a result leads to differences in the carbon footprints and resource management approaches (Ali et al., 2022; Luke

& Mageto, 2023a). Hence, there is a need to develop a deep understanding of how supply chain innovations and governance frameworks influence the environmental outcomes across these participatory countries.

1.3. Research Gap

The BRI-related economic and geopolitical implications have been pondered upon in many research studies, however, Nanli et al. (2022) and Wang et al. (2023) mentioned that its impact on the environment particularly through the lens of supply chain innovations has remained in the hindsight. The extant literature has a focus on emissions at the national level, however, scarcity appears when innovation in logistics and trade networks is required to be examined in terms of environmental sustainability at multiple countries' levels (Ge et al., 2022; Nanli et al., 2022; Ye et al., 2022). Furthermore, Mo and Madni (2023) and Ye et al. (2022) argue that limited comparative research has investigated the interaction between logistics efficiency, regulatory quality and the respective environmental outcomes. This paper has addressed these gaps by evaluating the role of supply chain innovations in reducing environmental harm within the BRI framework. The study offers deep insights into five chosen countries i.e. Pakistan, Russia, China, Kazakhstan, and Vietnam.

1.4. Research Objectives and Contribution

Given what has been argued in the previous section the study has devised the following research objectives:

1. To assess the environmental impact of infrastructure and supply chain innovations in selected BRI countries.
2. To analyse cross-country variations in environmental standards and regulatory compliance in selected BRI countries.
3. To investigate the role of supply chain innovations in reducing carbon emissions and resource use in selected BRI countries.

In this study, a gap was reduced that exists currently between trade logistics, environmental performance and governance, in the context of BRI countries. It presents a comparative analysis between the five countries for the interplay of trade openness, logistics efficiency and carbon emissions. This study has attempted to reduce the existing gap present between trade logistics, environmental performance and governance, in the context of BRI countries. The study offers a comparative analysis across five countries to provide valuable insights into the respective interplay of trade openness, logistics efficiency and carbon emissions. The study will enable the practitioners to develop a deep understanding of how they can devise sustainable strategies without damaging the environment and without compromising the economic well-being of the BRI countries.

1.5. Significance of the Study

This study offers myriad practical implications for the stakeholders including policymakers, environmental regulators and the private organizations that are directly involved in BRI projects. The study provides empirical evidence along with recommendations to enhance logistics performance while promoting sustainable practices. The study offers actionable insights to create the balance between economic growth and environmental stewardship based on the impact of trade openness and supply chain innovations on emissions. Furthermore, the study has highlighted the role of regulatory quality and governance to make sure that the BRI projects are well aligned with the sustainability goals.

This paper is divided into five sections, starting from the introduction where the background has been provided and the objectives of the study are devised, after this section a thorough review of the literature is presented encapsulating the extant literature covering supply chain innovations along with the environmental sustainability in cross border contexts. The third section is dedicated to the development of methods incorporated to meet the objectives of the study. In the further section, the empirical results are presented and the discussion is provided. In the end, the study has discussed the environmental implications of logistics performance, trade openness and governance to draw recommendations based on the findings.

2.0. Literature Review

The Belt and Road Initiative (BRI) is a transformational driver of infrastructure development and respective trade across Asia, Europe, and Africa, as the boons of interregional infrastructure and economic trade bloom (Upadhyay, 2023; K. Zhang, 2023). Increasingly, scholars and policymakers have become concerned about the environmental consequences of such large-scale projects. As the BRI is a huge infrastructure and resource-intensive project, numerous studies have examined its environmental challenges which include increased carbon emissions, deforestation, pollution, and high energy consumption (Q. Chen & Madni, 2023; Sattar et al., 2022a). To allow BRI to thrive in the long term, its sustainability is underpinned by addressing the associated challenges as infrastructure projects continue to proliferate.

This literature review evaluates the joint effect of supply chain innovations, governance rules, openness to trade, and logistics in shaping environmental outcomes in countries participating in the Belt and Road Initiative (BRI) (Li et al., 2023; W. Zhu & Fu, 2022). Further, the extant literature emphasises uneven adoption of green logistics and renewable energy efforts in countries including China, Pakistan, Kazakhstan and Vietnam. The mentioned countries and their respective performance effectiveness depend heavily on their economic priorities and governance structure (Awez et al., 2023; Rezaeinejad et al., 2023). Secondly, within the BRI framework, various researchers have tried to combine perspectives on how sustainability is being measured through digital technologies, eco-friendly transportation systems, and regulatory quality (Ahtyamov et al., 2023; Majeed et al., 2022). This review concludes by identifying existing gaps in the literature and suggests future research routes to help build towards sustainable development. The following sections will explore further these themes in the context of improving sustainable practises within the five selected BRI participant countries.

2.1. Institutional theory.

To examine the environmental impact of supply chain innovations across the Belt and Road Initiative, it is essential to consider institutional theory, which includes assumptions such as regulatory quality, government effectiveness, voice and accountability, and the rule of law. Strengthening these institutional dimensions could help mitigate emissions and promote supply chain innovation. In contrast, weak institutions are often associated with high emission rates and can hinder national growth. Several studies have demonstrated the role of institutions in designing, implementing, and addressing environmental challenges, contributing to national progress (Ali et al., 2023; Ješić & Jakšić, 2020). For example, China serves as a notable case, where strong and effective institutions have helped reduce emissions through numerous policies, including tax incentives and the provision of electric vehicles to companies meeting established environmental standards, while penalizing those that violate these regulations. These efforts have positioned China among the countries with lower emissions globally (Ali et al., 2022; Majeed et al., 2022).

However, many scholars have emphasized how weak institutions can exacerbate environmental challenges, threatening both supply chains and national development. For instance, in Vietnam, poor adherence to environmental policies by companies, coupled with government inaction in penalizing frequent violators of sustainability regulations, exacerbates environmental issues. Similarly, Pakistan and Kazakhstan face challenges due to weak institutional frameworks, marked by inconsistent and unstable environmental policies. These governments lack adequate monitoring and evaluation of sustainability measures, ranking these nations among the highest emitters globally (Awez et al., 2023; Khatri et al., 2022). This highlights the importance of strengthening institutions to help control environmental challenges and align with global emission reduction standards.

