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How Does Energy Insecurity Hurt Green Growth? The Role of Financial Stability

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Abstract

Climate change is one of the most disturbing issues for people all around the globe. Green growth has become the most viable solution for achieving economic goals without damaging environmental quality. Consequently, our main interest in this analysis is to examine how energy security risk and financial stability affect green growth in top carbon emitter economies. The CS-ARDL model is our selected estimation technique for examining the relationship between energy security risk, financial stability, and green growth. The long-run estimates reveal that higher energy security risk lowers green growth. In contrast, financial stability, technology, and human capital lead to a rise in green growth in the long run. The short-run estimates reveal the negative connection between energy security risk and green growth, while technology boosts green growth. These findings suggest policymakers should lower energy security risks and enhance financial stability to achieve green growth in top carbon emitter economies.

Keywords: Energy insecurity, green growth, financial stability, CS-ARDL

JEL Classification: O44, Q43, G10, Q54

1. Introduction

Sustainable development is often defined as a developmental approach that meets the needs of the present generation without compromising the resources and opportunities available to future generations. A development is sustainable when it encompasses not only economic advancement but also social inclusivity and environmental preservation (Lehtonen, 2004). Due to the linkage of sustainable development with sustainability, both these ideas are used as an alternative, even in the academic and scientific domains (Ruggerio, 2021). According to different schools of thought, there is a contradiction regarding the genuine concept of sustainable development because it is hard to achieve sustainable economic growth for an infinite period in a finite world (Sachs, 1999). Thus, the objectives of sustainable development seem to be contradictory (Spaiser *et al.*, 2017). Since the 1990s, academics have emphasized the need to consider sustainability as a distinct concept, which has become important for emerging environmental strategies such as "degrowth" and "buen vivir" (Kothari *et al.*, 2014). Thus, both these ideas are still under discussion, highlighting the necessity to broaden the scholarly debate on their meanings (Whyte and Lamberton, 2020).

To achieve sustainable economic growth, an economy must transition toward a new economic paradigm that fuels development, addresses poverty alleviation, and enhances overall quality of life (Fritz and Koch, 2014). At its core, green growth (*GG*) strives to optimize resource utilization, promote equity, and incorporate environmental considerations into all aspects of production. It represents a concerted effort to harmonize economic progress with environmental protection. In a world, where protecting the global environment, improving living standards, and ensuring reliable energy sources are paramount, *GG* emerges as a critical and inevitable pursuit. Contemporary challenges, notably the pressing issue of climate change, underscore the urgency of adopting a new paradigm for development. The impacts of climate change serve as a compelling catalyst for the *GG* agenda (Hao *et al.*, 2021). As we steer toward this sustainable path, it becomes evident that the energy sector and financial stability play pivotal roles in driving and supporting *GG* initiatives. Their significance in this context cannot be overstated.

Energy plays a fundamental role in the development and growth of any economy (Yanzhe and Ullah, 2023). Ensuring a consistent and reliable energy supply becomes imperative as it underpins a wide spectrum of economic activities, encompassing communication, transportation, industrial processes, education, healthcare, and energy security (Asif and Muneer, 2007). This underscores the pivotal importance of energy, often described as the "lifeblood" of economies. It is evident that global economic progress hinges on the availability of sufficient, cost-effective, and reliable energy. Every sector within an economy relies on energy to function optimally, making the security of the energy supply a critical concern, given that supply fluctuations can disrupt economic operations (Doğan *et al.*, 2023). Recognizing the indispensability of energy, the concept of energy security takes center stage as a critical objective in advancing a green economy. Energy security, a foundational pillar of any nation's economic stability and growth, refers to reliable, affordable, and uninterrupted access to energy resources (Abdullah *et al.*, 2020; Wang and Ullah, 2023). It encompasses the assurance that a nation's energy needs can be met without undue vulnerability to supply disruptions, price volatility, or geopolitical conflicts. In the context of *GG*, the intersection of energy security risk with environmental sustainability becomes a pivotal consideration.

Energy security risk can influence *GG* through various direct and indirect channels. Firstly, energy security risks lead to price volatility in energy markets. This volatility can affect energy costs for businesses and consumers, influencing investment decisions. Hamilton (2009) found that energy price shocks can substantially impact economic growth. Higher energy prices reduce investment in energy-intensive industries and lead to economic slowdowns. Secondly, energy security concerns result in inconsistent energy policies, including subsidies, tax incentives, or regulatory frameworks. Policy uncertainty discourages investments in renewable energy. Apergis and Payne (2010) highlighted that policy uncertainty in the energy sector can hinder renewable energy investments. Clear and stable policies are crucial for attracting private sector investments in green technologies. Thirdly, energy security risks incentivize investments in R&D for cleaner and more efficient energy technologies. These innovations can drive economic growth in the green sector. A study by Yang *et al.* (2022) suggests that energy security concerns stimulate innovation in green technologies. Increased research and development in renewables, energy storage, and efficiency can contribute to *GG*. Last but not least, energy security risks can underscore the importance of building resilient and adaptive infrastructure. Investments in green infrastructure can enhance economic sustainability. Salimi and Al-Ghamdi (2022) described that investing in green infrastructure can reduce the economic costs associated with energy disruptions and climate-related events, contributing to long-term economic stability and growth.

