RESEARCH ARTICLE

Assessing the EKC hypothesis by considering the supply chain disruption and greener energy: findings in the lens of sustainable development goals

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Abstract

This paper investigates the effect of the supply chain disruption, greener energy consumption, and economic growth on carbon emissions in advanced economies and emerging markets from 1997 to 2021 using panel quantile autoregressive distributed lags (QARDL) and the panel quantile regression (QR). The results of the two models confirm, on the one hand, the validity of the environmental Kuznets curve (EKC) hypothesis and, on the other hand, the role of renewable energy consumption in mitigating carbon emissions in advanced and developing economies. Furthermore, the finding shows that the supply chain disruption for the long run is positive at all quantiles, indicating the evidence of association at the extreme low and high quantiles than at the intermediate quantile. In addition, the effect of the supply chain decreases at the lower quantile. It turns negative at the upper 90th quantile in the short run, indicating that the supply chain disruption reduces the environmental degradation under the bearish market conditions. In the future, the increasing supply chain disruptions due to the Russia-Ukraine conflict and further COVID-19 worldwide can consider sluggish economic growth and play an essential role in promoting renewable energy abundance and reducing CO_2 emissions. Practical implications are reported in the lens of carbon neutrality and structural changes.

Keywords Greener energy · Supply chain disruption · Carbon emissions · Panel quantile ARDL

Introduction

Global warming and climate change are not just transitory events; they represent an environmental concern for governments, companies, policymakers, and academic societies.

In this respect, no continent has been away from the harm thereof. Besides, carbon dioxide emissions contribute to GHG emissions, mainly due to fossil fuel combustion, cement production, and deforestation. Above and beyond, although carbon dioxide emissions resulting from fossil fuel combustion during 2020 decreased by 5.2%, because of the restrictions of the COVID-19 pandemic, global average carbon dioxide concentrations have recently reached a new high level of 413.2 parts per million in 2020, while CO_2 emissions have shown to be rising, in 2021, to 6% annually (IEA - International Energy Agency 2022). In fact, in light of the high emission of CO_2, the world is witnessing more economic growth and using renewable energy sources. Therefore, growth rates and the percentage of renewable energy consumption appear, out of total energy, as two essential variables that significantly affect carbon dioxide emissions (Çakmak and Acar 2022; Hoang et al. 2022; Zafar et al. 2022). Extensive literature results documented that renewable energy consumption mitigates carbon emissions for different periods, countries, and techniques. Mujtaba et al. (2022), Sharif et al. (2017a), and Chopra et al. (2022) employed the panel NARDL (with

asymmetric) and panel ARDL (without asymmetric) to examine the effect of renewable and non-renewable energy on the environment. It observes that renewable energy's linearity and nonlinearity effect compared to conventional energy tends to exert a significantly low level of elasticity, respectively, to increase CO_2. Dogan and Ozturk (2017) and Dogan and Seker (2016) found that the increase in renewable energy consumption mitigates carbon missions. Extensive research provided a positive and negative significant influence of renewable energy on environmental degradation by employing ECM, Var, and PVAR (Antonakakis et al., 2017; Apergis et al. 2010; Ben Jebli et al. 2015; Robalino-López et al. 2015). Furthermore, the literature has sufficiently studied the effect of economic growth on carbon emissions and tested environmental Kuznets curve (EKC) evidence, but the results are inconclusive. Zoundi (2017) used the panel cointegration to provide the incompletely environmental Kuznets curve (EKC) for 25 African countries. Multiple methods and models have provided the hold of the EKChypothesis, and the results obtained are contradictory (Balsalobre-Lorente et al. 2022; He et al. 2021; Lu et al. 2021; Ma et al. 2021; Vural 2020; Wang et al. 2022).

Furthermore, the performance of the supply chain contributes to enhancing the economic growth and the volume of trade, thus increasing the emissions of CO_2. Therefore, having a sustainable consumption and production is crucial to maintain the supply chain, economic growth, trade volume, and CO_2 emissions (Sharif et al. 2020a; Zhao et al. 2022). Previous scholars have paid great attention to the impact of logistics and transportation as the main parts of the supply chain system on the emissions of CO_2. Following the International Chambers of Shipping ICS (2020), the global sea routes are responsible for 90% of world trade transportation. The existing literature examined the relationship between logistics and carbon emissions, drawing mixed results. Karaduman et al. (2020) found a positive correlation in eleven Balkan countries. Magazzino et al. (2021) also demonstrated a similar effect for 25 topmost logistics countries. Sohail et al. (2021) focused on air-railway transportation and concluded that this logistic and environmental pollution mode has a positive nexus.

On the contrary, another group reports negative relationships. Rehman Khan et al. (2018) documented a negative effect of poor logistics transport on carbon emission. Zafeiriou et al. (2016) use the Baltic Dry Index (BDI) to measure economic growth and environmental degradation. They also noted the negative sign in the relationship between BDI and carbon emissions. Shafique et al. (2021) used freight transport to demonstrate that transport costs cause CO_2 emissions. Santosa et al. (2022) established a negative relationship between carbon emission and logistics performance in ten ASIAN countries in a similar region. Liu et al. (2018) indicated a significant relationship.