2.2. Environmental Impact of Infrastructure Development

The Belt and Road Initiative (BRI) infrastructure development has created a significant impact on trade connectivity, yet BRI has also given rise to environmental issues. This includes but is not limited to deforestation, land degradation, and emissions on a large scale that came from constructing highways, railways, and ports. During the construction phase of large-scale infrastructure expansions there is a dire need for heavy machinery, cement production, and land excavation which are major contributors of greenhouse gases and pollutants (M. Ali et al., 2022; Peredy et al., 2023). Improved transportation networks may ideally mitigate long-term logistical inefficiency but soon the immediate environmental mitigation actions become imperative (Anam et al., 2023; Zhou et al., 2023).

The development of infrastructure also relies on fossil fuels that only exacerbate emissions. BRI countries, for instance, Pakistan and Kazakhstan are heavily dependent on coal and natural gas, both resulting in carbon emissions and air pollution (Raza et al., 2023; Yerassyl et al., 2022). In Kazakhstan, for example, the expansion of rail networks has caused emissions to rise initially, exactly in line with the reliance on energy-intensive construction. Even if these rail networks are supposed to substitute more polluting road freight, effective reduction of $CO2$ emissions will take some time. China, had a short-term rise in emissions during its high-speed rail system's development but saw its freight-related emissions come down substantially with rail operations opened (Jiang & Zhang, 2023; L. Zhu et al., 2023).

Another factor of environmental concern is the excessive use of land that significantly disrupts ecosystems and biodiversity. Deforestation and conversion of natural habitats into industrial or transportation zones is a common feature of infrastructure projects made under the BRI (Du et al., 2022; Zhang et al., 2022). These activities are important to habitat fragmentation, which in turn results in local wildlife populations becoming in danger as well as increasing the risk of biodiversity loss. The effectiveness of environmental measures such as impact assessments and green building practices varies, widely among different countries. For instance, China has implemented green construction standards that advocate the utilization of eco-friendly materials, however, such steps are not evident in many of the BRI countries (Bin, 2023) due to the said disparities of policy.

Integrating renewable energy sources into BRI infrastructure projects will preserve the long-term sustainability of these projects. This means countries that actively develop infrastructure with solar, wind, and hydropower can drastically lower their emission and environmental degradation. But for countries like Pakistan, a fossil fuels-heavy energy mix persists (Chen, 2023; Khatri et al., 2022). To address the environmental impact of future projects, policymakers are required to encourage investors to invest in green infrastructure investments. In addition, there is a need to develop policies that promote sustainable construction practices (Y. Wang, 2023).

2.3. Trade Openness, Logistics Performance, and Environmental Sustainability

Trade openness plays a critical role in determining the environmental outcomes of the Belt and Road Initiative (BRI). Fostering cross-border economic cooperation will ultimately result in trade liberalization which will provide countries with access to cleaner technologies, advanced infrastructure, and sustainable practices (Wang et al., 2022). Engaging in international trade encourages firms to adopt environmental standards required by global markets, which in turn promotes green practices (Zhong, 2023). However, increased trade volumes also raise environmental risks. With the surge in transportation networks more extensive emissions, energy consumption, and pollution resulted (Tang et al., 2023). The environmental impact of trade is therefore closely linked to the efficiency of logistics systems and the capacity of countries to adopt sustainable solutions.

2.3.1. Trade Liberalization and Access to Sustainable Technologies

By improving trade openness, BRI countries are able to import energy-efficient equipment, environmentally friendly materials and clean technologies. China has used its role in global trade to embrace all forms of electric vehicles as well as renewably powered energy systems in transportation and logistics (Qian & Li, 2023). For example, Kazakhstan has gained from improved logistics infrastructure through the import of modern technologies improving both operational efficiency and environmental performance (Kredina et al., 2022). The environmental benefits of trade are however not automatic. Without green logistics infrastructure among the member countries, if higher transportation activities are taking place, it will result in increased emissions, particularly in countries where trade's fossil fuel dependency is high (Salam & Xu, 2023).

Economic gains from trade liberalisation have been traded against the lack of improved environmental gains in Pakistan, where the newly liberalised markets have increased the range of economic opportunities, however, outdated road infrastructure and inefficient freight systems have been unable to reap the full benefits of environmental gains (Zahra et al., 2022). As trade relies more on road transport, emissions are rising, necessitating investments in rail and electric transportation systems (Zubedi et al., 2022). However, without targeted investments in sustainable logistics infrastructure, trade openness can make matters worse, by worsening rather than improving environmental degradation.

2.3.2. The Role of Logistics Performance in Sustainability

The Logistics Performance Index (LPI) provides a picture of how efficient a country's logistics system is, and that reveals how much impact it has on the environment. In light of that, the higher the LPI scores, the closer the transportation routes are optimized, the shorter the delivery times, and the less energy is consumed, resulting in lower emissions (Luke & Mageto, 2023b; Sumbal et al., 2024). Focusing on investing in smart logistics platforms automating supply chain operations and reducing emissions significantly in China (Dong, 2022) which does well on the

LPI. However, Pakistan and Vietnam also demonstrate lower LPI scores, not accounting for ageing infrastructure, limited access to digital technologies, inefficient logistics, etc., resulting in higher emissions and energy consumption (Mu et al., 2022; Xuan et al., 2023).

2.3.3. Balancing Trade Growth and Environmental Costs

While trade openness and logistics performance drive economic growth, they can also increase environmental costs if not managed sustainably. Trade activities without green logistics systems lead to higher emissions, negating the environmental benefits of trade liberalization (Fan et al., 2022). Effective governance frameworks are essential to ensure that environmental policies are enforced and that businesses are incentivized to adopt sustainable practices. Countries must invest in rail transport, electric vehicle fleets, and renewable energy infrastructure to support sustainable trade networks (Rimal et al., 2022). Collaborative efforts among BRI countries are also needed to share best practices, promote green logistics technologies, and align environmental policies with trade growth (Salam & Xu, 2023).

2.4. Governance, Regulatory Quality, and Environmental Compliance

2.4.1. Governance Frameworks and Environmental Regulation

In adherence to the environmental standard within the Belt and Road Initiative (BRI), an effective governance system is required. Implementation and enforcement of environmental regulations through the quality of the governance system will promote sustainability through logistics activities and infrastructure development (Panchenko, 2022; Y. Yan et al., 2022). For instance, the China governance system is a good example of a country that demonstrated how a robust governance system could set standard for environmental standards through the adoption of green logistics initiatives. The implementation of policies that aim at monitoring and supervision of compliance and noncompliance on emissions and renewable energy standards (Klimov, 2023). This has helped China gain a significant rate of emission reduction across the globe.