On the other hand, financial stability stands as a cornerstone within any economic system, serving as a robust foundation that empowers both the economic and social spheres to withstand and mitigate the shocks arising from inefficiencies inherent in the broader economic framework. This stability facilitates the effective distribution of financial resources throughout society by ensuring the timely and efficient allocation of savings and cultivating profitable investment prospects (Barra and Zotti, 2022). In the existing literature, it is widely acknowledged that financial stability is pivotal in shaping *GG* (Jamil and Rasheed, 2023). Financial stability influences *GG* through various mechanisms. Firstly, a financially stable environment gives businesses and investors greater confidence, making it easier to secure financing for green projects and sustainable initiatives. Financial stability reduces lending risks and lowers the cost of capital for green investments. Gupta (2012) found that financial stability enhances access to credit for renewable energy projects, stimulating economic growth. Secondly, financial stability encourages long-term planning and investments, which are essential for the development of green technologies and sustainable infrastructure. It allows businesses to commit to projects with longer payback periods, such as renewable energy installations. Bassanini and Reviglio (2011) demonstrate that financial stability is positively associated with long-term investments, particularly in green sectors like renewable energy, which are essential for *GG*. Thirdly, financial stability fosters the growth of green bond markets, providing a dedicated source of capital for green projects. These bonds attract environmentally conscious investors, facilitating green infrastructure development. Ning *et al*. (2023) revealed that a stable financial environment encourages the issuance and trading of green bonds, directing investments toward green projects that promote *GG*.

Although the relationship between energy security risk, financial stability, and *GG* has gathered attention in recent years, it is evident that there are significant research gaps that demand attention. Firstly, while theoretical literature on the influence of energy security risk and financial stability on *GG* is expanding, empirical studies providing robust evidence remain relatively scarce. Secondly, existing research has largely focused on either the energy security risk-*GG* nexus or the financial stability-*GG* nexus individually. A conspicuous gap exists regarding studies that comprehensively investigate the concurrent impact of these factors on *GG*. Hence, there is an imperative need for a comprehensive framework that seamlessly integrates the intricate relationships between energy security risk, financial stability, and *GG*. Furthermore, there is a notable scarcity of studies specifically probing into how energy security risk and financial stability affect *GG* in highly carbon emitter economies. These economies confront unique challenges due to their heavy reliance on polluting energy sources, which exacerbate environmental degradation. Therefore, there is a crucial research gap in exploring the impact of energy security risk and financial stability on *GG*, particularly within the context of highly carbon emitter economies.

To fill these gaps, this study aims to explore the impact of energy security risk and financial stability on *GG*, with a particular focus on highly carbon emitter economies. This research endeavor aspires to make several noteworthy contributions to the literature. Firstly, it addresses a substantial research gap by meticulously examining the simultaneous influence of energy security and financial stability on *GG* in highly carbon emitter economies. The prevailing literature has predominantly divided these energy and financial dimensions, neglecting the complete analysis of their combined effects. Secondly, this study aims to enhance the empirical foundation in this area by offering robust empirical evidence on how energy security and financial stability impact *GG*. This study employs CS-ARDL methods to investigate cross-sectional dependence, providing insights into both long-term and short-term outcomes. Lastly, the findings from this study are expected to guide the development of effective policies and strategies to enhance *GG*. By elucidating the nuanced relationships between energy security risk, financial stability, and *GG*, the study offers actionable recommendations to drive sustainable economic development in contexts characterized by environmental challenges.

The study is organized as follows: Section 2 explains the theoretical framework and describes the model. Section 3 explains the methodology. Section 4 presents the data and its summary statistics. Section 5 presents the empirical analysis and results discussion. Section 6 summarizes the findings and offers policy recommendations.

2. Theoretical framework and model

There is no agreed-upon definition of energy security in the available empirical literature (Cox, 2016). As a conceptual framework, different definitions have different meanings and understandings. However, some aspects of energy security are common, including the "availability, affordability, reliability and accessibility" of energy. The credit of recent interest in the topic of energy security can be given to the constrained oil market and volatile oil prices over the past ten years, and other menaces such as terrorism, uncertainty in exporting economies, geopolitical conflicts, race for resources, and the indispensable requirement of nations for energy to support their economic growth (Vivoda, 2009). Energy security can be achieved by ensuring the availability of different types of sustainable and affordable energy sources. Thus, the transition towards renewable energy sources is the most reliable solution for the issue of energy security as it covers most aspects of energy security, such as sustainability, reliability, and affordability (Cergibozan, 2022). It is also widely recognized that renewable energy sources promote economic progress without causing any damage to the environment. Since renewable energy is related to both *GG* and energy security, we can state that there is a definite link between energy security risk and *GG*.

