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RESEARCH PAPER

How Does Health Uncertainty Impact Greenhouse Gas Emissions in European Union Economies? A Blessing in Disguise

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Abstract

The global outbreak of COVID-19 caused serious threats to public health and economic growth all around the world, but on the other hand, the betterment of the environment took place. How pandemics' health uncertainty will affect environmental quality is a crucial matter to address. The paper investigates the asymmetric association between pandemics-related health uncertainty and greenhouse gas emissions (GHG) in the top emitter European Union economies (Italy, Germany, France, Poland, Netherlands, Spain, Czech Republic, Belgium, Romania, and Greece). Employing data from 1996 to 2019, a unique approach called 'Quantile-on-Quantile', is adopted to evaluate the influence of various quantiles of the health uncertainty on GHG emissions. According to estimates, health uncertainty enhances environmental quality by minimizing GHG in most of our chosen nations at certain quantiles of data, which makes pandemics a blessing in disguise for environmental quality. Additionally, the estimations indicate that the grades of asymmetry between our variables varies by locality, accentuating the requisite for authorities to give specific consideration while executing health uncertainty and environmental quality policies.

Keywords Pandemics-related health uncertainty · Greenhouse gas emissions · Quantile-on-Quantile estimation · Environmental quality

Introduction

The universal outbreak of COVID-19 endangers not merely human health but similarly impedes economic growth and greenhouse gas emissions (GHG) (Tobias et al. 2020; Jafari et al. 2022). COVID-19 is believed to have a detrimental influence on the international economy for two key reasons. First, the dramatic increase in the epidemic throughout the world has significantly increased the unpredictability of economic growth, causing instability in capital and financial markets. Second, in order to contain the propagation of the pandemic, governments have rigorously limited the people and transportation movement, as well as economic activities (Yazdani et al. 2021; Aghashariatmadari et al. 2022), putting strain on economic activities from both the production and consumption sides. Many economists believe that COVID-19 will have a greater economic impact than the 2008 financial crisis. According to ongoing investigations, pollution rises with economic expansion and falls with economic downturns (Nicolini et al. 2022; Tobias et al. 2020). Because COVID-19 causes an economic slowdown, it also reduces pollution by lowering GHG levels.

COVID-19, in reality, has shocked our global economy, causing devastation worse than World War II (Muhammad et al. 2020; Heidarin and Jafari 2021). Restrictions on travel, border closure, and quarantine designed to flatten the pandemic curve have created legitimate concerns about a long-term economic disaster (Menut et al. 2020). Economic crises are often caused by a shock to either supply or demand. However, pandemics-related health uncertainty (PU) disrupted both components, resulting in a disaster from a global perspective (Yazdani et al. 2021). The government enforced safety regulations that limited the peoples' access to their professional activities, altering output and, eventually, the economy's aggregate supply. Furthermore, constraints on free moment caused a reduction in the consumption of commodities, leading to a fall in aggregate demand and a direct

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impact on the environmental quality (EQ) due to reduced GHG (Muhammad et al. 2020; Ayodeji et al. 2022). However, pandemic breakouts have severe environmental repercussions owing to the increased volume of local and clinical waste, which may be hazardous and can spread infections to other society members if not properly managed (Syed et al. 2022). Cheval et al. (2020) claimed that each environmental repercussion may not be favorable. PU degraded the EQ by boosting the amount of wastage that is unable to be recycled, creating huge amounts of organic waste owing to reduced agricultural and fisheries exports, and making it impossible to manage and monitor natural habitats (Zambrano-Monserrate et al. 2020; Amini et al. 2022).

The investigation of the PU-GHG link is complicated. Is it true that PU boosts EQ in European Union (EU) nations? Is the PU-EQ association shows non-linear behavior? What are the policy implications of PU-caused environmental change? Literature study reveals that these are unsolved challenges, and as far as we are aware, a few experimental works addressed the said concerns. The contribution of the present study to earlier available literature might be classified into many groups: In the beginning, several researches regarding the connection between PU and EQ have been organized during previous years (e.g., Tobias et al. 2020; Yazdani et al. 2021; Nicolini et al. 2022). As far as the authors are aware, no prior research has been done on the connection between PU and GHG in the most polluted EU nations. PU is the cause of several communal changes, but its impact on EQ is unidentified. Understanding how pandemic-induced severe behavioral disruptions influence GHG will give crucial information on its relationship with environmental sustainability. As per our knowledge, it is the pioneer investigation to apply the World Pandemic Uncertainty Index (WPUI) proposed by Ahir et al. (2018) to investigate the impact of PU on GHG in the top polluted EU nations.[1]