However, nations with poor and weak governance systems often experience high rates of emissions. For instance, Vietnam and Pakistan are experiencing poor environmental issues in adopting policies that could help the nations achieve sustainable practices, this is due to poor governance systems (Arif et al., 2022). Specifically, Vietnam's economy is at increase, despite this growth, the country is battling with poor policies as there is no consistency in the implementation of the environmental law to achieve environmental compliance which could lead to a reduction of emissions (Pham et al., 2022). A similar case in Pakistan as the country also facing the challenges of the governance system in addressing environmental issues, this makes the country find it difficult to enforce policies that could mitigate these challenges(Amin, 2023). The unbalance between China and other BRI members underscores the governance quality in order to curtail the environmental challenges and achieve optimum benefits of sustainability across the BRI framework.

Additionally, the regulatory quality in adopting green logistics quality is crucial and also influences the rate at which companies and factories adopt green logistics practices. Companies and the various factories are ready to join the race of emission reduction via the regulatory quality that provides incentives to the companies by utilization of modern technologies, and further promotes energy efficiency (Wang et al., 2023). The subsidies policies that China introduced by providing electric vehicles and tax incentives to the companies that adhere to the green standards policy, encourage businesses to invest more in sustainable logistics infrastructure, this not only promotes sustainability but also ensures that firms align their operations with environmental goals (Charles TAN, 2023; Liang & Li, 2023).

In contrast, countries and regions with poor quality policies often set numerous environmental challenges to the companies as many companies consider the savings over the environmental sustainability issues, this further underrate the efforts of the undermining efforts of green logistics (Korkmaz et al., 2022). For instance, the inconsistency of the green logistics policies in Vietnam and Pakistan due to poor and weak regulatory policies has discouraged a number of investors from engaging and participating in environmental sustainability processes (Luu & Tam, 2023). There is a need to address the regulatory quality in order to promote sustainability practices across the companies and the factories that are directly involved in environmental issues. It is undeniable that strengthening the regulatory quality across BRI nations will help and stimulate the efforts of green logistics practices, further curtail the environmental challenges that are attributed to the trade and transportation networks.

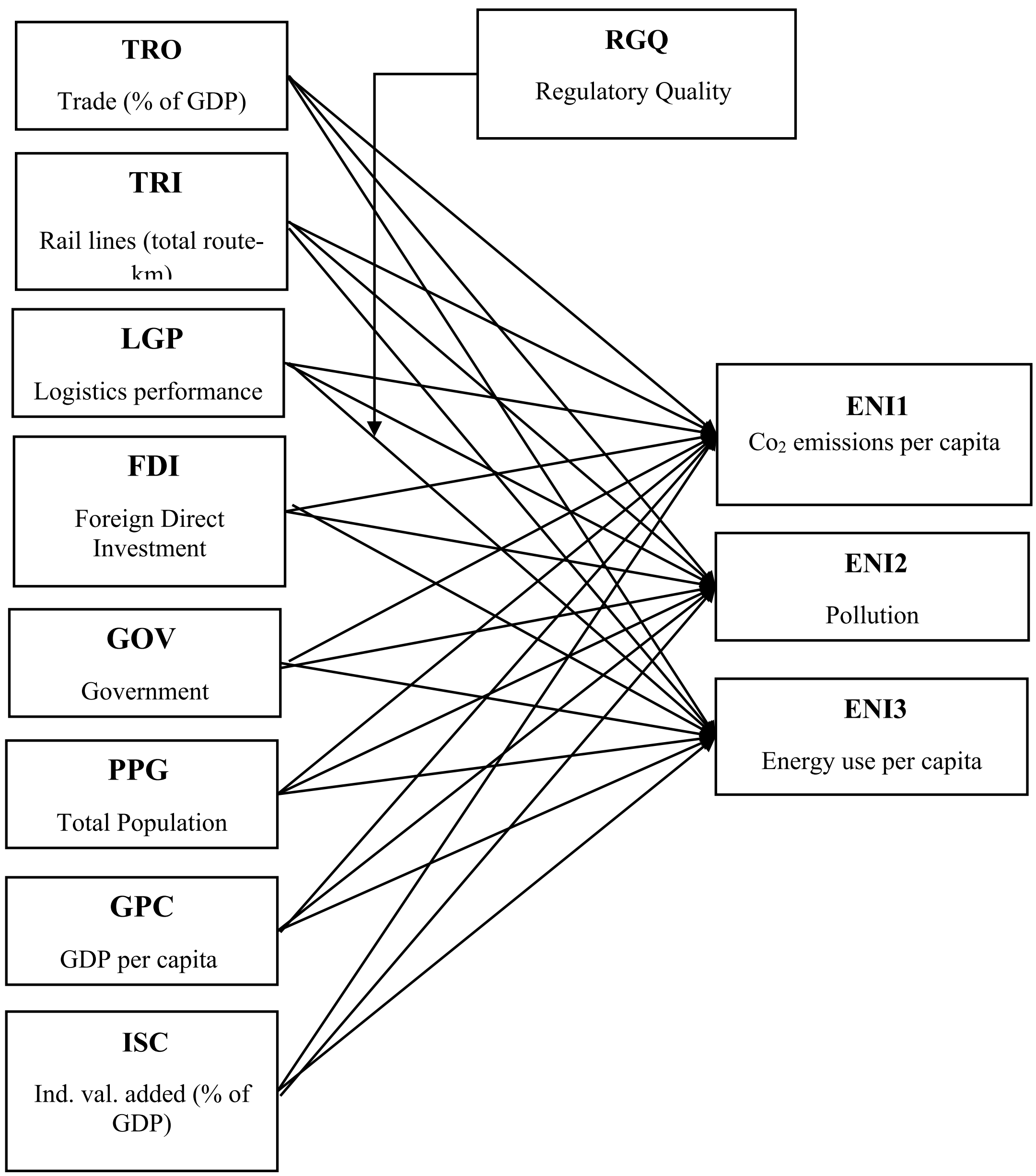
2.5. Cross-Country Comparisons and Disparities within the BRI

2.5.1. China's Leadership in Sustainability

Regarding renewable energy adoption and green logistics, China has been one of the leading nations in the BRI. The usage of electric vehicles and high-speed rail networks in many cities in

Figure 1

Conceptual Framework



Note. Developed by the author for the study

China has contributed to the reduction of emissions urban logistics has decreased the environmental challenges which often emanate from the emissions (Chen, 2023; Eskenazi, 2022). The rate at which China is investing in the smart logistics arena, electric vehicles, and high-speed rail networks, has significantly reduced the emission rate across the country (Z. Yan et al., 2023). China's emphasis on green logistics aligns with its broader environmental goals, which include transitioning to renewable energy and achieving carbon neutrality by 2060 (Ma, 2023).