The role of the financial sector is also vital in providing the necessary capital for development operations, working as a catalyst for fueling economic progress in a country (Alsagr, 2023). Levine (1997) states that a well-established and stable banking industry and efficient stock markets are the two important determinants of economic development. In the context of economic growth rates, a country with progressive and efficient financial institutions such as banks and stock markets has an edge over other countries with ineffective and poorly designed banking and stock market structures (King and Levine, 1993). Historically, financial institutions have provided financial capital for the most profitable businesses without considering environmental aspects. The upsurge of *GG* requires the separation of CO2 emissions from economic growth. Consequently, the concept of green finance emerges, which prioritizes eco-friendly endeavors while forwarding the loans. Contemporary literature highlights that the stable financial sector benefits traditional economic growth (Ang and McKibbin, 2007). Nevertheless, we hypothesis a link between financial stability and *GG* due to recent advancements in how the finance industry has approached environmental issues. In line with the studies by Le and Nguyen (2019) and Li (2023), we have designed the following function for *GG*:

$$GG_{it} = \delta_0 + \delta_1 ESR_{it} + \delta_2 FS_{it} + \delta_3 Tech_{it} + \delta_4 HC_{it} + \delta_5 REC_{it} + \delta_6 FG_{it} + \delta_7 Trade_{it} + \varepsilon_{it} \tag{1}$$

Where green growth (*GG*) is a function of energy security risk (*ESR*), financial stability (*FS*), technology (*Tech*), human capital (*HC*), renewable energy consumption (*REC*), financial globalization (*FG*), and trade openness (*Trade*), and error term (ε_{it}). Energy security risks can affect *GG* positively or negatively. If tackled by increasing renewable energy sources, energy security risks can promote *GG*. In contrast, *GG* declines if the demand for non-renewable energy sources increases due to energy security risk. Financial stability can boost *GG* by providing funds for investment in green innovations and energy technologies, which help to decouple economic growth and CO_2 emissions. Technology can positively impact *GG* because technology can bring innovations to production techniques to make them more resource-efficient, which is crucial for *GG*. Moreover, technology can help make smart appliances, automobiles, and electronic items less energy-intensive, thus contributing to *GG*. Renewable energy consumption is widely recognized to have a positive link with *GG* due to its simultaneous contribution to economic growth and environmental quality. Financial globalization is a process that connects the financial sectors of different economies. This increases the availability of funds for investment in green technologies and renewable energy sources. All of these factors are vital in separating economic growth and carbon emissions. Trade openness boosts *GG* due to an exchange of green technologies between the nations.

3. Econometric methodology

3.1 Cross-sectional dependence and homogeneity tests

Conventional panel data approaches are developed on the presumption that the slope coefficients are homogeneous and there is no correlation across cross-section units. Nevertheless, we may obtain incorrect conclusions from estimators if we don't care about the cross-sectional dependency (Chudik and Pesaran, 2015). In addition, the coefficients we obtain after the analysis may vary depending on the panel units, *i.e.*, countries in this analysis. Thus, before formal analysis, it is crucial to first look at the presence of slope homogeneity and cross-sectional dependency (CSD). We have used the Pesaran CSD test to confirm the CSD in the error term within the model (Pesaran, 2004). The equation is as:

$$CSD_{test} = \sqrt{\frac{2T}{N(N-1)}} \left(\sum_{i=1}^{N-1} \sum_{k=i+1}^{N} \hat{\tau}_{ik} \right) \tag{2}$$

The homogeneity of the slope coefficient is another assumption of the panel data to reach the correct estimates. However, this assumption is violated, and the slope coefficient is normally heterogeneous through several cross-sections. Pesaran and Yamagata (2008) test of slope homogeneity is our choice in this analysis, which is an advanced variant of Swamy's (1970) test. The null of this test indicates the homogeneity of the slope coefficient, and its rejection will confirm the heterogeneity of the slope across panel units. Following are the two specifications (3 and 4) that represent the delta and adjusted delta:

$$\widetilde{\Delta}_{HPY} = (N)^{\frac{1}{2}} (2k)^{-\frac{1}{2}} \left(\frac{1}{N} \widetilde{S} - k \right) \tag{3}$$

$$\widetilde{\Delta}_{ASH} = (N)^{\frac{1}{2}} \left(2k \left(\frac{T-k-1}{T+1} \right)^{-\frac{1}{2}} \left(\frac{1}{N} \widetilde{S} - 2k \right) \right) \tag{4}$$

3.2 Panel unit root tests

The key purpose of unit root tests is to confirm the stationarity properties. Some famous first-generation unit root tests are LLC, IPS, ADF. In these tests, there is believed to be no CSD within the panel series. After confirming the CSD, relying on this generation may be misleading when deciding about the stationary characteristics of the panel series. The solution to this problem is to shift towards the next generation of panel unit root testing, including the CIPS and CADF proposed by Pesaran (2007). CADF is estimated via the following specification (5):

$$\Delta V_{i,t} = \quad \alpha_i + \alpha_i X_{i,t-1} + \alpha_i Y_{t-1} + \sum_{l-0}^{p} \alpha_{i1} \Delta \bar{V}_{t-1} + \sum_{i-1}^{p} \alpha_i \Delta Y_{i,t-1} + \mu_{it} \tag{5}$$

From specification (5), the most important information we have derived is the cross-section averages as $\bar{V}_{t-1}$. In order to derive the CIPS, we have used the CADF in the following form:

$$\widehat{CIPS} = \frac{1}{N} \sum_{i=1}^{n} C_{ADF}^{i} \tag{6}$$

3.3 Cointegration test

Several cointegration tests help analyze long-term links between variables. However, we used Kao (1999) and Pedroni (2004) tests to examine the connection between key variables. Pedroni (2004) cointegration estimator is driven by Engle and Granger (1987). The general form of this test is shown below:

$$Y_{it} = \alpha_i + \lambda_i t + \sum_{j=i}^{m} \beta_{ji} X_{jit} + \varepsilon_{it} \tag{7}$$

The specification (7) has the following important information: *m*, *t*, *i*, which signify the regressors, time, and countries. On the basis of the assumption that the outcome variable (Y) and the set of regressors (X) are non-stationary, this test offers the following equation used to estimate residuals:

$$\varepsilon_{it} = \rho_i \varepsilon_{it-1} + \mu_{it} \tag{8}$$

Once we reject the null hypothesis, we can confirm that the relationship between our selected variables is genuine, and they all converge toward equilibrium in the long run. Kao (1999) follows a similar procedure and hypothesis as Pedroni (2004) but proposes additional statistics.