International shipping drove the harmful carbon emission, while the logistics timeliness led to increased carbon emissions. The emissions of CO_2 are being determined by multiple factors, and supply chain disruption, renewable energy consumption, and economic growth are some of the leading ones (Farhan Bashir et al. 2022; Sharma et al. 2021a). In the situation like COVID-19 pandemic and Russia-Ukraine conflict, these effects are more palpable and significant, and this has been documented by several studies (Aktar et al. 2020; Wang and Su 2020; Muhammad et al. 2020; Baloch et al. 2020; Bannister-Tyrrell et al. 2020; Wu et al. 2020; Tosepu et al. 2020; Bilal et al. 2021). Furthermore, collective and sustainable integration of supply chain disruption, renewable energy consumption, and economic growth is required for green energy and environmental sustainability via reducing CO_2 emissions (Tiwari et al. 2022).

Nonetheless, the increasing disruption of supply chains interacts with the decline in economic growth, the decrease in freight operations, and the reduction in the emissions of CO_2. However, the economic literature has overlooked the impact of supply chains on the emission of CO_2. Consequently, the supply chain variable has become more efficient and modern than logistic and transportation proxy. In this context, Benigno et al. (2022) developed a new indicator drawn to capture supply chain problems and measure different dimensions of global chain disruption in developed and emerging markets, namely the USA, China, Japan, UK, Taiwan, and South Korea. These countries represent nearly 60% of world GDP, are highly dependent on renewable energy, and heavily approximate supply chain pressures. Our study uses this barometer to shed light on its effect on CO_2 emissions. We also examine the impact of economic growth and renewable energy consumption on carbon emissions. This is the first study to investigate the effect of the supply chain disruption on CO2 emission in the recent data of the COVID-19 pandemic as a phenomenon that draws attention.

Furthermore, present work examined this effect for two decades, including the subprime crisis's breakpoint and the COVID-19 outbreak. This study opens a novel theoretical lens that adds the supply chain pressure as a primary determinant of environmental degradation. Indeed, examining the effect of the supply chain on CO_2 emission due to the interaction with economic growth exhibits urgent attention to guide and contribute to the firms, monetary policymakers and governments, and international institutions. Additionally, our study employs a panel quantile ARDL model to check the effect of our explanatory variables on carbon emissions. Already previous research have used panel quantile regression with QARDL approach for dealing with panel data. QARDL method initiated by Cho et al. (2015) is an extended procedure of the autoregressive distributed lag approach of Pesaran and Shin (1998) and provides a great deal of information about the quantile-dependent short-run

dynamics and the long-run cointegrating parameters. Hence, QARDL is the best approach to measure different effect levels of the independent variables at all levels of the dependent variable in both short and long run.

The remainder of the paper is organized as follows. The "Literature review" section summarizes the literature review. The "Data sources" section provides the user data in this study. The "Methodology" section describes the model and the methodology. The "Results and discussion" section discusses the findings. Finally, the "Conclusion" section concludes the paper.

Literature review

Nexus supply chain—CO2 emissions

Supply chains have shown to be the most affected during the COVID pandemic due to the loss of thousands of employees and disruption of production, logistics, and transport sectors (Chen et al. 2022; Choi 2020; Chowdhury et al. 2021; Ivanov 2020; Nundy et al. 2021). The immediate consequence was the gradual paralysis of supply chains in several continental areas (Asia, Europe, North America) and sectors (automotive, chemicals, electronics, garments and textiles, machinery, metal, and medical devices). The transportation modes, particularly maritime transport, are operated in the supply chain, affecting the macroeconomic variables (Pham and Sim 2020). Zafeiriou et al. (2016) tested the relationship between Baltic Dry Index (BDI) and environmental degradation by applying the Threshold Vector Error Correction Model (TVECM). They provided the negative effect of the BDI on carbon emission besides the existence of the causality relationship between them. Suki et al. (2021) employed the CS-ARDL in the Asian region and confirmed the logistics index's significant effect as the main determent to counter emission carbon. Besides maritime and road transport, Sohail et al. (2021) focused on the air-railway transportation increase in Pakistan from 1991 to 2019 to positively affect environmental pollution using the nonlinear ARDL. Shafique et al. (2021) carried out a similar analysis, and they used freight transport to assess the transport cost and its relationship with economic growth and CO_2 emissions in ten Asian countries from 1995 to 2017. Their study demonstrated that freight transport increases environmental degradation. The environment Kuznets curve (EKC) hypothesis is most trusted and tested approach to measure the environmental issues such as CO2 emissions, environmental degradation, global warming, and climate change due to economic growth, supply chain, and trade volume (Sharif et al. 2017b). The EKC hypothesis states that economic growth and

high supply chain cause environmental problems for the certain period of time, and once establishing a balance between production and consumption, it becomes a factor to reduce environmental problems. Several studies used the EKC hypothesis for assessing the relationship between economic growth and environmental degradation like CO_2 emissions (Stern et al. 1996; Bella 2018; Katircioglu 2014; Sharif et al. 2019; Khan et al. 2019; Sharif et al. 2020b; Suki et al. 2020; Sharma et al. 2021b).

