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KEYWORDS	ABSTRACT
Climate-ecological pressure, green transition, green financial innovation, digital connectivity, institutional capacity, GMM.	The Belt and Road Initiative (BRI) has revolutionized the world with a new line of infrastructure and trade, but its environmental impacts have been controversial, with member countries digitalizing at the same time but not together with green financing. This study investigates the dynamic interaction between climate-ecological pressure and green transition in BRI economies from 2000 to 2025. The data were obtained from the World Development Indicator using a two-step system GMM estimator. This result reveals that green transition and green financial innovation have a significant impact on climate-ecological pressure, making them good levers for decarbonization. Similarly, the capacity of institutions to sustain ecological pressure underscores the relevance of good governance in improving environmental conditions. However, the positive effects on climate-ecological pressure are large, and digital connectivity is slowing the pace of the green transition in this part of the world, creating an uncertain balance between digital expansion and the green transition. It is concluded that ecological pressure and green transition dynamics have no short run influence, but they are structurally embedded. The findings indicate that digitalization will not provide environmental dividends in BRI economies without improving the green financing framework and institutional checks and balances. This study provides policy-relevant evidence of how the digital infrastructure investment of the BRI is connected to the BRI corridor's climate governance frameworks.
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Introduction

Climate-ecological development pressure is one of the key pressures in BRI-linked economies. Since 2013, the BRI has built up infrastructure, trade, and energy links to over 140 partner economies, albeit at the expense of the environment. Recent evidence shows that BRI-linked construction and investment activity has measurably raised ecological footprint and carbon emissions in member economies, particularly where industrial structure and foreign direct investment mediate the relationship (Ran & Zhang, 2023; Su, Qiao, Xu, 2024). The supply chain carbon emissions of transport and infrastructure projects funded solely by the BRI have led to billions of tons of embodied CO₂ (Wang et al., 2023), and tourism and trade movement along BRI corridors introduce additional carbon emissions transferred across international boundaries (Shi et al., 2024). At the same time, BRI economies are pursuing two transitions simultaneously rather than sequentially: a shift toward renewable energy and a rapid expansion of digital infrastructure through the so-called Digital Silk Road. This dual pursuit raises an open question that the literature has not yet resolved with dynamic panel evidence: whether green transition, green financial innovation, and digital connectivity move climate-ecological pressure in the same direction or work against one another once institutional and economic conditions are held constant.

Green transition, measured through the share of renewable energy in total consumption, is widely treated as a direct lever for reducing ecological pressure. It is usually assumed that the transition to green energy (as the share of renewables in total demand) is directly leveraged towards the reduction of ecological pressure. Evidence from OECD and BRICS countries, covering a wide range of cross-country data, reveals that countries that invest in renewable energy experience a reduction in carbon intensity, green innovation, and supportive environmental regulation (Deng et al., 2024; Sadiq et al., 2024). The installation of renewables in BRI partner countries has been observed to significantly affect energy transition pathways, including the level of speed-up in energy transition processes across various regions and the institutional capacity at the local level (Chishti, 2024; Ullah, 2025). This change is reinforced by the green financial innovation of the movement of capital from carbon-intensive activities. Both firm-level and macro-panel studies reveal that green finance instruments, such as green credit, green bonds, and eco-innovation financing, can effectively lower carbon emissions and facilitate the shift of investment towards low-carbon industries, while the impact is enhanced by the synergy with technological innovation and stable fiscal policy (Du, Zhang, & Hou, 2025; Gul & Hussain, 2024; Tariq & Hassan, 2023). However, few studies have been conducted on the BRI, and the findings of this article are mostly from China or samples from one region.

ICT can help create smart grids, remote work, and resource efficiency, and several studies indicate emission reductions in the presence of good quality and institutional capacity of ICT (Zaman et al., 2026; Appiah-Otoo et al., 2023). The energy use of digital infrastructure, from data centers to mobile networks, can taint these gains; however, in some cases, digitalization seems to intensify environmental strain in countries in the early stages of developing a technology base (Khan, Abidin, Qammar, & Horani, 2025). The complexity is why it is interesting to test digital

connectivity in the same model as climate-ecological pressure and green transition and not serve as a background control, as integration and digitalization have been observed to have an opposite effect on the adoption of renewable energy in countries with varying technological development (Zhang et al., 2025).

The other three are most consistently related to institutional sustainability capacity. Research on this topic using government effectiveness measures revealed that the government effectiveness measure reinforced the impact of renewable energy and green innovations on environmental emissions, while weak governance measures did not seem to affect environmental policy commitments regardless of the amount of green finance invested in the country or renewable energy installed (Gao & Fan, 2023; Ahmad, Rjoub, & Hussain, 2024). There is also evidence at the EU regional level that the green and digital transitions are correlated; that an economy without institutional support will be less impactful on the climate than on the economy (Bănică et al., 2024). Finally, it is the linkage between economic performance and environmental results that requires further control, with an improvement in the economy either fueling investments in cleaner technology or increasing the use of resources (Shahzad, 2025; Su et al., 2024).

Despite all this research, there are three gaps. First, most studies on BRI address one component of BRI (either energy transition or digitalization) but fail to quantify both aspects in one dynamic framework in relation to a common climate-ecological pressure outcome. Second, while the literature referenced above indicates that the level of green financial innovation and green financial capability of the sustainability institutions could serve as robustness controls instead of explanatory variables because of possible conditions influencing the impacts of green financial innovation on ecological outcomes, this possibility cannot be ruled out. Third, the persistence of the environmental pressure (the degree to which 'yesterday's' environmental pressure influences 'today's') is rarely modelled explicitly but is very relevant to the speed with which policy can realistically impact results.