3.4 CS-ARDL and PMG-ARDL methods

The CS-ARDL is a renowned econometric approach developed by Chudik and Pesaran (2015), which examined the possible short-run (SR) and long-run (LR) effects of energy security risk, financial stability, renewable energy, technology, trade, human capital, and financial globalization on *GG*. The CS-ARDL is an extension of the conventional ARDL-PMG approach of Pesaran *et al*. (1999), as it incorporates cross-section means of variables as well as their lags. The CS-ARDL is driven by its several advantages over conventional econometric techniques in addressing heterogeneity, CSD, slope and endogeneity (Chudik *et al*., 2017). The CS-ARDL approach mitigates the influence of unknown common factors by using the panel ARDL modeling methodology proposed by Pesaran *et al*. (1999), utilizing the lag of the outcome variable (*GG* in this analysis) as a weakly exogenous parameter. This method replaces cross-sectional averages of the observable indicators and their lags with unseen components, efficiently documenting the cross-sectional dependence under hypotheses of slope heterogeneity and parameter endogeneity. Furthermore, it may provide reliable estimates of the panel data having stationary and non-stationary variables while addressing sample selection bias. Below we have presented the general framework of the CS-ARDL model that uses the error correction approach:

$$\Delta GG_{it} = C_i + \Psi_i(GG_{it-1} - \Upsilon_i Z_{it-1} - \phi_{1i}\overline{GG}_{t-1} - \phi_2 \bar{Z}_{t-1}) + \sum_{j=1}^{p-1} \omega_{ij}\Delta GG_{it-j} + \sum_{j=0}^{q-1} \lambda_{ij}\Delta Z_{it-j} + \pi_{1i}\Delta\overline{GG}_t + \pi_{2i}\Delta\bar{Z}_t + \varepsilon_{it} \quad (9)$$

While, specification (9) has LR (GG_{it}, Z_{it}) and SR (outcome variable and regressors (ΔGG_{it}, ΔXt) as well as the cross-sectional averages of the LR ($\overline{GG}_{t-1}$, $\bar{Z}_{t-1}$) and SR ($\Delta\overline{GG}_t$, $\Delta\bar{Z}_t$) for the outcome and independent variables. Checking the validity of the main findings by using an alternate estimating method has become standard recently. We use the PMG-ARDL of Pesaran *et al*. (1999) for a robustness evaluation in line with Usman *et al*. (202). In many respects, the PMG-ARDL is like the CS-ARDL: it simultaneously provides SR and LR outcomes, deals with mixing I(0) and I(1) variables, and controls endogeneity. PMG-ARDL is, thereby, the appropriate method to complement CS-ARDL.

4. Data and descriptive analysis

This study examines the impact of energy security risk and financial stability on green growth using 53 top carbon emitter economies panel datasets from 1995 to 2021. Green growth (*GG*) is the dependent variable, which is measured in terms of adjusted net savings excluding particulate emission damage in the current US$. The data series is retrieved from the WDI. Energy security risk (*ESR*) is assessed through an index, which is formulated by the Global Energy Institute. Financial stability (*FS*) is assessed through the Bank *Z*-score. The data series is obtained from the GFDD. Technology, human capital, renewable energy consumption, financial globalization, and trade openness are control variables in our model. Fu and Ullah (2023) documented that technological development contributes significantly to *GG* by improving resource efficiency, reducing emissions, and fostering sustainable practices. Technology (*Tech*) variable data has been extracted from the WDI, which is measured by total patent applicants. A stock of human capital is crucial for the green economy. The data for human capital is taken from the WDI, which has been measured through the gross percent of tertiary school enrollment. Dong and Ullah (2023) stated that renewable energy consumption (*REC*) positively influences *GG* as the increased use of renewable energy sources contributes to a reduction in carbon emissions. Data for *REC* has been extracted from the EIA. Financial globalization (*FG*) and trade openness (*Trade*) can positively influence *GG* as documented by Chen *et al*. (2023). Financial globalization and trade bring in investments for sustainable projects and facilitate the exchange of eco-friendly technologies that are crucial for *GG*. Financial globalization index data is extracted from the KOF, whereas trade openness data is retrieved from the WDI (see, Table A). Log transformations are used for all variables.

In Table 1, the highest mean score is documented for *GG* (24.10) with a maximum range 28.57 and minimum range 17.95. Mean scores for the remaining variables are documented as: 6.953 for *ESR*, 2.566 for *FS*, 8.046 for *Tech*, 3.743 for *HC*, 1.064 for *REC*, 4.118 for *FG*, and 4.218 for *Trade*. The highest standard deviation score is documented for *REC* (2.628), whereas the lowest is documented for *ESR* (0.245). The skewness test affirms that *ESR*, *Tech*, and *REC* series are positively skewed, and all other series exhibit negative skewness.