Karaduman et al. (2020) employed fixed panel data and used the logistics performance index from the World Bank to measure the logistics effect on carbon emissions for eleven Balkan countries. The results indicate a positive relationship between logistics and carbon emission, indicating that countries with higher logistics performance tend to have lower carbon emissions per capita (Santosa et al. 2022). A similar study for ten ASIAN countries shows a negative correlation between carbon emission and logistics performance. Liu et al. (2018) report a significant relationship between logistics index and environmental degradation for 42 ASIAN countries. Rehman Khan et al. (2018) focused on logistics transport to arrive in their study that the poor logistics contribute negatively to carbon emission and economic growth using the generalized method of moment (GMM) for 43 countries. Mariano et al. (2017) constructed a composite index to measure the low carbon logistics index in the transport sector for 104 countries on different continents. Magazzino et al. (2021) have engaged in panel GMM, fully modified ordinary least squares (FMLOS), and panel quantile regression in 25 topmost logistics countries. They found a positive impact of the logistic index on carbon emissions and a negative effect on economic growth. Zhu et al. (2022) also demystified the nexus between global supply chains and CO2 emissions by using input–output model. The results demonstrated a potential significance of global supply chain disruption in managing low level of CO2 emissions by directing policies measuring for economic growth and development.

Nexus renewable energy consumption—CO2 emissions

Clean energy has become the concern of many countries worldwide, in concurrence with the energy transformation within the plans aiming to reduce emissions due to fossil fuels, climate changes, and switch to renewable energy sources, especially with the increase of population and the energy consumption. In 2020, the International Energy Agency (IEA) reported that global energy consumption considered with 601.5 quadrillion BTU will increase to quadrillion BTU 842.8 in 2045, Annual Energy Outlook, 2021 (U.S. Energy Information Administration 2021). The previous literature has sufficiently studied the effect of renewable energy on carbon emissions, but the results

are inconclusive. Note that renewable energy mitigates environmental degradation. Mujtaba et al. (2022) employed the panel NARDL (with asymmetric) and panel ARDL (without asymmetric) to examine the effect of renewable and non-renewable energy on the environment. It observes that renewable energy's linearity and nonlinearity effect compared to conventional energy tends to exert a significantly low-level elasticity to increase CO_2. Dogan and Ozturk (2017), Dogan and Seker (2016) found that the increase in renewable energy consumption mitigates carbon missions. Extensive research provided a positive and negative significant influence of renewable energy on environmental degradation by employing ECM, Var, and PVAR show (Antonakakis et al. 2017; Apergis et al. 2010; Ben Jebli et al. 2015; Robalino-López et al. 2015; Shahzad et al. 2022). Few studies examined the effect of renewable energy by focusing on interaction via economic growth (Ehigiamusoe and Dogan, 2022). In their research, the interaction is positive and varied with the GDP level of 31 low-income countries by using modified ordinary least squares (FMLOS) and dynamic ordinary least squares (DLOS). York and McGee (2017) documented the small impact of renewable electricity via GDP interaction on CO_2 emissions in 128 countries using fixed panel regression. Moreover, as per the study conducted by Adebayo et al. (2022) shows that there is negative impact of renewable energy on emissions of CO_2 in all quantiles. This illustrates the degradation of natural environmental in accordance to upsurge in renewable energy consumption. Findings suggested the adoption of green technologies in supply chain and trading system with increased government's effort towards raising eco-friendly policies such as restriction on fuel subsidies, decreasing CO_2 emissions, and increase in bio-fuel consumption. Furthermore, uses of renewable energy resources like solar, wind, hydropower, and bioenergy are always good for environmental well-being.

Nexus economic growth—CO2 emissions

A larger empirical study has investigated the economic growth-environmental nexus, which follows an inverted U-shaped association. The literature has known the environmental Kuznets curve (EKC) (Kuznets 1955). Multiple methods and models have provided the hold of the EKC hypothesis, and the results obtained are contradictory. Some groups validate the EKC hypothesis (Balsalobre-Lorente et al. 2022; He et al. 2021; Ma et al. 2021; Shahbaz et al. 2013; Vural 2020), and the other group does not hold this postulate (Bölük and Mert 2014; Frodyma et al. 2022; Robalino-López et al. 2015; Soytas et al. 2007). In addition, the third group examined the link between economic growth and carbon emissions without verifying the EKC hypothesis. Namahoro et al. (2021) found negative economic growth in carbon emissions for 50 African countries, but the effect varies across countries and GDP per capita levels. Banday and Aneja

(2020) detect the causality from GDP to CO_2 emissions for BRICS countries except for Russia. Song (2021) establishes a positive association between economic growth and carbon emission in 30 China provinces using a panel threshold regression. Zoundi (2017) provided the incompletely environmental Kuznets curve (EKC) evidence in the long run for 25 African countries. Adebayo et al. (2022) measured the association between economic growth and CO2 emissions with the help of quantile-on-quantile regression (QQ) and quantile regression (QR) approaches. Findings suggested the negative impacts on economic growth on CO2 emissions at most of the quantile combinations. Outcome of the study also validates and supports the EKC hypothesis.