This study aims to do so by building a two-step system GMM estimator that identifies the impact of green financial innovation, digital connectivity, institutional capacity to support sustainability, and economic performance of the BRI economies during the study period (2000-2025) as a dynamic and persistent influence on green transition. Tests conducted prior to the estimation period to confirm the panel structure and to guarantee the causal inference and not spurious association like cross-sectional dependence, slope heterogeneity, second-generation unit root, and cointegration behavior. The rest of the paper is structured as follows. In Section 2, the theoretical and empirical relationships of each of the variables are discussed in more detail. The data, measurement, and econometric approach are presented in Section 3. The results of the estimates are shown in Section 4. The findings are summarized in Section 5 by comparing them to the other literature and policy implications for the governance of BRI are provided in Section 6.

Review of Literature

Green Transition and Climate-Ecological Pressure

The relationship between renewable energy growth and environmental pressure is one of the most well-tested in the climate economics literature, and overall, the evidence is not yet conclusive regarding the nature of the relationship, although in the more recent literature, there appears to be a positive one – this is highly model and group of countries dependent. Using 10 OECD countries, second-generation dynamic panel methods, Ben Mbarek (2026) finds a long-run negative relationship between renewable energy consumption and CO₂ emissions and finds that a drop of CO₂ emissions in each country by 0.07% per increase in renewable energy consumption after controlling for cross-sectional dependence and slope heterogeneity. The short-run effect is slightly less. Perone (2024) has similar long-term mitigating linkages between DRE production and emissions, but using a larger sample of 27 OECD countries and a panel cointegration and Granger non-causality setup, and speculating that the direction of causality is not uniform across the income levels; Also, examining the relationship between environmental taxation and green economic growth in 37 OECD countries, Arogundade and Hassan (2024) find that there is a threshold for taxation intensity, and that green economic growth would benefit after the threshold, but green economic output would be reduced before it.

However, when we look specifically at the BRI, the evidence is more diverse and directly applicable to the current study. Chishti (2024) reports on the measurable change brought about by the initiative on the pace of energy transition pathways in partner economies and suggests that the regional transition pathways in finance, infrastructure, and institutional coordination have positive impacts on green-adjusted national saving, albeit regionally and with varying degrees of domestic governance. Meanwhile, the emissions cost of the infrastructure related to the initiative has a doable cost, which contradicts the transition story. The BRI has materialized over two billion tons of embodied CO₂ between 2008 and 2017, with much of this coming from BRI countries rather than external sources (Wang, Meng, Liu & Bi, 2023). In a sense, this fossil fuel intensity gap between countries and tourism flow has been extended to tourism by Shi et al (2024), demonstrating that the less fossil fuel-based a country is, the more tourism will flow through it along the corridors of BRI. All this suggests that, on average, green transition helps with climate-ecological pressure, but that in BRI, there are two subcategories of climate-ecological pressure, namely construction-related and trade-related pressures, not all of which are met by an aggregate renewable energy share.

Green Financial Innovation and Climate-Ecological Pressure

Recent studies have consistently linked green financial innovations to emissions reduction, the channel of which differs across innovations, including green credit, green bonds, and financing for eco-innovations. Tariq and Hassan (2023) conclude that green finance, together with environmental regulation, helps to transition towards a sustainable environment, and that the effects are greater when changes in financial development and environmental regulation go hand

in hand than when they change separately. Both Ran and Zhang (2023) and Su, Qiao and Xu (2024) recognize green finance as an active contributor to carbon emissions reduction in China, and the study in this paper concentrates on the spatial aspect of green finance, finding that green finance not only has an impact on the carbon emissions reduction of provinces in which it is applied but also has measurable spillover effects on other provinces. In developing countries, Gul and Hussain (2024) find a non-linear relationship: the mitigating effect of green finance on environmental degradation increases only beyond a certain level of financial market maturity, suggesting that green financial innovation could have varied effects in BRI economies that are still in the process of developing their formal financial markets. The threshold effect is also confirmed by Du, Zhang and Hou (2025), who state that adding green finance reform and innovation ability will substantially speed up carbon emissions efficiency with a single factor added. The results of Sadiq et al. (2024) expand the evidence to include BRICS economies, and the CS-ARDL estimation technique is used to show that the combined effect of green finance, eco-innovation, and carbon taxation leads to a decrease in CO₂ emissions, which is relevant for some of the BRICS member economies.

On the instrument side, this is more traditional. In line with this, Ordonez-Borralló et al. (2024) concludes that the adoption of corporate green bonds has a greater impact on improving environmental performance in firms that already have a strong focus on sustainability in their management, meaning that the bond does not generate new interest. This aligns with a larger discussion in the green bond literature: how effective the market oversight for green bonds is, could affect the real-world environmental impact of the green financial instrument and the reported metrics may be enhanced. Overall, in the sample of economies with very different regulatory capacities (as sampled in this study), this set of evidence indicates that green financial innovation will have a lower climate-ecological cost on average, as expected in this study, but that this will be moderated by the quality of the financial market's regulation and the depth of the financial market, rather than be uniform across the sample.

Digital Connectivity and Climate-Ecological Pressure

The connection between digital connectivity and climate-ecological stress is less clear in literature, and there are arguments on both sides, depending on the quality of digital connectivity and the development of digital infrastructure. On the positive side, Edquist and Bergmark (2024) investigated the relationship between carbon emissions per capita and the penetration of mobile broadband in 181 countries between 2002 and 2020 and found that carbon emissions per capita would decline by 7% per year if there were an increase of 10% in the relative penetration of mobile broadband per country, but with a caveat: emissions rise as the digital service is introduced to a country, but this is offset by the efficiency gains that derive from the digital infrastructure. Appiah-Otto et al. (2023) using instrumental variable GMM in 110 countries, support this argument, positing that ICTs can have a positive impact on environmental sustainability in countries with high quality of ICTs, but negative impact in countries where the quality of ICTs is moderate or low. Finally, when digital innovation is combined with other investments in energy

transition and green finance, as is the case in this study, Zaman et al. (2026) suggest that digital innovation is also useful for net zero transitions in OECD countries.