Table 1: Descriptive statistics

	Mean	Median	Max	Mini	Std. Dev.	Skewness	Kurtosis
GG	24.10	24.18	28.57	17.95	1.607	−0.204	3.444
ESR	6.953	6.951	7.975	6.342	0.245	0.579	4.839
FS	2.566	2.640	4.275	−0.812	0.654	−0.567	4.088
Tech	8.046	7.865	14.24	4.635	1.685	0.922	4.363
HC	3.743	3.952	4.778	0.871	0.658	−1.264	4.310
REC	1.064	0.278	22.76	−0.168	2.628	5.183	33.63
FG	4.118	4.205	4.585	1.792	0.374	−1.373	5.674
Trade	4.218	4.214	5.804	2.750	0.485	−0.016	3.077

Source: Authors' own calculations

Table 2: Correlation matrix

	GG	***ESR***	***FS***	***Tech***	***HC***	***REC***	***FG***	***Trade***
GG	1							
ESR	−0.281	1						
FS	0.184	0.145	1					
Tech	0.421	−0.219	0.202	1				
HC	0.127	−0.071	0.052	0.192	1			
REC	0.294	−0.218	0.189	0.673	0.166	1		
FG	0.246	−0.229	0.042	0.208	0.613	0.155	1	
Trade	0.081	0.376	0.085	−0.277	0.351	−0.343	0.459	1

Source: Authors' own calculations

Table 2 displays the correlation results among variable pairs in the variables. A negative correlation of 0.281 exists between *ESR* and *GG*, suggesting that higher *GG* is associated with lower levels of energy security risk. However, *FS* and *GG* are positively associated. While *Tech* and *REC* are comparatively highly correlated. The results of the VIF analysis are presented in Table 3, which is employed to assess the presence of multicollinearity among a set of variables. It is observed that all VIF values are under 10, affirming the absence of multicollinearity.

Table 3: VIF results

Variable	VIF	1/VIF
FG	2.46	0.406
Trade	2.43	0.411
REC	2.04	0.490
Tech	1.98	0.506
HC	1.67	0.600
ESR	1.57	0.638
FS	1.11	0.899
Mean VIF	1.89	

Source: Authors' own calculations

5. Empirical results and discussion

As a preliminary step, confirming the CSD and slope homogeneity assumptions is important while dealing with cross-section data. CSD occurs mainly due to local or global common economic shocks, oil price shocks, financial or economic integration, globalization, and unobserved factors. If cross-section dependence and slope homogeneity problems are not dealt appropriately, it causes biased and inefficient results. CSD is checked through Pesaran and Friedman CSD tests. Likewise, slope homogeneity is checked through Pesaran and Yamagata (2008) test. Table 4 reports the results obtained from Pesaran CSD test and Friedman CSD test. All the variables are found statistically significant, which confirms that all the variables used in this model are CSD. Table 5 reports the results of slope homogeneity test, which confirms that the null hypothesis of homogeneity is rejected. It describes that all the variables in the model are heterogeneous. Thus, both tests confirm that all the variables in our model are CSD and heterogeneous.

Table 4: CSD tests results

	GG	*ESR*	*FS*	*Tech*	*HC*	*REC*	*FG*	*Trade*
Pesaran's test	45.39***	22.91***	5.698***	9.951***	30.18***	2.291**	21.47***	21.54***
Prob.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Friedman's test	376.3***	206.5***	76.94**	120.1***	242.3***	59.86*	155.1***	172.5***
Prob.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Note: ***, **, * denote statistical significance at 1%, 5%, and 10% levels, respectively.
Source: Authors' own calculations

Table 5: Slope heterogeneity test results

	GG	*ESR*	*FS*	*Tech*	*HC*	*REC*	*FG*	*Trade*
$\widehat{\Delta}$	11.80***	23.42***	21.16***	22.16***	28.31***	1.692*	23.06***	23.85***
$\widehat{\Delta}_{\text{adjusted}}$	14.46***	28.68***	25.92***	27.14***	34.67***	1.987*	28.24***	29.22***

Note: ***, * denote statistical significance at 1%, and 10% levels, respectively.
Source: Authors' own calculations

After confirming CSD and heterogeneity among variables, in the next step, unit root tests are performed. The study conducted CIPS and CADF unit root tests. CADF test is useful for addressing CSD and slope heterogeneity issues. Table 6 displays the outcomes of the CIPS test and CADF test. The corresponding results report a mixed integration order among the variables. In the CIPS test, *FS*, *FG*, and *Trade* are level stationary and *GG*, *ESR*, *Tech*, *HC*, and *REC* are the first difference stationary series. Whereas, in CADF, *FS*, *HC*, *Trade*, and *FG* are stationary at level, and *GG*, *ESR*, *Tech*, and *FG* are stationary at first difference. The mixed integration order and CSD validate the choice of the CS-ARDL for estimation purposes.

Table 6: Unit root tests results

	CIPS		CADF	
	I(0)	I(1)	I(0)	I(1)
GG	–1.422	–3.800***	–1.542	–4.368***
ESR	–1.447	–4.108***	0.722	–22.34***
FS	–3.394***		–14.27***	
Tech	–1.624	–4.769***	–1.207	–24.88***
HC	–1.811	–3.104***	–4.504***	
REC	–0.743	–5.288***	1.807	–11.19***
FG	–2.937***		–12.06***	
Trade	–1.764**		–12.06***	

Note: ***, ** denote statistical significance at 1% and 5% levels, respectively.
Source: Authors' own calculations

Before proceeding towards the CS-ARDL estimation, it is appropriate to confirm whether there exists an LR association between the concerned variables. To perform this task, the study adopted the Kao cointegration and Pedroni cointegration tests. Table 7 reports the outcomes of both cointegration tests. Both the tests produce statistically significant coefficient estimates. Thus, it is confirmed that *GG* has LR relationships with *ESR*, *FS*, *Tech*, *HC*, *REC*, *FG*, and trade.