Hence, based upon the literature; well-grounded in literature the study proposed the following conceptual framework (see Figure 01).

3.0. Research Methodology

This study assessed the impact of environmental supply chain innovations across the Belt and Road Initiative across Pakistan, Russia, China, Kazakhstan, and Vietnam. The panel analysis was employed in analyzing the study objectives. World Development Indicators (WDI), and World Governance Indicators (WGI), 2024 were used for the required data for the study. Several data were considered based on their relevancies to the study, this includes the three (3) dependent variables: CO2 emissions per capita (ENI1), which measure the environmental impact of the supply chain and the economic activities. Regarding the measurement of the environmental externalities of supply chains, it is crucial to consider the Pollution (ENI2) and energy use per capita (ENI3), this indicator is essential in assessing energy demands for the supply chain and industrial activities. While the independent and the control variables for the study are the following: To examine the extent of rail transport to reduce the environmental footprint of supply chains along the BRI, the study considers Rail lines (total route-km) (TRI) as one of the important indicators, Logistics performance index (LGP), This index assesses logistics quality, infrastructure, and service efficiency. Foreign direct investment (FDI), Trade (% of GDP) (TRO), and GDP per capita (GPC) play an important role in examining the economic impact of these environmental challenges. Government Effectiveness (GOV), and Regulatory Quality (RGQ), are crucial in assessing the extent to which the quality of public services and the policy formulation across these countries. Total population (PPG) is also a valuable indicator to be considered for this study as to which population influences the environmental and supply chain processes, and Industrial Value added (% of GDP) (ISC), which measures the industrial activity, serve as the economic driver and a major source of environmental pollution. This study captured the period of twenty-eight (28) years (1996 – 2023). In order to achieve the objectives of the study, preliminary tests (descriptive statistics and correlation matrix) were conducted as they are very crucial in the data analysis (Fan et al., 2015). **This paper expands the data to cover the latest data available between 1996 and 2025 and adds new indicators of both the World Development Indicators (WDI, 2025) and World Governance Indicators (WGI, 2025). The extension enhances the strength and topicality of the results as it reflects the latest trends in green logistics, online supply chains, and post-COVID trade relationships.** For the main objectives, several tests were also considered in which Panel Corrected Standard Error (PCSC) Regression was used as the most appropriate and suitable for a study like this (Ha et al., 2023; Zakari et al., 2022). There are three major models that were considered for this study which were based on the objectives of the study:

In assessing the environmental impact of infrastructure and supply chain innovations in BRI countries, the model followed the work by Hall (2000) and Vachon (2007).

$ENI1_{it} = \beta_0 + \beta_1 TRI_{it} + \beta_2 LGP_{it} + \beta_3 RGQ_{it} + \beta_4 PPG_{it} + \beta_5 GPC_{it} + \mu_i + \epsilon_{it}$………………Eq. (1)

The second objective is to analyse cross-country variations in environmental standards and regulatory compliance. The model was:

$ENI2_{it} = \beta_0 + \beta_1 TRO_{it} + \beta_2 GOV_{it} + \beta_3 RGQ_{it} + \beta_4 GPC_{it} + \beta_5 ISC_{it} + \mu_i + \epsilon_{it}$………….. Eq. (2)

The third objective is to investigate the role of supply chain innovations in reducing carbon emissions and resource use. The model used is:

$ENI3_{it} = \beta_0 + \beta_1 LGP_{it} + \beta_2 FDI_{it} + \beta_3 PPG_{it} + \beta_4 GPC_{it} + \beta_5 ISC_{it} + \beta_5 LGP_{it}*RGQ_{it} + \mu_i + \epsilon_{it}$… Eq. (3)

Dependent Variables (Environmental Indicators)

The paper uses three major dependent variables to reflect the environmental externalities of supply chain activities in BRI countries. To obtain the CO2 emissions per capita (ENI1), the data on the World Development Indicators (WDI) is used to estimate the metric tons per person. The variable demonstrates the intensity of economic and logistic activities on carbon and is one of the main indicators of environmental degradation (World Bank, 2024). Second, the levels of pollution (ENI2) are obtained based on PM2.5 concentration, which is measured in micrograms per cubic meter. It is generally accepted that PM2.5 is an effective proxy of environmental pollution because it represents emissions produced by transportation, industrial production, and logistics (WHO, 2023; World Bank, 2024). Greater levels of PM2.5 implies that there is more harm caused to the environment due to the supply chain externalities. Third, per capita consumption of energy (ENI3) is calculated in kilograms of oil equivalent per capita, derived out of WDI. This variable is the level of energy used in logistics, transportation, and industrial processes of supply chains (IEA, 2023).

Independent Variables

The independent variables represent the impact of logistics performance, infrastructure, trade integration and investment in environmental outcomes. The Logistics Performance Index (LPI) is calculated as per the LPI scale of the World Bank (1-5) which assesses the customs efficiency, the quality of infrastructure, the reliability of shipment and competence of logistics. An increase in LPI scores implies the existence of more efficient logistics systems that can minimize emissions due to optimized operations (World Bank, 2023). Total rail lines in route-kilometers (Rail infrastructure (TRI)) is a proxy of sustainable transport infrastructure because rail systems tend to cause fewer emissions than road freight (Zhu et al., 2023). Trade openness (TRO) is an indicator of the extent of integration of the country to the world markets and is calculated as a ratio of trade to GDP. Trade openness allows a country to have access to advanced technologies and environmentally friendly practices, but its impact on the environment is contingent on the supporting infrastructure (Wang et al., 2022). The foreign direct investment (FDI) is calculated as net inflows as a percentage of GDP and it reflects the inflows of international capital, which can raise industrial production and energy consumption in the short term and technological transfer and efficiency in the long term (Qamruzzaman, 2022).