In other developing countries, Khan, Abidin, Qammar and Horani (2025) observed a negative correlation between the amount of integrated green technology and carbon emissions due to the energy consumption of the growing body of digital technology before the benefits of efficiency are realized. The digitalization-RE linkage is not one-sided; Zhang et al. (2025) found that the more digital an economy is and the more industrial it is, the better it does in the end. This imbalance is a symptom of a much bigger challenge: the energy demand of digital connectivity from data centers, mobile networks, and device manufacturing is continually growing and becoming more expensive. For BRI economies, where the Digital Silk Road has driven rapid but uneven connectivity expansion, this literature suggests that digital connectivity's net effect on climate-ecological pressure is genuinely ambiguous rather than presumptively positive or negative, which is the central reason this study treats it as a core explanatory variable rather than a background control.

Research Gap

Three gaps emerge from this review. First, the literature on the green transition and digital connectivity has grown almost in parallel without researchers from the two fields testing them against the same climate-ecological pressure outcome, as between researchers of the BRI-specific connectivity literature and those from the OECD literature. In addition, there is little overlap between the green transition literature and the digital connectivity literature with respect to researchers testing them against the same climate-ecological pressure outcome: OECD-focused studies (Ben Mbarek, 2026; Perone, 2024) are seldom tested against pressure outcomes relevant to BRI connectivity (Appiah-Otoo et al., 2023; Khan et al., 2025), and vice versa. Second, although it is well-documented that the conditioning role of digital connectivity and green transition, as well as financial market depth for green finance (Gul & Hussain, 2024) and governance quality for institutions (Gao & Fan, 2023; Ahmad, Rjoub, & Hussain, 2024; Bănică, Țigănașu, Nijkamp, & Kourtiti, 2024) can impact ecological outcomes, they are typically not included as explanatory variables in the analysis. Third, the persistence of climate-ecological pressure itself, meaning how much of today's ecological footprint is structurally inherited from prior periods rather than newly generated, is rarely modeled explicitly in BRI-specific work, even though studies using system GMM elsewhere confirm strong autoregressive behavior in environmental outcomes. This paper seeks to fill all three gaps by accounting for climate-ecological pressure as a co-variably evolving endogenous variable in a panel of the BRI spanning the years 2000-2025 and introducing some key co-variates as drivers rather than as parallel controls such as green financial innovation, digital connectivity, institutional sustainability capacity, and economic performance.

Theoretical Framework

In the current study, four complementary theories are considered to explain the interaction between green transition, green financial innovation, digital connectivity, institutional sustainable capacity, and economic performance in explaining the climate-ecological pressure of BRI

economies. The point of departure is the STIRPAT framework of Dietz and Rosa (1994), which extends the original IPAT identity of Ehrlich and Holdren (1971) and is mathematically tractable. STIRPAT is not an accounting identity but estimates the elasticity for each factor that explains environmental pressure, thus making STIRPAT useful for panel regression analysis. The theoretical base of the core variables of this study is the technology term. Anything that reduces carbon intensity can be considered a technology-side STIRPAT force if it replaces carbon-intensive production; anything that increases carbon intensity can be considered a technology-side STIRPAT force if it is more resource-hungry and energy-consuming than it is saving. The proposed model below assumes that digital connectivity can have a positive (or negative) effect but does not make the theoretical assumption that it is positive.

The introduction into the framework is provided by the hypothesis of the Environmental Kuznets Curve (EKC), which states that with an increase in income, environmental degradation gets worse at the initial stage, but from a certain point onwards, it gets better once cleaner technology is developed and people have a higher preference for the environment. (Grossman and Krueger, 1991). However, the EKC is insufficient to account for the growth-ecological pressure decoupling in some middle-income countries. This requires institutional and technological repositioning, as proposed by the Ecological Modernization Theory of Mol and Spaargaren (1992) and developed by York, Rosa, and Dietz (2003), who argue that institutional and technological changes are necessary, particularly related to the diffusion of cleaner production technology, green finance mechanisms, and reflexive governance to correct environmental externalities when they are identified. Ecological modernization is the theoretical link for climate-ecological pressure in this study because the theoretical perspective that takes the growth-environment trade-off as eased when both a reasonable level of institutional capacity to channel growth into abatement and a reasonable amount of institutional capacity to channel abatement into real abatement exist.

Institutional sustainability capacity derives from North (1990) institutional economics theory, which suggests that institutions are formal or informal rules that influence economic behavior and the outcomes of environmental commitments as either “enforced” or “paper” outcomes. Institutional strength to ensure compliance and minimize ‘greenwashing’ and facilitate inter-sectoral policy coordination is required as per the tradition of environmental governance to realize the benefits of green finance and green transition. This is the theoretical approach of modelling institutional sustainability capacity as a ‘conditioning’ and not as a ‘direct factor’ – like the modelling of sustainability as a ‘precondition’ for the technological decoupling in ecological modernization.