Table 7: Cointegration test results

		Statistic	*p*-value
Kao test	**Modified DF test**	2.661***	0.004
	DF test	1.431*	0.076
	ADF test	2.212**	0.014
	Unadjusted DF test	3.529***	0.000
	Unadjusted modified DF	4.462***	0.000
Pedroni test	**Modified PP test**	7.837***	0.000
	PP test	–1.337*	0.091
	ADF test	–1.417*	0.078

Note: ***, **, * denote statistical significance at 1%, 5%, and 10% levels, respectively.
Source: Authors' own calculations

In the next step, our study employed the CS-ARDL method to obtain the SR and LR estimates. However, PMG-ARDL and CCEMG models are employed to confirm the robustness of the baseline model results. In Table 8, the ECM terms are found to be significant and negative, confirming the existence of LR associations among the concerned variables. The coefficient estimates of ECM terms, which are 0.352 in the CS-ARDL and 0.179, confirm that the LR convergence will take place at the rate of 35% per annum according to the CS-ARDL and approximately 18% according to the PMG-ARDL. Regarding the LR coefficient estimates, the findings of all three models demonstrate that a higher level of *ESR* reduces *GG* in the LR. A rise in the *ESR* by 1% reduces the growth rate of *GG* by 4.038% in the CS-ARDL model, 0.895% in the PMG-ARDL model, and 3.644% in the CCEMG model. It confirms that *ESR* negatively influences *GG*. These findings match with the studies of van Tilburg *et al*. (2016), who noted that high *ESR* limits the expansion of *GG* and leads to fluctuations in consumption patterns. *ESR* disturbs the development path of *GG*. The study of Zhao *et al*. (2023) described that geopolitical uncertainties adjacent to fossil fuel resources have the potential to disturb energy supplies, leading to supply chain disruptions and price volatility. Such instability poses significant difficulty to the transition to *GG* by creating an unfavorable environment for renewable energy investments. Therefore, *ESR* hurts *GG*. This also means that *ESR* diverts crucial funds away from green technology research and development. Our findings also infer that mitigating *ESR* is imperative for ensuring stable and affordable energy access and pivotal for *GG*. Our study results also infer the hindering impact of *ESR* on the path toward eco-friendly and sustainable *GG*. The study argued that uncertainties arise due to *ESR*, which limits private investments in renewable energy technology initiatives. Furthermore, Lucas *et al*. (2016) reported the potential interruption to innovation in the renewable energy sector due to *ESR*, which reduces overall *GG*.

However, *FS* documents a significant positive impact on *GG* in all three models in the LR. A 1% rise in *FS* enhances the growth rate of *GG* by 0.352% in the CS-ARDL model, 0.282% in the PMG-ARDL model, and 0.302% in the CCEMG model. Our findings are consistent with Jamil and Rasheed (2023), who reported a positive impact of *FS* on *GG*. This also means that *FS* gives rise to green loans that bring favorable effects on *GG*. The study of Sun *et al*. (2022) noted that *FS* reduces financial costs and increases profitability and ultimately enhances *GG*. While study by Coccorese (2008) stated that *FS* improves *GG* through the channel of market power. The result infers that *FS* increases the allocation of capital in the banking sector which drives companies to increase quality, drive green innovation, and reduce prices of green products, which in turn enhances *GG*. Li (2023) study also justified the positive effects of *FS* on *GG* in the case of Vietnam. The results also described that *FS* diminishes uncertainties and facilitates capital allocation to renewable energy sectors, thus encouraging the renewable energy. Moreover, Mertzanis (2023) reported *FS* plays a fundamental role in risk mitigation, prompting investor confidence in green energy projects. This risk mitigation results in increased capital inflows into green sectors that enhance *GG*. Furthermore, Xu and Xu (2023) documented that *FS* creates an environment favorable to the enforcement of *GG* policies, that leads to *GG* in the LR.

Table 8: Estimates of *GG*

	CS-ARDL	PMG-ARDL	CCEMG
Variables	**(1)**	**(2)**	**(3)**
	Long-run		
ESR	−4.038** (1.841)	−0.895*** (0.339)	−3.644*** (1.130)
FS	0.352** (0.142)	0.282*** (0.102)	0.302* (0.164)
Tech	0.645** (0.299)	0.295*** (0.081)	0.508** (0.225)
HC	1.313** (0.608)	0.832*** (0.241)	1.066** (0.478)
REC	2.109 (1.947)	0.169 (0.817)	1.376 (3.925)
FG	1.053 (1.112)	0.194 (0.401)	0.963 (0.677)
Trade	0.331 (0.430)	1.596*** (0.353)	0.182 (0.429)
	Short-run		
D(*ESR*)	−3.038* (1.581)	−0.746** (0.351)	
D(*FS*)	0.234 (0.352)	0.094 (0.189)	
D(*Tech*)	1.287*** (0.446)	0.481* (0.263)	
D(*HC*)	0.075 (1.451)	0.588 (0.550)	
D(*REC*)	1.170 (1.341)	0.686 (1.211)	
D(*FG*)	0.985 (1.757)	0.289 (0.373)	
D(*Trade*)	0.744 (0.786)	0.123 (0.201)	
Constant		3.478*** (0.513)	5.183*** (0.270)
Observations	1,378	1,378	1,431
Number of countries	53	53	53
ECM(−1)	−0.352*** (0.012)	−0.179*** (0.026)	