Data sources

This paper investigates the effect of the supply chain pressure, renewable energy, and economic growth on the carbon emissions from 1997 to 2021 for a panel of annual data in advanced economies (Euro Area, Japan, UK, USA) and emerging markets (China, South Korea). The first variable represents a new indicator drawn to capture supply chain problems and measures different dimensions of global chain disruption. It offers country-specific supply chains in developed and emerging markets, namely the USA, China, Japan, UK, Taiwan, and South Korea. In addition, it regroups 27 variables, including logistics networks, transportation, container shipping costs, and Purchase Manager Index (PMI) surveys.

This new index was downloaded from the St Louis Federal Reserve Bank. Taiwan is not included where the other variable data are not available. The second variable is the economic growth per capita and retrieved from Organization for Economic Cooperation and Development (OECD). The third and four datasets include renewable energy consumption as a percent of total final energy consumption (REC) and CO_2 emissions per capita. These two last variables were collected from the World Development Indicators. The data extend from 1997 to 2021 for many reasons. First, the New York Federal Reserve calculates the supply chain pressure index based on principal component indices extracted communally since 1997. Second, the GDP growth and GHG emissions have become more prominent and faster since the second half of the 1990s, especially in Asian countries. The panel quantile ARDL model is favorable for more than 20 observations per country (Arshed et al. 2022). The period estimation reflects enough time to capture the effect of this study in the long run.

Methodology

Our research employs the panel quantile regression and panel quantile ARDL to determine the effect of supply chain disruption, economic growth, and renewable energy on carbon

emissions in advanced and developing economies. The panel quantile proposed by Sim and Zhou (2015) is widely used in the literature to quantify the effect of the quantile-dependent variable on the quantile explanatory variable under different market conditions (bearish, normal, and bullish) (Adebayo et al. 2022; Mo et al. 2022; Su et al. 2022). The panel QR assess the effect and symmetric test among variables. On the contrary, a traditional model can only estimate the average effect and cannot avoid feasible market conditions. The panel quantile regression can help avoid false results through heteroskedasticity, skewness, and multicollinearity (Dawar et al. 2021) and structural breaks (Selmi et al. 2018; Xiao et al. 2019).

Further, QR tests the relationship and symmetric effects among variables. In addition, the panel quantile regression was developed for the panel quantile ARDL approach, which can capture the outcome in the short and long run. It is much more feasible and performant in the long- and short-run estimation. The panel quantile ARDL model is appropriate with the time of more than 20 and the presence of cointegration and stationarity but not more than the first difference (Arshed et al. 2022).

The mathematical equation of panel QARDL is estimated as follows:

$$\Delta CO_{2it} = \alpha + \beta_1 \Delta SCH_{it}^\theta + \beta_2 \Delta GDP_{it}^\theta + \beta_3 \Delta GDP_{it}^{2,\theta} + \beta_4 \Delta REC_{it}^\theta + \beta_5 SCH_{it}^\theta + \beta_6 GDP_{it}^\theta + \beta_7 GDP_{it}^{2\theta} + \beta_8 REC_{it}^\theta + \varepsilon_t^\theta \tag{1}$$

where CO_2 denotes the carbon emissions, SCH depicts the slope coefficient of the supply chain disruption, which detects the effect of the quantile of SCH on the quantile of CO_2 β_2 GDP_t represents the economic growth (constant US dollar) while B_3 GDP^2. The validity of the environmental Kuznets curve assumes that the coefficient of economic growth at different quantile β_2 GDP is positive and β_3 GDP^2 is negative and vice versa.. REC can explain the renewable energy in the model that t and I respectively stand the time and cross-section. Θ is the quantile level. β1, β2, β3, and β4 are the coefficients in the short run, whereas β5, β6, β7, and β8 are the coefficients in the long run. Finally, ε_t^q represented the quantile error correction term correcting of speed adjustment error term.

Results and discussion

Table 1 presents summary statistics of the panel and country-specific data. The mean of renewable energy consumption as a percent of total final energy in (China, the Euro Area, and the USA, respectively) is higher than in other countries (Japan, the UK, and Korea). The minimum renewable energy consumption remains weak and near 0.7% for Korea, while the maximum is evidently in China (30.6%).

The USA is the biggest carbon dioxide emitter during the period estimation. It also is the most volatile CO_2 emission.

Additionally, we observe that the Euroa Area is less volatile in standard deviation CO_2 emission. The mean per capita incomes in advanced economies were higher than in emerging markets like China. In this context, the standard deviation exceeds 7 SD compared to 4 SD and 3 SD in China and Korea. The supply chain disruption variable is negative in the panel and individual descriptive statistics. According to Table 1, the Jarque–Bera test and normality for all the panel variables are significant, meaning the series times are not a normal distribution.