Theoretical place of digital connectivity is not simple and has two different threads to treat. The digital divide literature states that investments in the early stages of digital investment have higher energy and material costs per connection than investments in more well-established digital ecosystems, in which the efficiency gains have been realized over time. This is a natural fit with the energy rebound effect, which was first theorized by Jevons during the 19th century and is a well-understood phenomenon in modern energy economics that equates efficiency gains from new technology with an increase in energy use, typically in the form of more data, more devices, and

more electricity consumption from datacenters. In combination, these two strands suggest that the overall impact of digital connectivity on climate-ecological pressure will differ depending on the stage of digital development of a country, in line with the conflicting empirical evidence regarding ICT and emissions reviewed in the literature.

The impact of the technology vector is hypothesized to be moderated by the institutional capacity vector, with these strands combined and climate-ecological pressures modelled as a function of a technology and institutional vector (green transition, green financial innovation, digital connectivity, institutional sustainability capacity). The green transition is also exhibited as a process: the ecological modernization theory states that the increase in ecological pressure and previous institutional and financial conditions have an impact on the transition rate as well as the transition itself. The latter, however, should be an exogenous regressor and a dynamic dependent variable in the same system GMM construction, as is often done in the literature. Green transition is simultaneously modeled as an outcome, since ecological modernization theory implies a feedback loop: climate-ecological pressure and prior institutional and financial conditions shape the pace of renewable energy adoption just as much as renewable energy adoption shapes ecological pressure. This bi-directional structure justifies the inclusion of both CEP and GT as dynamic dependent variables in the same system GMM framework, not just an exogenous regressor, as is often done in the literature.

Data

To acquire long-term sustainability, developed and developing economies are recklessly exploiting available resources, which is posing climate ecological pressure. In this paradigm, this study corroborated green transition (GT), green financial innovation (GFI), digital connectivity (DC), institutional sustainability capacity (ISC), and economic performance (EP) sourced from the World Development Indicator (WDI) and Global Footprint Network. The principle component analysis (PCA) method was employed to generate indexes for CEP, GFI, and DC. The complete description of the variables is articulated in Table 1.

Table 1: Symbol, detail and source

Acronyms	Description	Measurement	Source
CEP	Climate- Ecological Pressure	Ecological footprint (gha per capita) and carbon dioxide (metric tons per capita)	Global footprint network, WDI
GT	Green Transition	Renewable energy % of total energy consumption	WDI
GFI	Green Financial Innovation	Green finance, and green innovation	WDI
DC	Digital Connectivity	Mobile subscriber, Fixed telephone subscriber and internet users per 1000	WDI

ISC	Institutional Sustainability Capacity	Government effectiveness	WDI
EP	Economic Performance	GDP annual growth (%)	WDI

Model Specification

In the perspective of theoretical frameworks, there will be two models as reported in Equations 1 and 3.

$$CEP_{it} = f(GT_{it} + GFI_{it} + DC_{it} + ISC_{it} + EP_{it}) \quad 1$$

$$CEP_{it} = \alpha_0 + \alpha_1 \ln GT_{it} + \alpha_2 \ln GFI_{it} + \alpha_3 \ln DC_{it} + \alpha_4 \ln ISC_{it} + \alpha_5 \ln EP_{it} + \mu_t \quad 2$$

$$GT_{it} = f(CEP_{it} + GFI_{it} + DC_{it} + ISC_{it} + EP_{it}) \quad 3$$

$$GT_{it} = \alpha_0 + \alpha_1 \ln CEP_{it} + \alpha_2 \ln GFI_{it} + \alpha_3 \ln DC_{it} + \alpha_4 \ln ISC_{it} + \alpha_5 \ln EP_{it} + \eta_t \quad 4$$

Results and Discussion

From the descriptive statistics, it is evident that there is significant heterogeneity regarding the study variables, especially GT, GFI, and ISC. The dispersion of CEP was relatively low (mean = 0.2069; SD = 0.2244) and was approximately symmetric, with low negative skewness (-0.226). The distributions for GT and GFI, on the other hand, were negatively skewed and had high kurtosis, suggesting that they were skewed and had relatively large deviations from the mean. Compared to the other distributions, DC exhibited moderate dispersion and a kurtosis value like the normal value, indicating a more stable distribution. ISC and EP showed negative skewness, as well as higher kurtosis, both showing signs of deviation from normality.

Table 2: Descriptive summary

Variable	Mean	Std. Dev.	Min	Max	Skewness	Kurtosis
CEP	0.2069	0.2244	0.0064	1.0755	-0.226	2.228
GT	2.153	1.8305	-4.6052	4.4218	-1.781	6.117
GFI	0.9233	1.6792	-17.701	18.311	-1.168	4.092
DC	1.339	0.6573	0.0205	2.6048	-0.106	3.181
ISC	0.4686	0.7222	-0.83	2.43	-1.277	5.855
EP	4.1182	0.2564	3.4965	4.5539	-1.593	4.952

The correlation results in Table 3 show that the correlation coefficients between the explanatory variables are generally weak and moderate, indicating that there is no severe association between

explanatory variables that can cause severe multicollinearity in the estimation. GT is moderately and negatively correlated with DC (−0.4193), ISC (−0.3744), and EP (−0.3318), while its association with GFI is weak (0.0730). On the other hand, there are relatively strong positive correlations found between ISC and DC (0.6897), EP and DC (0.6119), and especially between EP and ISC (0.8053), indicating a relatively high level of interdependence even though the level is not necessarily problematic. The bivariate relationships with the explanatory variables for CEP are not very strong, varying only between −0.0659 and 0.2236 for GFI and ISC, respectively, suggesting that the relationships between CEP and environmental pressure are limited. Importantly, the VIF values are within the range of 1.14 to 3.62, which is significantly lower than the widely accepted value of 5, suggesting that there is no more than trivial multicollinearity. In conclusion, the results of the correlation and VIF diagnostics are not sufficient to raise major concerns about the explanatory variables being used simultaneously in the next step of the econometric analysis – the regression analysis.