Note: ***, **, * denote statistical significance at 1%, 5%, and 10% levels, respectively.
Source: Authors' own calculations

In terms of control variables, *Tech* and *HC* report significant positive associations with *GG* in the LR, confirming that technology and human capital significantly improve *GG* in highly carbon emitter economies. A 1% improvement in technology tends to enhance the growth rate of *GG* by 0.645%. 0.295%, and 0.508% in CS-ARDL, PMG-ARDL, and CCEMG. Similarly, a 1% increase in *HC* enhances the growth rate of *GG* by 1.313% in the CS-ARDL, 0.832% in the PMG-ARDL, and 1.066% in the CCEMG. *REC* and *FG* impact on *GG* is insignificant in all three models in the LR. Whereas *Trade* association with *GG* is documented as significant and positive only in the PMG-ARDL. The nexus between *Trade* and *GG* is also insignificant under the baseline model and CCEMG. A 1% rise in *Trade* enhances the growth rate of *GG* by 1.596% in the PMG-ARDL. *ESR* shows a significant and adverse effect on *GG* in the SR in both models. However, the statistical significance of the relationship between *FS* and *GG* is not observed in either model. The coefficient estimates report that a 1% rise in *ESR* reduces the growth rate of *GG* by 3.038% in the CS-ARDL and 0.746% in the PMG-ARDL. On the contrary, *Tech* is the sole control variable that has a significant and positive impact on *GG* in the SR. A 1% upsurge in *Tech* leads to a 1.287% (0.481%) rise in the growth rate of *GG* in CS-ARDL (PMG-ARDL) models.

5.1 Regional empirical analysis

Our study has also examined the impact of *ESR* and *FS* on *GG* in the context of regions. Table 9 reports the region-wise estimates of *GG* under the CS-ARDL model. The coefficient estimates display that *ESR* has a statistically significant and negative impact on *GG* in all four regions in the LR. It infers that a 1% rise in the level of *ESR* tends to diminish the level of growth rate of *GG* by 2.791% in Asia, 2.182% in America, 3.482% in Africa, and 1.788% in Europe. On the other hand, *FS* documents a significant and positive impact on *GG* in all regions in the LR. A 1% escalation in *FS* enhances the growth rate of *GG* by 0.115% in Asia, 0.962% in America, 0.646% in Africa, and 0.173% in Europe. Technology has a significant positive influence on *GG* in all four regions in the LR. It is shown that a 1% rise in *Tech* improves the growth rate of *GG* by 0.124% in Asia, 0.339% in America, 0.305% in Africa, and 0.214% in Europe. *HC* reports a positive influence on *GG* in America and Europe only in the LR. The coefficient estimates depict that a 1 % increase in *HC* enhances the growth rate of *GG* by 2.191% in America and 0.991% in Europe. The impact of *REC* and *Trade* on *GG* is insignificant in all regions in the LR. The nexus between *FG* and *GG* is significantly positive in all four regions except Africa in the LR. A 1% escalation in *FG* enhances the growth rate of *GG* by 1.510% in Asia, 3.045% in America, and 1.210% in Europe.

Table 9: CS-ARDL estimates of *GG* (Regions-wise)

	Asia	America	Africa	Europe
Variables	**(1)**	**(2)**	**(3)**	**(4)**
Long-run				
ESR	–2.791* (1.593)	–2.182* (1.210)	–3.482* (1.903)	–1.788** (1.009)
FS	0.115* (0.069)	0.962*** (0.057)	0.646*** (0.098)	0.173*** (0.022)
Tech	0.124** (0.052)	0.339* (0.183)	0.305** (0.143)	0.214*** (0.033)
EDU	–0.747 (0.651)	2.191** (1.014)	0.064 (0.271)	0.991** (0.433)
REC	1.156 (1.053)	0.301 (0.307)	1.105 (1.686)	0.898 (1.451)
FG	1.510** (0.627)	3.045* (1.697)	0.619 (0.638)	1.210* (0.625)
Trade	0.025 (0.653)	0.855 (0.848)	0.995 (1.156)	0.387 (0.317)
Short-run				
ESR	–1.791** (0.793)	–1.182** (0.510)	–2.082* (1.203)	–1.112* (0.579)
FS	0.900 (0.597)	0.652 (1.661)	1.347 (1.704)	0.128 (0.560)
Tech	1.199*** (0.078)	2.046* (1.034)	0.669* (0.347)	0.706** (0.315)
EDU	1.826 (2.257)	1.572 (2.804)	1.829 (2.371)	0.700 (1.462)
REC	–1.035 (1.325)	1.045 (1.013)	1.079 (1.159)	0.147 (1.331)
FG	2.398 (1.950)	2.079 (4.820)	1.981 (2.361)	1.561 (2.841)
Trade	1.807 (1.772)	0.595 (2.373)	1.386 (2.614)	1.036 (1.646)
Observations	442	234	130	572
***R*-squared**	0.231	0.213	0.445	0.365
Number of countries	17	9	5	22