Governance Variables

The variables related to governance are included in order to reflect the institutional environment that impacts on environmental results. The World Governance Indicators (WGI) are used to measure government effectiveness (GOV) and it has a range of values between approximately -2.5 and +2.5. This indicator shows the level of quality of the services provided by the government, policy execution, and the efficiency of the administration, which are important to implement environmental regulations (World Bank, 2024). Another measure based on WGI is regulatory quality (RGQ), the capacity of governments to develop and adopt effective policies to enhance development of the private sector and at the same time ensuring environmental compliance. Good-quality regulation prompts companies to develop a sustainable approach and invest in green technologies (Kamal et al., 2022).

This paper expands the collection of data to the latest data available since 1996 to 2025, with new indicators in the World Development Indicators (WDI, 2025) and World Governance Indicators (WGI, 2025). The extension enhances the strength and topicality of the findings as it reflects the latest trends in green logistics, digital supply chains, and post-COVID trade relations**.**

4.0. Results and Discussion

4.1. Summary Descriptive Result

The descriptive statistics provide valuable insights into the variables used in this study (see Table 1). The means and standard deviations highlight variability across key indicators, such as CO2 emissions per capita (ENI1), energy use per capita (ENI3), and trade openness (TRO). Specifically, the mean CO2 emissions are 6.51 tons per capita, with a standard deviation of 5.01, indicating significant cross-country variation. Similarly, the wide range of logistics performance index (LGP) scores, from 2.12 to 3.70, reflects disparities in logistics efficiency among the countries studied. Skewness and kurtosis values reveal moderate normality deviations, suggesting the data is well-behaved for regression modelling. Notably, TRO exhibits high skewness (1.20), implying some countries are outliers in terms of trade openness. Overall, these statistics confirm sufficient variability, ensuring reliable empirical analysis. The panel observations are made up of 30 years (1996-2025) of 5 countries, and the total number of observations is 150 (5 countries x 30 years). This panel balanced design facilitates consistency and reliability in the regression estimates.

Table 1

Summary Descriptive Result

Variable	Definition	Source	Mean	Std. Dev.	Min	Max	Skewness	Kurtosis
ENI1	CO2 emissions per capita	WDI	6.51	5.01	0.52	16.16	0.17	1.48
ENI2	Pollution	WDI	32.85	16.97	11.27	71.71	0.60	1.91
ENI3	Energy use per capita	WDI	2097.36	1563.78	308.38	5160.64	0.46	1.77
TRO	Trade (% of GDP)	WDI	67.34	40.16	21.46	186.68	1.20	3.51
TRI	Rail lines (total route-km)	WDI	37240.32	35583.41	2347.00	109767.00	0.51	1.53
LGP	Logistics performance index	WDI	2.87	0.39	2.12	3.70	0.55	2.24
FDI	Foreign direct investment	WDI	3.42	2.62	0.39	9.71	0.99	3.34

GOV	Government Effectiveness	WGI	0.32	0.36	-1.07	0.81	0.59	3.04
RGQ	Regulatory Quality	WGI	0.45	0.23	-1.14	0.15	0.05	3.35
PPG	Total population	WDI	48.87	16.54	22.56	75.33	0.24	1.70
GPC	GDP per capita	WDI	4720.05	4537.43	329.00	15941.45	0.87	2.34
ISC	Ind. val. added (% of GDP)	WDI	33.07	8.28	17.16	47.56	-0.28	2.32

Note. Developed by the author for the study

4.2. Correlation Matrix Results

The correlation matrix provides preliminary insights into relationships among key variables (see. Table 2). CO_2 emissions (ENI1) show a positive correlation with energy use per capita (ENI3, $r = 0.71$, $p < 0.01$), suggesting that higher energy consumption contributes to increased emissions. However, ENI1 is negatively associated with trade openness (TRO, $r = -0.12$, $p = 0.15$), indicating that open trade may facilitate access to cleaner technologies. A positive relationship between ENI1 and GDP per capita (GPC, $r = 0.74$, $p < 0.01$) suggests that economic growth drives emissions, reflecting potential trade-offs between growth and sustainability. Regulatory quality (RGQ) correlates positively with ENI1 ($r = 0.56$, $p < 0.01$), implying that governance measures may initially boost emissions due to industrialization efforts. Notably, logistics performance (LGP) demonstrates a weak negative correlation with emissions ($r = -0.19$, $p = 0.03$), supporting the hypothesis that better logistics efficiency reduces environmental impact. These correlations provide a foundational understanding for further regression analysis, reinforcing the importance of trade, governance, and logistics performance in environmental sustainability.

Table 2

Correlation Matrix Results

	ENI1	ENI2	ENI3	TRO	TRI	LGP	WFDI	GOV	RGQ	PPG	GPC	ISC
ENI1	1.00											
ENI2	-0.61	1.00										
	0.00											
ENI3	0.71	-0.54	1.00									
	0.00	0.00										
TRO	-0.12	-0.51	-0.23	1.00								
	0.15	0.00	0.01									
TRI	0.50	-0.14	0.57	-0.45	1.00							
	0.00	0.09	0.00	0.00								
LGP	-0.19	0.25	-0.34	0.11	0.16	1.00						
	0.03	0.00	0.00	0.19	0.05							