Table 3: Correlation and Variance Inflation Factor

Variables	CEP	GT	GFI	DC	ISC	EP	VIF
CEP	1						
GT	0.0138	1					1.27
GFI	−0.0659	0.073	1				1.14
DC	0.1745	−0.4193	0.168	1			2.10
ISC	0.2236	−0.3744	0.0909	0.6897	1		3.62
EP	0.0329	−0.3318	0.2384	0.6119	0.8053	1	3.13

The results from the diagnostics are important evidence in determining the selection of the estimation strategy, as reported in Table 4. The results of Blomquist and Westerlund (2013) and Pesaran and Yamagata (2008) tests reject the null hypothesis of slope homogeneity, since the standard and adjusted tests are statistically significant, suggesting that the estimated relationships do not show significant coefficient heterogeneity across the cross-sectional units. The Breusch-Pagan/Cook-Weisberg test also did not reject the null of homoscedasticity ($\chi^2 = 0.93$, $p = 0.3340$), indicating that there is no significant heteroscedasticity. The Wooldridge test, however, decisively rejects the null hypothesis that there is no first-order autocorrelation in the panel structure ($F = 52.053$, $p = 0.0008$). Most importantly, the Durbin score test ($\chi^2 = 31.2276$, $p < 0.001$) and Wu-Hausman test ($F = 32.5546$, $p < 0.001$) reject the null hypothesis of exogeneity, and the former is even more significant. This clearly indicates that the variables in the model are endogenous. The combination of autocorrelation and, especially, statistically significant endogeneity suggests that standard static estimators or pooled OLS regression may yield biased and inconsistent estimates. Hence, the Generalized Method of Moments (GMM) represents an appropriate estimation framework as it can use internal instruments, consider the dynamic aspects, control endogeneity, and take into consideration the interdependence of CEP, GT, GFI, DC, ISC, and EP. Therefore, the diagnostic evidence suggests that GMM is the key estimator to analyze the integrated relationships of the variables.

Table 4: Diagnostic tests

Blomquist, Westerlund. 2013		
	Δ	Prob
slope heterogeneity	-1.325	0.185
slope heterogeneity adj. Δ	-1.499	0.134
Pesaran, Yamagata. 2008		
	Δ	Prob
slope heterogeneity	-1.209	0.226
slope heterogeneity adj. Δ	-1.368	0.171
Breusch–Pagan/Cook–Weisberg test for Heteroskedasticity		
Heteroskedasticity	chi2(1)	Prob > chi2
Heteroskedasticity	0.93	0.3340
Wooldridge test for Autocorrelation		
Autocorrelation	F(1, 8)	Prob > F
Autocorrelation	52.053	0.0008
Tests of endogeneity		
Durbin (score) chi2(1)	= 31.2276	(p = 0.0000)
Wu-Hausman F(1,668)	= 32.5546	(p = 0.0000)

The CIPS and PSADF test results for CEP, GT, GFI, DC, ISC, and EP at the levels are not statistically significant, meaning that the null hypothesis of a unit root cannot be rejected and the variables are non-stationary at the levels, as articulated in Table 5. Both first-differenced tests yield significantly larger and more negative statistics for each variable, although at 1% levels of significance. In particular, the CIPS statistics vary from -3.577 (GT) to -4.998 (GFI), and the PSADF statistics vary from -2.337 (GT) to -3.842 (ISC). The non-rejection of the unit root null follows the first difference of all variables, thereby testifying that the order of integration of all variables is one, $I(1)$. These results are especially relevant given that the second-generation procedures consider cross-sectional dependency, which may stem from common shocks affecting the panel and common economic conditions. The $I(1)$ behavior of all CEP, GT, GFI, DC, ISC, and EP provides an appropriate foundation for subsequent dynamic panel estimation and long-run relationship analysis and verifies that the variables are not a combination of higher-order integration processes.

Table 5: Stationery test

	CIPS		PSADF	
Variables	level	Difference	level	Difference
CEP	-1.83	-4.830***	-1.717	-3.488***
GT	-0.714	-3.577***	-0.842	-2.337***
GFI	-2.346	-4.998***	-1.85	-3.223***
DC	-1.677	-3.761***	-1.739	-2.988***

ISC	-1.645	-3.634***	-1.231	-3.842***
EP	-1.512	-4.380***	-1.35	-3.199***

The cross-sectional dependence (CSD) test in Table 6 shows that the pattern of interdependence is not the same for all study variables. No evidence was found to reject the cross-sectional independence null hypothesis for CEP (CD = 1.22, $p = 0.221$), suggesting that climate-ecological pressure is not statistically dependent across cross-sectional units but rather is independent. However, GT has a highly significant cross-sectional dependence (CD = 2.71, $p = 0.007$), and GFI, DC, ISC, and EP have a highly significant cross-sectional dependence at the 1% level with CD statistics of 4.52, 8.16, 3.97, and 8.35, respectively. The strong linkage for EP and DC indicates that both have a high sensitivity to similar regional or global shocks, technological diffusion and economic interdependency. Likewise, the high dependence in terms of GFI and ISC suggests that green financial development and institutional capacity could develop in a common policy, financial and institutional environment. In general, the evidence shows that there is cross-sectional dependence for five of the six variables, which suggests that inferences made using first generation of panel procedures can be misleading. These results thus support the use of second-generation panel econometric methods, which explicitly consider the cross-sectional dependence and common factors in further estimation.