Note: ***, **, * denote statistical significance at 1%, 5%, and 10% levels, respectively.
Source: Authors' own calculations

While *ESR* reports a significant and negative impact on *GG* in all four regions in the SR. The coefficient estimates report that a 1% rise in *ESR* reduces the growth rate of *GG* by 1.791% in Asia, 1.182% in America, 2.082% in Africa, and 1.112% in Europe. In contrast, the nexus between *FS* and *GG* is insignificant in all four regions in the SR. As far as control variables are concerned, only *Tech* reports a significant and positive impact on *GG* in all regions in the SR. A 1% increase in *Tech* enhances the growth rate of *GG* by 1.199% in Asia, 2.046% in America, 0.669% in Africa, and 0.706% in Europe.

6. Conclusion and policy recommendations

The widespread influence of various environmental crises experienced worldwide has raised the urgent need to take action towards reassessing the existing growth models. Hence, *GG* is deemed essential within the scope of COP-26. It is argued that the transition towards *GG* will ensure sustainable growth that raises living standards. Some countries have taken steps towards the achievement of *GG*, while others are at the stage of incorporating *GG* agenda in their economic plans. In ensuring this *GG* transition, *ESR* and *FS* emerge as vital determinants. However, the existing evidence on this debate is limited. Considering this, our study attempted to model the interaction of *ESR*, *FS*, and *GG*. The study examines the impact of *ESR* and *FS* on *GG* using top carbon emitter economies from 1995 to 2021. The study adopted the CS-ARDL regression techniques. The CS-ARDL offers both SR and LR estimates. In the LR, higher *ESR* causes the *GG* to fall.

On the other hand, *FS*, technology, and human capital lead to a rise in *GG* in the LR. The SR findings also confirm the negative connection between *ESR* and *GG*, while technology boosts *GG*. Nevertheless, most of the SR estimates are statistically meaningless. Regarding the regional analysis, the *ESR* threatens *GG* in Asia, America, Africa and Europe in the SR and LR. However, *FS* and technological development boost *GG* in all four regions in the SR and LR. Further, education favorably influences *GG* in America and Europe, and financial globalization boosts *GG* in Asia, America, and Europe only in the LR.

Based on the findings, the study offers policy recommendations. Governments should prioritize the diversification of energy sources and invest in sustainable and renewable alternatives to mitigate the risks associated with over-reliance on conventional and polluting energy. This can be achieved through targeted financial subsidies that encourage the adoption of cleaner technologies, fostering financial stability is crucial for creating an environment conducive to *GG*. Policymakers should implement measures to attract sustainable investments in the energy sector, providing financial incentives. Additionally, we suggest that financial regulations should be designed to enhance green investments in polluting industries, helping these industries in their journey toward green transformation. In this regard, it is suggested that the government should try to cut the overall expenditures of these industries by providing them subsidies and tax incentives while tying these subsidies to the development of cleaner technologies and green energy sources. Due to reduced expenditures and commitment to the government, the owners of the polluted firms are more likely to enhance their investment in clean and green technologies. To further support the polluted firms in their journey towards green transformation, policymakers collaborating with financial institutions should offer low-interest loans or grants to help businesses upgrade their technologies and production techniques and reduce pollution. Governments should redefine policies based on the evolving energy structure, technological advancements, and changing global economic conditions to ensure sustained *GG*. Collaborative efforts on an international scale are crucial for addressing global environmental challenges. Countries should engage in multilateral agreements and partnerships to share best practices, green technology transfer, and financial resources for the promotion of *GG*. Governments should focus on diversifying energy sources to lessen dependence on fossil fuels, which both promote *GG* and mitigate energy security risks. Policies should encourage developing and adopting of renewable energy technologies to promote sustainable growth.

The study has made significant contributions to contemporary literature but has left some loopholes that must be addressed in future works. This analysis explores the influence of overall financial stability on *GG* in highly carbon emitter economies, excluding a specific focus on the funding of green technologies essential for achieving *GG*. Therefore, future studies should estimate the role of green finance in promoting *GG* in top carbon emitter economies. Moreover, this study has collected data from top carbon emitter economies and we have performed the analysis on the full sample as well as on regions. In the future, researchers should concentrate on doing comparative analyses between developed and developing nations, which will be a good addition to the current literature. Lastly, the current analysis only uses the *ESR* index as a representative of energy security in top carbon emitter economies. Future studies, in addition to the *ESR* index, must add individual factors, such as energy intensity, energy demand, energy efficiency, etc., that represent energy security risks for more robust analysis.

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Appendix

Table A: Variables description and data sources

Variables	Symbol	Definitions	Sources
Green growth	*GG*	Adjusted net savings, excluding particulate emission damage (current US$)	WDI
Energy security risk	*ESR*	Energy security risk index	Global Energy Institute
Financial stability	*FS*	Bank Z-score	GFDD
Technology	*Tech*	Patent applications, total	WDI
Human capital	*HC*	School enrollment, tertiary (% gross)	WDI
Renewable energy consumption	*REC*	Renewable energy consumption (quad Btu)	EIA
Financial globalization	*FG*	Financial globalization index	KOF
Trade openness	*Trade*	Trade (% of GDP)	WDI

Source: Authors' own elaboration