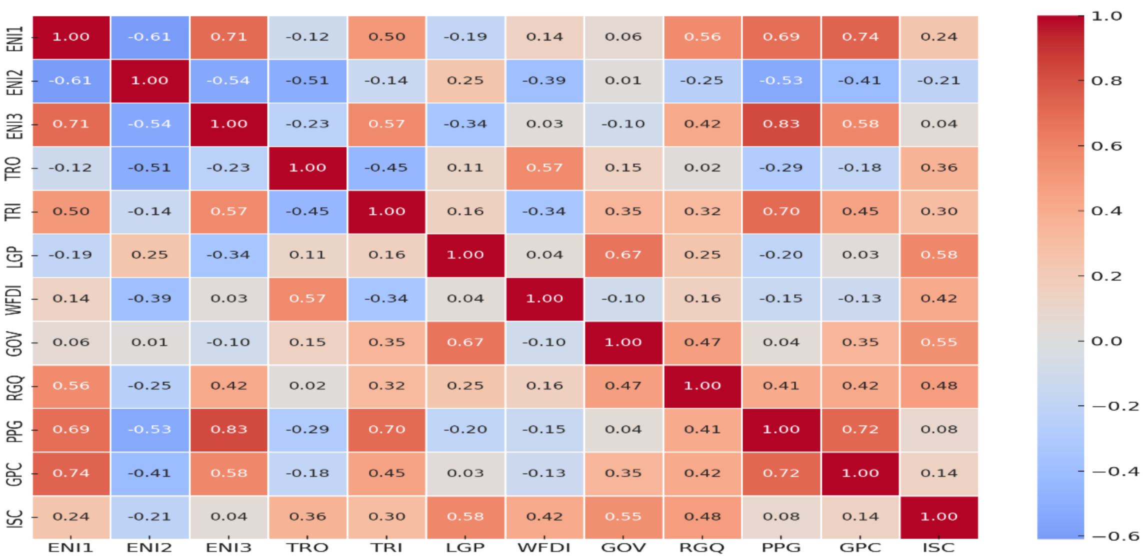
WFDI	0.14	-0.39	0.03	0.57	-0.34	0.04	1.00					
	0.10	0.00	0.69	0.00	0.00	0.61						
GOV	0.06	0.01	-0.10	0.15	0.35	0.67	-0.10	1.00				
	0.49	0.95	0.24	0.07	0.00	0.00	0.24					
RGQ	0.56	-0.25	0.42	0.02	0.32	0.25	0.16	0.47	1.00			
	0.00	0.00	0.00	0.83	0.00	0.00	0.06	0.00				
PPG	0.69	-0.53	0.83	-0.29	0.70	-0.20	-0.15	0.04	0.41	1.00		
	0.00	0.00	0.00	0.00	0.00	0.02	0.09	0.62	0.00			
GPC	0.74	-0.41	0.58	-0.18	0.45	0.03	-0.13	0.35	0.42	0.72	1.00	
	0.00	0.00	0.00	0.03	0.00	0.76	0.14	0.00	0.00	0.00		
ISC	0.24	-0.21	0.04	0.36	0.30	0.58	0.42	0.55	0.48	0.08	0.14	1.00
	0.00	0.01	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.32	0.09	

Note. Developed by the author for the study

Figure 2 below illustrates and supports the correlation results obtained above, where the darker shades indicate stronger relationships in the visual below.

Figure 2

Correlation Matrix

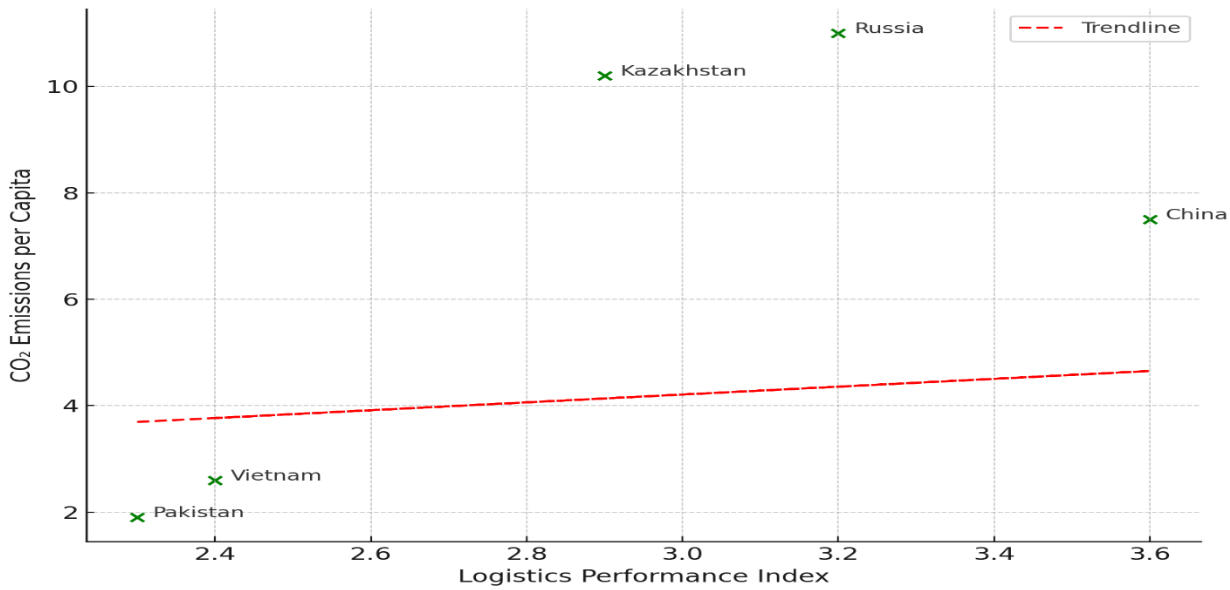


Note. Developed by the author for the study

Figure 3 shows the negative relationship between logistics performance and CO_2 emissions, as this supports the argument that strong regulatory quality can help reduce the emissions across BRI countries.

Figure 3

Relationship Between Logistics Performance and CO_2 Emissions in BRI Countries



Note. Developed by the author for the study

4.1. Discission of Findings

Table 3 presents the Panel-Corrected Standard Errors (PCSE) Regression. Several analyses were conducted to actualize the set-out objectives of the study. Hausman test was conducted after the Fixed and random effect regression to decide the appropriate technique to be considered, the Hausman result of all three objectives favored the FE with significant p-value of (0.000, 0.000, and 0.0077) respectively. The Panel heteroskedasticity test was also considered to ascertain the presence or the absence of heteroskedasticity in the model. The three results revealed the following p-value (0.000, 0.000, and 0.000) respectively, this suggests that there is the presence of the Panel heteroskedasticity in the models, which needs to be addressed, in order to address this, we employed the use of PCSE.