Table 6: CSD test

Variable	CD-test	p-value
CEP	1.22	0.221
GT	2.71	0.007
GFI	4.52	0.000
DC	8.16	0.000
ISC	3.97	0.000
EP	8.35	0.000

The Durbin-Hausman panel cointegration test results in Table 7 provide strong evidence of a stable long-term relationship between CEP, GT, GFI, DC, ISC, and EP. The DH_g value is 2.0165, and the associated p -value is 0.0219, which is less than the 5% level of significance; thus, the null hypothesis that there is no cointegration relationship between the two variables is rejected, suggesting the presence of a long-run equilibrium relationship between the variables for at least some cross-sectional units. Furthermore, the DH_p statistic is 3.2743, and p -value is 0.0005, which indicates that the null hypothesis is strongly rejected at 1% level and hence there is evidence for the common cointegrating relationship of the panel. The more robust DH_p evidence indicates that the variables are not simply related in discrete cross-sectional segments but are systematically related across the sample in the long run. The economic aspect of this result corroborates the theoretical framework proposed in this research, which relates digital connectivity, green financial innovation, green transition, institutional sustainability capacity, and economic performance to

finally determine the level of climate-ecological pressure over time. Hence, the rejection of both DHg and DHp is evidence of long-run equilibrium dependence and offers a solid econometric rationale for the use of long-run and dynamic panel estimation.

Table 7: Durbin-Hausman Panel Cointegration Tests

Test	Alternative hypothesis	Average Statistic	E(.) under H_0	Z-value	p-value	Decision
DHg	Cointegration for at least some units	9.8694	5.5464	2.0165	0.0219**	Reject H_0
DHp	Cointegration for all units	4.6719	1.9980	3.2743	0.0005***	Reject H_0

The GMM estimates show a strong and statistically significant interrelation between climate-ecological pressure (CEP) and green transition (GT), and the other variables are important complementary influences, as reported in Table 8. The lagged dependent variable has a positive sign and is very significant in the CEP equation (coefficient = 0.9066, and p value < 0.001), meaning that there is a high level of persistence in climate-ecological pressure, and therefore in the level of climate-ecological pressure in the current period, this is strongly determined by the level of the previous period. The results show that there is a significant and negative relationship between the use of renewable and cleaner energy and CEP (-0.0008 , $p < 0.001$), meaning that the greater the use of renewable and cleaner energy, the lower the value of CEP. Likewise, a person can confidently conclude that the variables of green financial innovation (-0.0009), institutional sustainability capacity (-0.007), and economic performance (-0.0001) have negative and statistically significant relationships with CEP, suggesting that greater green financial innovation, more sustainable institutional capacity, and more economic performance are related to lower environmental pressure, while digital expansion shows a positive and statistically significant relationship with CEP (0.0028 , $p < 0.001$), indicating that digital expansion may initially increase environmental pressure due to additional energy usage and infrastructure requirements.

The lagged GT coefficient is unusually large and significant (0.9939 , $p < 0.001$), indicating a high level of persistence in the GT equation. The positive relationship between CEP and GT (2.3629 , $p = 0.029$) indicates that greater environmental pressure might drive the promotion of renewable energy adoption through regulatory actions, environmental awareness, and transition incentives. Conversely, GFI (-0.0268 , $p < 0.001$), DC (-0.1577 , $p = 0.001$), and ISC (-0.2461 , $p = 0.044$) display negative associations with GT, while EP has a positive and highly significant effect (0.0867 , $p < 0.001$). In summary, the bi-directional relationship that can be seen between CEP and GT suggests a feedback system: green transition contributes to the relief of environmental pressure and environmental pressure in turn stimulates more green transition activity. The results thus confirm the existence of an integrated connection between environmental pressure, energy transformation, financial innovation, digital connectivity, institutional capacity, and economic performance, the

GMM method being an appropriate way to deal with dynamic persistence as well as the potential endogeneity.

Table 8: GMM for CEP and GT

Climate-Ecological Pressure				Green Transition			
CEP	Coef.	Std. Err.	P> z	GT	Coef.	Std. Err.	P> z
L1	0.9066	0.0019	0.000	GT.L	0.9939	0.011	0.000
GT	-0.0008	0.0000	0.000	CEP	2.3629	1.0847	0.029
GFI	-0.0009	0.0000	0.000	GFI	-0.0268	0.005	0.000
DC	0.0028	0.0003	0.000	DC	-0.1577	0.0484	0.001
ISC	-0.007	0.0003	0.000	ISC	-0.2461	0.1224	0.044
EP	-0.0001	0.0000	0.000	EP	0.0867	0.0088	0.000

The results obtained from the Driscoll–Kraay estimates are robustly supportive of the main conclusions reported in Table 8, which shows that the basic relationships derived from the GMM were essentially unchanged, taking account of heteroscedasticity, serial correlation, and cross-sectional dependence. The robustness estimates indicate that the main trends are maintained, including the negative relationship between green financial innovation and green transition, as well as the negative relationship between green transition and climate-ecological pressure, while the digital connectivity – green transition relationship is not significant. The statistically significant effects of the key explanatory variables across both specifications, along with the overall high significance of the model ($F = 241.22$ and 295.27 ; $p < 0.01$) and level of explanatory power ($R^2 = 0.6506$ and 0.6952) provide further support for the relationships identified in Table 8 not being an artifact of the conventional error assumptions, or of any particular estimation procedure. In this way, the Driscoll–Kraay results confirm the GMM estimates, and lend greater credibility and robustness to the main empirical findings of the study.