Unit root test results

We consider two types of panel unit root tests. The first type is applied with a common process and involves two different tests (Breitung 2001; Levin et al. 2002). The second type verifies unit root using individual procedures proposed by Im et al. (2003) and Maddala and Wu (1999). The results of the panel unit tests root results are shown in Table 2.

The results of the unit root tests show that the series is stationary at different orders. The null hypothesis of unit root with common and individual processes is rejected, indicating that the supply chain is stationary at the level. However, the individual unit root process shows that the CO_2 emissions, economic growth, and renewable energy series contain a unit root, which is stationary at first. Therefore, it is appropriate to use a method based on the ARDL approach for integrated series of a different order.

Cointegration test

Table 3 documents the results of the cointegration. This section examines the null hypothesis of no cointegrated among the variables against the alternative hypothesis that the variables are congregated. The (Kao 1999) test is preferable in this study and is more appropriate for mixed stationarity levels (Arshed et al. 2022). Our finding accepts the alternative hypothesis and provides the cointegration that the variables move together in the long run.

The panel quantile ARDL results

Table 4 shows the panel quantile ARDL model from economic growth, renewable energy, and the supply chain disruption effects on carbon emissions. This table is divided into two. First, we show the process estimation for the short run (see Table 4 (A)). Second, Table 4 (B) reported the process estimation for the long run. Economic growth's impact on the short-run carbon emissions shows a positive effect at all

Table 1 Descriptive statistics for individual and panel variables

		CO_2		EG	RE	SCH	
	Mean	10.26408		31.00413	8.120453	−0.110004	
	Median	9.440400		34.96064	6.396700	−0.106269	
	Maximum	21.33570		65.27953	30.50605	1.364182	
	Minimum	2.614400		0.781744	0.676453	−3.929505	
	Std. dev	4.453282		15.79625	6.773254	0.598408	
	Skewness	0.978795		−0.390446	1.401562	−1.505210	
	Kurtosis	3.579984		2.436933	5.008899	13.49541	
	Jarque–Bera	24.83756		5.522408	70.86356	710.3306	
	Probability	0.000004		0.043216	0.000000	0.000000	
	Sum	1467.763		4433.591	1161.225	−15.73055	
	Sum Sq. dev	2816.105		35,432.06	6514.530	50.84915	
	Observations	150		150	150	150	
Variable	Statistics	CHINA	EURO_AREA	KOREA	JPN	UK	USA
REC	Mean	18.669	11.239	1.354	4.684	3.119	6.881
	Maximum	30.506	16.400	2.868	6.975	8.680	9.919
	Minimum	11.338	7.231	0.676	3.580	0.853	4.514
	Std. dev	7.509	3.587	0.765	0.938	2.607	1.825
CO_2	Mean	5.288	8.707	9.635	11.086	8.027	18.723
	Maximum	7.412	9.348	10.251	13.125	9.748	21.336
	Minimum	2.614	7.742	8.150	8.118	4.855	14.238
	Std. dev	1.867	0.396	0.505	1.478	1.644	2.153
GDP	Mean	4.534	32.946	38.825	21.748	39.180	47.935
	Maximum	10.435	42.185	49.145	33.423	50.653	65.280
	Minimum	0.782	20.166	32.424	8.282	26.743	31.459
	Std. dev	3.453	7.523	4.267	7.824	7.169	10.121
SCH	Mean	−0.119	−0.053	−0.024	−0.210	−0.090	−0.095
	Maximum	1.547	1.347	0.269	1.046	1.142	1.360
	Minimum	−1.066	−1.202	−0.260	−3.930	−1.039	−1.198
	Std. dev	0.640	0.575	0.146	0.902	0.507	0.689

quantiles except at the upper quantile (0.9th). In addition, at low quantiles, the impact of 1% of economic growth leads to an increase in the emission of carbon by 0.22% and 0.14% from low quantiles (10 th and 20 th) at the mean and high quantiles, and the results indicate a weak influence, whereas at upper 90 th quantile, the effect turns negative. The gdp^2 is negative that detects strong evidence of the EKC hypothesis. The impact of renewable energy consumption decreases from 0.18 at lower quantile to 0.11 at high quantile, illustrating renewable energy consumption's role in mitigating

Table 2 Panel unit root test results

Unit root with common process				
	SCH	CO_2	RE	EG
Levin-Lin-Chu	−5.024*** (a)	−0.369	−4.725*** (b)	−5.132*** (b)
Breitung	−4.171*** (a)	−1.751** (b)	−1.723*** (b)	−3.790*** (b)
Individual unit root process				
Im, Pesaran, and Shin W-stat	−6.121*** (a)	−2.871*** (b)	−4.014*** (b)	−3.479*** (b)
ADF—Fisher chi-square	55.15*** (a)	27.897** (b)	40.906*** (b)	34.930*** (b)
PP—Fisher chi-square	306.104*** (a)	68.681*** (b)	71.830*** (b)	66.718*** (b)

***, **, and * denote statistical significance levels of 1%, 5%, and 10%, respectively. In addition, a and b imply level stationarity and first difference stationarity, respectively

Table 3 Cointegration test

Kao test	T statistic	Prob
	− 2.5929***	0.0048

***, **, and * denote 10, 5, and 1 statistical significance levels

environmental degradation in advanced economies and emerging markets. The effect of the supply chain decreases from 0.18 at the lower quantile, then converges to zero after the increase, and turns negative later at the extreme 90 th quantile.