For the first objective, assessing the environmental impact of infrastructure and supply chain innovations in BRI countries, the results show key insights. Trade openness (TRO) has a significant negative impact on CO2 emissions per capita, with a coefficient of -0.28016, suggesting that as BRI countries increase trade, their emissions per capita tend to decrease. This may be due

Table 3

Panel Corrected Standard Error (PCSC) Regression

Explanatory Variables	Label	First Objective		Second Objective		Third Objective	
		DV: CO2 EMISSION PER CAPITA (ENI1)		DV: POLLUTION (MICROGRAMS PER CUBIC METER) (ENI2)		DV: ENERGY USE PER CAPITA (ENI3)	
		Coef.	**Het-Cor. Std. Err**	**Coef.**	**Het-Cor. Std. Err**	**Coef.**	**Het-Cor. Std. Err**
Trade (% of GDP)	TRO			-0.28016***	0.01718		
Rail lines (total route-km)	TRI	0.00003***	0.00001				
Logistics performance ind.	LGP	-2.06252***	0.69594			-2477.27***	412.503
Foreign direct investment	FDI					109.44***	43.563
Government Effectiveness	GOV			19.36244***	2.94443		
Regulatory Quality	RGQ	1.08441*	0.64411	-11.83887***	5.29548		
Total population	PPG	0.18179***	0.02498			123.07***	13.735
GDP per capita	GPC	0.00018***	0.00004	-0.00225***	0.00025	-0.032	0.0328
Ind. val. added (% GDP)	ISC			-0.08732	0.13749	-44.127	27.779
Log. Per. * Reg. Qual.	LGP*RGQ					424.990***	148.734
Constant		2.13963	2.22823	66.09625***	6.94313		
		Model Specifications					
Hausman test Chi2		79.8400		80.4800		13.87	
Hausman test (P-Value)		0.0000		0.0000		0.0077	
R-Square		0.9633		0.6342		0.8278	
Panel het. test		806.2400		1199.43		7957.51	
Het. P-Value		0.0000		0.0000		0.0000	
Wald chi2		4299.04		289.36		914.01	
Model P-Value		0.0000		0.0000		0.0000	

Note: *, ** and*** denotes significant level at 10%, 5% and 1% respectively

Source: *Generated by Author using STATA*

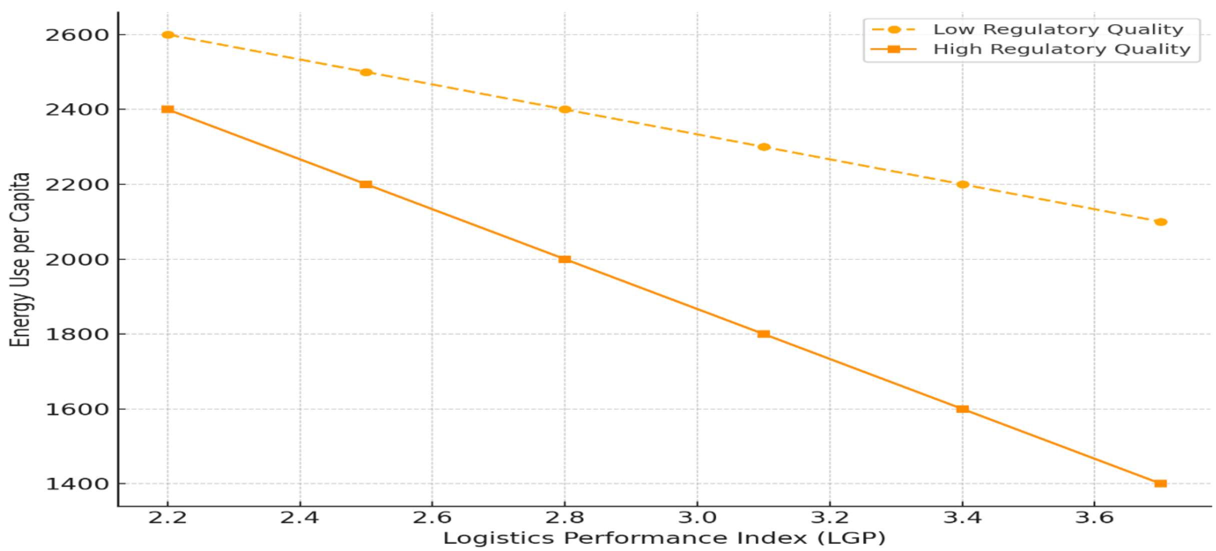
Note. Developed by the author for the study

to increased access to cleaner technologies and more efficient supply chain practices that come with global trade. The study corroborated with the study that emphasized the need to engage in modern technologies in reducing the emission rate (Ali & Wang, 2023). The coefficient for rail lines (TRI) is positive but small (0.00003), indicating that while expanded rail infrastructure supports supply chain connectivity, it may initially contribute to emissions, likely due to construction or increased use. The finding aligned with a study that stated how the infrastructure could enhance the supply chain (Alexandro & Basrowi, 2024). Logistics performance (LGP) demonstrates a strong negative effect on emissions, with a coefficient of -2.06252, suggesting that high logistics efficiency significantly reduces emissions by optimizing transportation. The study supported the study which revealed that logistics reduce the emission rate (Pomfret, 2023). However, regulatory quality (RGQ) shows a positive coefficient (1.08441), indicating that while regulations may help control practices, certain regulatory policies might push for rapid

Figure 4 illustrates that regulatory quality helps and improves logistics performance, which could reduce energy use; this reinforces the crucial role of strong governance in achieving environmental benefits across these countries.

Figure 4

Interaction effect of logistics performance and regulatory quality on energy use per capita



Note. Developed by the author for the study

industrialization, temporarily increasing emissions. The finding agreed with the study which stated that poor regulatory policies associated with increase in emission rate (Wu et al., 2023; Zhang & Han, 2022). Population size (PPG) and GDP per capita (GPC) both have positive impacts on emissions, with larger populations and economic growth creating additional demand for transportation and industrial activities, leading to higher emissions. The findings is consistence with the numerous studies that argued on how higher population could increase the demand (Sattar et al., 2022b; Zhang & Han, 2022).

The second objective focuses on cross-country variations in environmental standards and regulatory compliance. The results reveal that trade openness is associated with lower pollution levels, as indicated by a significant negative coefficient for TRO (-0.28016). This may suggest that open trade environments encourage environmentally friendly practices through global partnerships. Also supported by the studies that emphasized on the need for trade partnership (Kapma, 2023). However, government effectiveness (GOV) has a significant positive impact on pollution (19.36244), which could imply that while these governments enforce policies effectively, they might also support industries that increase pollution as part of economic development. This was also supported by the believe on the poor institutions in speeding the environment challenges (Geng & Lo, 2022; Kamal et al., 2022). Regulatory quality (RGQ) has a strong negative effect (-11.83887), confirming that better regulatory quality tends to reduce pollution levels through stricter enforcement of environmental standards. This supported the studies on how the role of institutions in minimizing the emission rate (Sheng et al., 2023). Higher GDP per capita (GPC) also shows a negative relationship with pollution, indicating that wealthier countries may have more resources to invest in cleaner technologies, thus reducing pollution. This supported the debate of how access to trade flow could reduce the emission rate through the modern technologies (Zhang et al., 2020). Industrial sector value-added (ISC) shows a non-significant yet negative coefficient, suggesting that industrial activity may not necessarily increase pollution if cleaner production methods are implemented.