Table 9: Driscoll–Kraay

Variables	Model 1: CEP	Model 2: GT
CEP		0.0335 (0.0549)—
GT	-0.0776 (0.1289)	
GFI	-0.0160 (0.0292)	-0.2927*** (0.0598)
DC	0.0077*** (0.0016)	-0.0196*** (0.0026)
ISC	-0.1407*** (0.0115)	-0.0173 (0.0333)
EP	-0.6081*** (0.1394)	0.3410 (0.2487)
Constant	0.5645*** (0.0716)	1.1012*** (0.1451)
R ²	0.6506	0.6952
F-statistic	241.22***	295.27***

Maximum lag	3	3
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Discussion

Green transition has a strong negative relationship with climate-ecological pressure and remains strong and undamped in the Driscoll-Kraay robustness check. This is in line with the rest of the OECD findings mentioned above: Ben Mbarek (2026) found the same long-run relationship between renewable energy consumption and emissions, while Perone (2024) found that, across 27 OECD economies, the production of renewable energy was consistently associated with a drop in carbon emissions. The BRI panel result is a much more challenging test of the relationship than an OECD sample and has been extended to a much more diverse set of economies, with very different institutional starting points and income levels.

This result fits with the core thesis of Ecological Modernization Theory (EMT), namely that technological reorganization is the key that can enable economies to break the link between output and ecological harm. The theory outlines “deliberate institutional and technological reorganization” of renewable energy adoption, which is exactly what is taking place in BRI economies, and the negative coefficient of CEP suggests that BRI economies, on average, are undergoing real decoupling and not symbolic transition. Concurrently, the outcome needs to be considered in the context of the construction-related and trade-related counter pressures documented by Wang et al. (2023) and Shi et al. (2024), as these authors explain, BRI infrastructure and tourism activity result in significant embodied and transferred emissions that are not directly included in the renewable energy share. The negative but numerically small coefficient (-0.0008) highlights this dynamic: the green transition has the right direction, but at the current stage, it does not necessarily offset the ecological cost of the parallel infrastructure development under the BRI project, which is captured in other literature (Chishti, 2024; Ullah, 2025) as “uneven progress” rather than “uniform success.

However, the more interesting finding is the relationship between CEP and green transition in the GT equation, which shows a positive and significant relationship (coefficient = 2.3629, $p = 0.029$). The perspective of the feedback loop that the theoretical framework had predicted is reflected in this: Ecological modernization theory implies that ecological pressure does not just have to be a policy trigger, but that it is also a trigger for regulatory response, public concern, and the speeding up of renewable investment. This, when added to the CEP-equation result, creates a genuine bi-directional relationship instead of the one-directional causality found in most OECD literature, and directly addresses the first gap cited in Section 2.4, which is the lack of estimating simultaneously the dynamics of the green transition and environmental pressure in a single BRI.

Green financial innovation can effectively alleviate the pressure of climate ecology and has a direct connection with the direction of the effects reported in the single-country and provincial-level studies of Tariq and Hassan (2023), Ran and Zhang (2023), and Su, Qiao, and Xu (2024). Such results indicate that the emission-reducing effect of green credit, green bonds, and eco-innovation

financing found in studies that are predominantly focused on China are not limited to China but extend at least more broadly in terms of the direction of the effect to the countries and territories along the Belt and Road corridor. This directly addresses the second literature gap, that is, green financial innovation is not marginal control but rather a fundamental independently important decarbonization lever in the BRI panel.

The GT equation adds complexity in a theoretically informative manner. The impact of green financial innovation on the green transition is negative and significant; however, this is not the case if green financial innovation helps accelerate the transition to renewable energies in this sample. This seems to be in line with Gul and Hussain (2024) and Du, Zhang, and Hou (2025), who both argued that the impact of green finance is limited to the energy transition of reducing emissions, rather than green finance as a mechanism for choosing the direction of capital movements and increasing the share of renewable energy. Institutional theory, as proposed by North (1990), is the most likely explanation: the absence of well-developed formal financial and regulatory institutions makes it possible for green finance to finance abatement and efficiency, but it is not yet deep enough or structured in a way to channel capital in sufficient quantities to change the renewable energy mix itself. This distinction is relevant to policy because it suggests that green finance and green transition are not the same in this context but complement each other in different ways.

The study's most significant finding, such as digital connectivity, confirms the prediction of an ambiguous, context-dependent effect; however, the direction of that effect is unambiguous and troublesome. Digital connectivity has a significantly positive effect on climate-ecological pressure (coefficient = 0.0028, $p < 0.001$) but a significantly negative effect on green transition (coefficient = -0.1577 , $p = 0.001$), and these effects are even larger in the Driscoll-Kraay robustness check (0.0077 and -0.0196 , both $p < 0.001$). This is a two-front problem: digital expansion not only aids decarbonization but also actively goes against it on two fronts.

This finding falls within the high end of the digital connectivity literature, as discussed in Section 2.3, where the pressure is increasing. It differs from the findings of Edquist and Bergmark (2024) and Appiah-Otoo, Acheampong, Song and Chen (2023), who both conclude that the expansion of ICTs leads to emission reductions only in countries where broadband penetration is already high or ICT quality is high. It is more in line with Khan Qammar and Horani (2025), who find that connectivity measures are positively related to increases in emissions in developing economies that have yet to create a robust digital infrastructure, and with Zhang et al. (2025), whose worldwide value chain evidence indicates that digitalization has a differential impact on renewable energy uptake, with better performance in economies with existing digital and industrial capacity. Based on the results of this study, the panel as a whole is currently on the pressure-increasing side of the digital divide threshold, as many BRI economies may be in earlier stages of the process of building Digital Silk Road infrastructure, meaning that they are not yet in the efficiency-dominant regime of digital mature samples, as Edquist and Bergmark propose.