Moving on to the effect, in the long run, we also observe that the impact of economic growth on the carbon emissions, in the long run, is positive at low and the intermediate quantiles while turning to be negative at high quantiles. Economic growth in the short run seems to be more critical than in the long run. The square of the GDP is negative from quantiles (40 th–90 th), which accepted the EKC hypothesis in the long run. These results support the findings related to impact of renewable energy consumption on the is negative for most of the combination of couple prices quantiles reported in the literature.

Moreover, it is noted that the supply chain disruption for the long run is positive at all quantiles indicating stronger evidence of association at the extreme low and high quantiles than at the intermediate quantile. Furthermore, the

adjustment coefficient (ECM) speed seems negative and significant, indicating that the model corrects itself to equilibrium very slowly at the mean by 0.8%. Likewise, low and high quantiles at the extremes, showing the converge towered slowly in the bullish and moderate than bearish market conditions. GDP growth is not the only reason beyond environmental degradation in our cases. Renewable energy consumption and supply chain disruption are also the primary reasons for the CO_2 emissions.

In contrast, the positive effect in the short and long run of the supply chain is significant for most quantiles. It is somewhat converging relatively for advanced economies and emerging markets. The impact of renewable energy consumption seems more critical than economic growth and supply chain disruption during the short- and long-run periods. In this context, it would engage in the manufacturing more depending on renewable energy and intensifying competitive pricing under supply chain disruption. Additionally, it is essential to imply that the global supply chain will keep being under authorities' attention in the present and future to interact with economic growth as a catalytic effect on the carbon emissions. Furthermore, supply chain managers can consider the permanent inflation and price escalations, especially during the Russia-Ukraine war and further COVID-19 worldwide that can be lagging the economy directly and the environmental degradation indirectly.

Table 4 Panel quantile ARDL process estimates

The short-term effect (A)						
Quantile	EC	EG2	RE	sch	Lco2	ECT$_{t-1}$
0.100	0.2244*	− 0.0024*	− 0.1527*	0.1577**	− 0.0422*	− 0.6300*
0.200	0.1448*	− 0.0013*	− 0.1437*	− 0.0699**	− 0.0173*	− 9.2500*
0.300	0.1171**	− 0.001*	− 0.1795*	0.0548**	− 0.0084*	− 1.0600*
0.400	0.0452**	− 0.0002*	− 0.1305*	0.0414**	− 0.0079*	0.0200*
0.500	0.2392*	− 0.0025*	− 0.1779*	− 0.0211**	− 0.0365*	− 0.8000*
0.600	0.0718*	− 0.0012*	− 0.1068*	0.1941**	− 0.0083*	2.1300*
0.700	0.0369*	− 0.0002*	− 0.1091*	0.0520**	0.0016*	− 9.5600*
0.800	0.0895**	− 0.008324	− 0.1131*	0.0102**	− 0.0076*	2.1300*
0.900	− 0.3166***	.0077904	− 0.1133*	− 0.0025***	0.0617	− 1.8900*
The long term effect (B)						
	EG	EG2	RE	SCH		
0.100	0.0266*	− 0.0006*	0.0042*	0.2029*		
0.200	0.1598*	− 0.0005*	0.0010*	0.0345*		
0.300	0.0089*	− 0.0003*	− 0.0030*	0.0404*		
0.400	− 0.0002*	− 0.0001*	− 0.0077*	0.0920*		
0.500	0.0291*	− 0.0006*	0.0055*	0.0518*		
0.600	− 0.0177*	0.0002*	− 0.0001*	0.2509*		
0.700	− 0.0152*	0.0001*	− 0.0110*	0.0900*		
0.800	− 0.0162*	0.0002*	− 0.0149*	0.1237**		
0.900	− 0.1164*	0.0021*	− 0.0004*	− 0.3630***		

***, **, and * denote 10, 5, and 1 statistical significance levels

Panel quantile regression

Panel quantile process estimates

Figure 1 shows panel quantile regression from economic growth, square GDP, renewable energy consumption, and the disruption of the supply chain on the CO2 emissions across ten quantiles. The red area represents 95% confidence bonds, while the blue indicates the impact estimates. The impact of economic growth shows a positive effect and progressively increases for high quantiles. The impact of GDP^2 on CO2 emissions is negative, confirming the EKC existence of panel quantile ARDL results. The effect of renewable energy consumption is negative from 0.1th to 0.7 th and then decreases slightly. We also observe that the impact of supply chain disruption is stable at all quantile and less critical compared to economic growth and renewable energy consumption.