For the third objective, investigating the role of supply chain innovations in reducing carbon emissions and resource use, the results show that logistics performance (LGP) has a substantial negative effect on energy use per capita (-2477.27), suggesting that advanced logistics practices lead to significant reductions in energy consumption. This aligns with expectations that optimized logistics reduce fuel consumption and emissions (Paisarnvirosrak & Rungrueang, 2023; Ye et al., 2022a). Foreign direct investment (FDI), on the other hand, has a positive coefficient (109.44), indicating that FDI may initially increase energy demand due to energy-intensive industrial projects. This agreed with the study on how FDI could demand for more energy as to actualize the mission of the investors (Qamruzzaman, 2022). However, this effect might lessen over time as sustainable practices are integrated. Population size (PPG) has a positive effect on energy use (123.07), likely reflecting increased demand for goods and services with larger populations. The study corroborated with the studies that emphasized on how higher population could increase the demand for energy (Sattar et al., 2022b; Zhang & Han, 2022). Although not statistically significant, GDP per capita (GPC) shows a slightly negative coefficient, hinting at a potential decrease in energy use as economies develop and adopt more efficient practices. The interaction term between logistics performance and regulatory quality (LGP*RGQ) has a significant positive effect (424.990), suggesting that when strong regulations are in place, advanced logistics practices can lead to even greater energy efficiency. This aligned with the study that emphasized the need for effective regulatory system (Tsymbal et al., 2023b; Ye et al., 2022b).

The difference between Pakistan, Russia, China, Kazakhstan, and Vietnam can be attributed mostly by the differences in the quality of the institutions, logistics efficiency, energy structure, technological adoption levels. An example of a country that shows relatively low emissions is China, which has a robust governance system, a high level of enforcing regulations, and high investment in green logistics and renewable energy infrastructure (Majeed et al., 2022; Ma, 2023; Yan et al., 2023). Conversely, Pakistan and Kazakhstan have a greater level of emissions, which is mainly determined by their still using fossil fuels, especially coal and natural gas, weaker institutional arrangements, and inconsistent adherence to environmental regulations (Khatri et al., 2022; Yerassyl et al., 2022; Amin, 2023). The environmental performance of Russia is affected by the fact that the country has a resource-based economy, in which energy-intensive sectors are major sources of emissions despite the fact that some measures have been improved (Klimov, 2023). In the meantime, Vietnam is a transitional dynamic, with fast industrialization and export-oriented growth putting pressure on the environment, which can far exceed the creation and implementation of environmental policies (Pham et al., 2022; Luu and Tam, 2023). The differences point to the fact that not all BRI countries have an equal effect on the environment because the results of supply chain innovations are highly dependent on the national governance capacity, the economic system, and the priority of the national policies (Sheng et al., 2023; Kamal et al., 2022).

5.0. Conclusion

This study examined the environmental impact of supply chain innovations across the Belt and Road Initiative (BRI) in Pakistan, Russia, China, Kazakhstan, and Vietnam. The study revealed several findings, as several factors were identified as barriers against the environmental sustainability of BRI projects, these factors include logistics performance, institutional quality, and trade flow in these countries. Also revealed how the growth of the economy across the BRI could be enhanced through channels, like infrastructural development, and effective trade flow as these will help in addressing the environmental challenges. This corroborated with the studies that emphasized the effectiveness of institutional quality as the grease and booster of economic activities (Huang & Wang, 2022; Tsymbal et al., 2023b; Ye et al., 2022b). The study also shows that trade flow reduces CO2 emissions and pollution. This implies that countries gain access to cleaner technologies and improved logistics practices depending on their engagement with global market activities. The implementation of advanced logistics practices, such as digitalized transport systems and green logistics, will not only optimize operations but also contribute to the broader sustainability goals of the BRI. This is aligned with the studies that argued that technology is crucial in assessing logistics activities (Kwon et al., 2022; Mokhammad, 2023). While the study identified challenges in reaping the outcome of sustainability benefits, these challenges were associated with poor and weak governance systems in some countries.

The results of this research can have a number of relevant managerial and policy implications to stakeholders participating in the Belt and Road Initiative (BRI) projects. To begin with, the efficiency of logistics, measured by the Logistics Performance Index (LGP) is of paramount importance in terms of the minimization of emissions and energy usage, which implies that companies must focus on the implementation of digital logistics solutions, technologies of route optimization, and smart supply chains. Second, effective regulatory systems, which are embodied by regulatory quality (RGQ), can greatly improve environmental sustainability, which means that governments should implement environmental rules and regulations fully and offer incentives to green innovation. Third, the development of rail infrastructure (TRI) ought to be favored over road transport since road systems are less energy-efficient and carbon-intensive than railway systems are. Fourth, foreign direct investment (FDI) policies must be well formulated to get environmentally friendly projects as opposed to energy consuming industries that cause environmental degradation. Lastly, improved regional integration between BRI countries is necessary to coordinate environmental standards, minimize inconsistency in regulations, and eliminate environmental arbitrage. Hence, sustainable supply chain management in the BRI has to be a coordinated effort that incorporates technological innovation, institutional fortification and cross-border environmental management.

The findings are accompanied by a number of implications, as these findings will help the policymakers and all the stakeholders within BRI projects. This will help stimulate environmental sustainability, through adequate and effective investment in sustainable infrastructure and strengthen logistics performance through policy incentives for ecosystem practices. Strengthening the regulatory quality and ensuring effective enforcement of environmental standards will be important in managing pollution levels and promoting responsible industrial practices. In addition, fostering regional collaboration among BRI countries will enable the establishment of consistent environmental standards and quality practices, amplifying the collective impact of individual national policies. Future researchers should consider the dynamics of FDI, governance, and logistics performance which are essential for effective strategies to foster a sustainable future for the BRI and its member countries. Additionally, comparative research across multiple BRI countries will help highlight best practices and provide a roadmap for harmonizing environmental policies and trade regulations.

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