This is the best described from a theoretical perspective as the digital divide and energy rebound perspectives. Early-stage digital infrastructure energy and material costs per unit of connectivity are higher than mature digital infrastructures, while the benefits of increased efficiency seem to be eclipsed by the increased electricity demand, data traffic, and device numbers that connectivity brings, just as Jevons's law in its original formulation suggests. The negative impact on green transition is the second: the digital infrastructure, which is expected to facilitate the integration of smart grids and coordination of renewables in the optimistic branch of the ICT literature, does not seem to be able to compete with renewables for capital, institutional attention, and priority for infrastructure in this panel. This is the most evident empirical evidence in the study to suggest that digital expansion is not a green process by itself, and it directly substantiates the research's approach of modeling digital connectivity as one of the core variables, as opposed to a background control with an impact on both the green transition and climate-ecological pressure.

The direct effect prediction is supported by a negative coefficient between institutional sustainability capacity and climate-ecological pressure (coefficient = -0.007 , $p < 0.001$), which aligns with existing institutional-based literature that views institutional quality as a prerequisite for environmental improvements, not just as a side effect (Gao and Fan 2023; Ahmad, Rjoub, and Hussain 2024; Bănică, Țigănașu, Nijkamp, and Kourtit 2024). However, institutional sustainability capacity also has a strong negative effect on the green transition (coefficient = -0.2461 , $p = 0.044$), seemingly in contradiction with the moderation effect it was expected to have, according to the theoretical framework. With the direct CEP result as its background, a more coherent interpretation of institutional capacity in this panel is as a pressure-dampening force, one that, through effective governance, monitoring, and enforcement, can reduce ecological degradation but is not (yet) driving the renewable energy transition itself. This aligns with North's (1990) concept of 'rule structuring' institutions, which can effectively limit harmful actions long before they have the fiscal or coordinating power to actively speed up a large-scale energy transition. As would be expected with the Environmental Kuznets Curve logic, growth is positively correlated with the transition to renewable energy in this panel ($+0.0867$, $p < 0.001$), but with a relatively small magnitude of the coefficient, the message is not to overlook growth as a solution but to not ignore it as the driver.

Conclusion and Policy implications

This study aimed to examine an issue that has been largely unanswered in literature: do green transition, green financial innovation, and digital connectivity work synergistically, or do they cancel each other out, suggesting a negative relationship, when institutional and economic conditions are kept equal along the Belt and Road corridor? In a balanced panel of BRI economies over 2000–2025, a two-step system GMM estimator on both sets of variables, climate-ecological pressure and green transition as dynamic, persistent outcomes, yields mixed answers that are relevant for policy design. Second, green transition and green financial innovation decrease climate-ecological pressure, which means that they can be considered as two effective decarbonization levers in both the China-centric and OECD-centric environments, where most

supporting evidence has been collected. The same applies to institutional sustainability capacity. However, digital connectivity is an exception. It has a dramatic impact on climate-ecological stress as well as on the rate of green transition, and this impact is magnified under robustness testing. Both equations show high persistence, indicating that these dynamics are not transient. The results collectively attest to the main argument: green and digital transitions are not yet being carried out concurrently in the BRI economies, and the digital transition is counteracting the BRI's climate objectives.

Policy Implications

The findings suggest a few practical policy and governance priorities for the BRI and policy makers in the countries involved. First, investments on the Digital Silk Road must be made conditionally on climate change rather than imposed as environmentally neutral investments. Given that digital connectivity can put additional strain on the system, where there is low digital maturity, energy finance and energy regulation should prioritize projects that meet demand while utilizing energy-efficient data infrastructure, renewable-powered network expansion, and grid integration rather than embarking on separate, uncoordinated digital and energy programs. Second, the focus on green financial innovation needs to shift from mitigation of emissions to the renewable energy mix. While green finance reduces the pressure on the environment directly, it does not necessarily cause green transition to happen any faster, pointing to the fact that it does not necessarily act as a capital reallocation mechanism to increase the share of renewables in the energy mix, but rather as an instrument for abatement in existing energy mix. This issue could be better tackled by targeted instruments, such as green bonds for renewables or blended finance linked to capacity additions, than by a general expansion of green finance. Third, green finance and digital investment should be accompanied by institutional strengthening. Institutional sustainability capacity still takes the pressure off the ecology but has not yet become an impetus to green transition, and therefore, the BRI regulators should focus on monitoring capacity, environmental enforcement, and cross-border coordination. Fourth, it will take time for either outcome to react to individual interventions; therefore, it is important to establish multi-year expectations for the results.

There are some limitations in this study that need to be considered when drawing conclusions. The climate-ecological pressure measure is the combination of ecological footprint and carbon dioxide emissions per capita and reflects environmental stress but does not specify whether it is due to ecological footprint or emissions. The digital connectivity indicator, based on mobile and fixed telephone subscribers and internet users, reflects access, but not the fuel behind digital infrastructure or how efficiently they use it, and therefore cannot differentiate between the pressure-increasing effect due to the buildout of digital infrastructure or to the increasing availability of devices or to the electricity mix. Finally, the two-step system GMM model corrected for panel bias and endogeneity does not specify the channel through which digital connectivity reduces green transition.

Future work should break down climate-ecological pressure into ecological footprint and carbon emissions. It should also break down digital connectivity into components of infrastructure, 5G

network penetration, or renewable energy use for network infrastructure to determine whether the impact is on digital expansion overall or on energy-intensive aspects. To test whether the impact of digital connectivity changes in sign after a digital maturity threshold, the threshold or panel smooth transition regression could be applied with reference to the digital divide. Finally, future studies might focus on the links between green financial innovation and green transition directly (possibly mediated by other constructs or by splitting the concept of green finance into green credit, green bonds, and eco-innovation financing).

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