Slope and symmetry-asymmetry tests

First, we test that the slopes do not change differently across the panel. Table 5 presents the chi-square of the slope equality test. This value is 36.86, which is statically significant and indicates that the slope is different across panel quantile levels.

Next, we analyze whether the effects have the same character at high quantiles (0.75) and low quantiles (0.25). According to the Wald test and the chi-square value represented in Table 5, we find evidence of an asymmetric effect at the sum panel quantile of explanatory variables on CO_2 emissions for advanced economies and emerging markets.

Table 6 reports the slope and symmetry-asymmetry check. The positive sign and asymmetric value of the economic growth on clean energy at (0.25–0.75) quantiles imply that the response is stronger when economic growth increases than the dependence during the decrease period. This finding reveals the role of economic growth in catalyst environmental
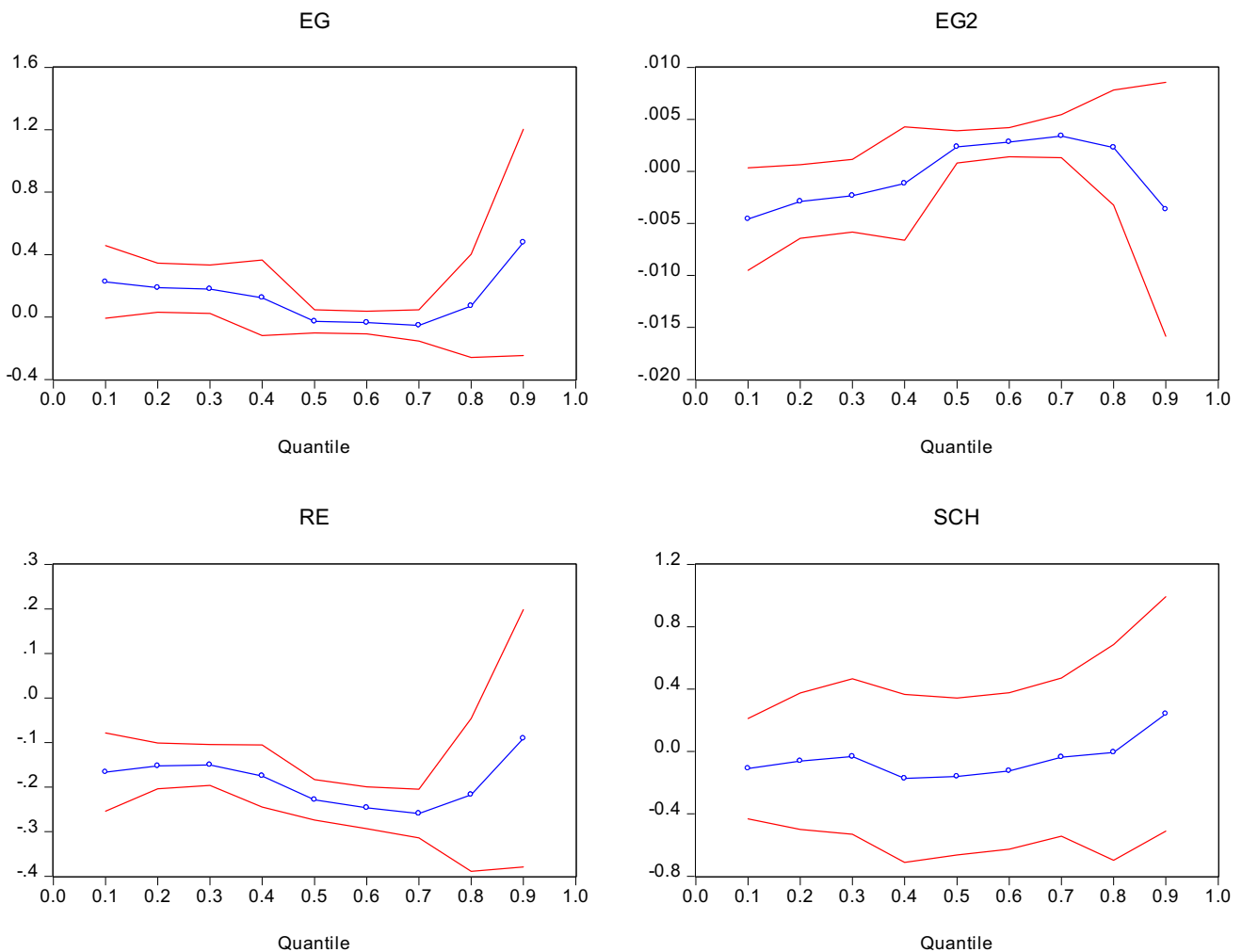

Fig. 1 Quantile progression Graph

Table 5 Quantile slope equality test

Test summary	Chi-Sq. statistic	Chi-Sq. d.f	Prob
Wald test	36.86	08	0.0000

Table 6 Slope and symmetry-asymmetry check

Test summary		Chi-square stat	Chi-sq. d.f	Prob
Wald test		17.49	05	0.06
Restriction detail: $b(tau) + b(1-tau) - 2*b(.5) = 0$				
Quantiles	Variable	Restricted value	Std. error	Prob
0.25, 0.75	EG	0.3	0.140	0.03
	EG^2	−0.005	0.002	0.04
	RE	0.04	0.030	0.09
	SCH	0.25	0.432	0.54
	C	−3.15	1.794	0.0789

degradation in the bullish and moderate market conditions. Similar results of the asymmetric test have existed for EG^2. In other words, the effect of economic growth on CO_2 emissions under the EKC hypothesis differs according to low and high quantiles. However, this is the same case in renewable energy and shows the asymmetrical effect. The supply chain disruption is not asymmetrical. It offers a relationship worth the emissions with the same slope on a quantile basis.

Conclusion

This study analyzes the effect of the supply chain disruption and renewable energy on CO_2 emissions in advanced and developing economies between 1997 and 2021 through the panel quantile ARDL model and panel quantile regression. Firstly, it indicates the positive impact of economic growth on carbon dioxide emissions. Secondly, we provide the environmental Kuznets curve (EKC) hypothesis. Third, renewable energy consumption is a negative effect, indicating that renewable energy reduces the CO_2 emissions.

It is noted that the supply chain disruption for the long run is positive at all quantiles indicating stronger evidence of association at the extreme low and high quantiles than at the intermediate quantile. Furthermore, the adjustment coefficient (ECM) speed seems negative and significant, indicating that the model corrects itself to equilibrium very slowly at the mean by 0.8%. Likewise, low and high quantiles at the extremes, showing the converge towered slowly in the bullish and moderate than bearish market conditions. GDP growth is not the only reason beyond environmental degradation in our cases. Renewable energy consumption and supply chain disruption are also the primary reasons for the CO2 emissions.

Moving on to the effect, in the long run, we also observe that the impact of economic growth on the carbon emissions, in the long run, is positive at low and the intermediate quantiles while turning to be negative at high quantiles. Economic growth in the short run seems to be more critical than in the long run. The square of the GDP is negative from quantiles (40th–90th), which accepted the EKC hypothesis in the long run. Above said results support the findings in view of impact of renewable energy consumption on the is negative for most of the combination of couple prices quantiles reported in the literature. Economic growth's impact on the short-run carbon emissions shows a positive effect at all quantiles except at the upper quantile (0.9th). In addition, at low quantiles, the impact of 1% of economic growth leads to an increase in the emission of carbon by 0.22% and 0.14% from low quantiles (10th and 20th). At the mean and high quantiles, the results indicate a weak influence, whereas at upper 90th quantile, the effect turns negative.

The impact of renewable energy consumption decreases from 0.18 at lower quantile to 0.11 at high quantile, illustrating renewable energy consumption's role in mitigating environmental degradation in advanced economies and emerging markets. Therefore, it is essential to use renewable energy sources especially clean renewable energy such as solar or wind by the advanced economies and emerging markets in view of minimizing pollution and CO_2 emissions (Godil et al. 2021). Moreover, it would also help in combating global warming and climate change. Furthermore, sustainable development goals especially goal no. 6 (clean water and sanitation), goal no. 7 (affordable and clean energy), goal no. 12 (responsible consumption and production), and goal no. 13 (climate action) must be the part of planning and policy implications related to CO_2 emission, environmental degradation, global warming, climate change, etc. as these goals are particularly designed to focus on these issues. The effect of the supply chain decreases from 0.18 at the lower quantile, then converges to zero after the increase, and turns negative later at the extreme 90th quantile. In contrast, the positive effect in the short and long run of the supply chain is significant for most quantiles. It is somewhat converging relatively for advanced economies and emerging markets. The impact of renewable energy consumption seems more critical than economic growth and supply chain disruption during the short- and long-run periods. In this context, it would engage in the manufacturing more depending on renewable energy and intensifying competitive pricing under supply chain disruption. Additionally, it is essential to imply that the global supply chain will keep being under authorities' attention in the present and future to interact with economic growth as a catalytic effect on the carbon emissions. Furthermore, supply chain managers can consider the permanent inflation and price escalations, especially during the Russia-Ukraine war and further COVID-19 worldwide that

can be lagging the economy directly and the environmental degradation indirectly. The supply chain disruption reduces the environmental degradation under the bearish market conditions. For perspective research, we will be trying to quantify the impact using extensive data, which is helpful from the high-frequency information. Moreover, it would evaluate the effect during the Russia-Ukraine conflict. Present research work is limited to investigation of the effects of supply chain disruption, greener energy consumption, and economic growth on carbon emissions in advanced economies and emerging markets, which gives direction to future research to conduct similar studies in poor economies and upcoming markets. Furthermore, this study is carried out with reference to COVID-19 pandemic and Russia-Ukraine war; therefore, upcoming research would also be conducted in pre and post of above said situations.

Declarations

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