Prior works depend on the panel data to find the PU-GHG link, despite of the reality that few other localities do not have validation regarding this kind of link distinctly. Nevertheless, this research utilized the Quantile-on-Quantile (QQ) tool to offer international yet economy-related awareness of the relationship between PU and GHG. The QQ methodology estimates the time-series dependency of every nation individually. Numerous aspects of the PU-GHG relationship make it challenging to study with conventional econometric techniques. Typical parametric estimated values are receptive to deviations and do not tolerate heterogeneous slopes (Shahbaz et al. 2018). Therefore, evaluating the PU's influence over EQ demands the use of a persuasive econometric method, like QQ, that is reluctant towards deviations and might tackle slopes heterogeneity (Sharif et al. 2020). Many of the prior works on pandemics-environment nexus have included carbon dioxide emissions (CO_2) while ignoring GHG as a proxy for EQ. Only CO_2 comprises a small portion of the total anthropogenic impact on the environment (Gu et al. 2021). On the other hand, GHG is made up of a variety of emissions such as CO_2, CH_4, N_2O, and SF_6, and it might be a beneficial indication to exchange CO_2 in appraising EQ (Gu et al. 2018; Gu et al. 2020). Previous research tested negative, positive or neutral signs of parameters throughout the whole sample data. This research, conversely, entails that unique signs (either negative or positive) might be obtained throughout a spread of quantiles. While the economy is in a depression, the PU's influence might be unlike as compared to when it is flourishing. Likewise, the effect of the increase in PU ranks on the EQ might diverge from that of lesser PU ranks. The complexity and dynamic nature of the relationship between PU and EQ may increase as the intensity of PU grows. We predict an asymmetrical PU-GHG nexus because dispersed features cause non-linear variations (Yu et al. 2022). We might additionally realize co-movements (causalities) at several segments of the data (at tails, mid, or top). Because the PU-GHG correlation changes, our single-economy tool might offer officials of government and policymakers critical nation-related recommendations to achieve economic, political, and social assessments on the top, lower, and medium ranks of PU and GHG.

The present research considers the EU countries on diverse grounds. First, the economies picked by us experience both the consequences of environmental degradation and pandemics (Nicolini et al. 2022). Second, EU countries' features are associated according to their mutual social, economic, and political structures. Third, we apply the QQ method, which regresses every economy autonomously to handle the slopes heterogeneity and cross-sectional interdependence, as these concerns may create considerable bias and deformations (Sharif et al. 2020). Regional integration is essential in various economies because it fosters social, economic, and financial progress. As history revealed that a nation-related uncertainties can quickly expand to other economies in the zone, as history has demonstrated. Furthermore, the economic sector is dependent on its neighbours' economic sectors, besides internal and external shocks (Chang et al. 2022). Health-related uncertainties, financial crises, quick policy changes, and political disputes all lead to regime-switching conduct that introduces asymmetry into the PU-GHG connection (Chang et al. 2022; Hartono et al. 2021). Resultantly, the initial stage of our investigation was to observe every economy exclusively with a view to overcome the aforesaid hurdles. Fourth, even with their close relationship, these economies can recurrently be exceptionally not dependent because everyone holds its own arrangements in the efficacy of PU to alter EQ. The experimental

[1] Germany, Italy, France, Poland, Spain, Netherlands, Czech Republic, Belgium, Romania, and Greece.

model structure cannot manage country-specific heterogeneity without an econometric method like QQ. We hope that the results derived from the present study will offer a more comprehensive overview of the relation among the above said factors that may be challenging to get by utilizing usual econometric tools. Lastly, the research's findings would facilitate upcoming studies related to PU-EQ links and its repercussions for different economies.

The remaining components of this paper are planned as follows: A review of earlier empirical investigations is offered in Section "Literature Review". Section "Data and its Description" of the study examines the data, whereas segment 4 sets out the methodology used in the study. Section "Outcomes and Discussion" contains basic and major outcomes along with a discussion regarding outcomes. Section "Concluding Remarks and policy implications" abridges the study by suggesting certain possible policy ramifications.

Literature Review

As climatic variations are the foremost concern in various places globally, there are various studies on the elements that influence EQ (e.g., Ali et al. 2020; Khalid et al. 2021; Guo et al. 2021). Previous empirical research has overlooked the relevance of PU, which is inextricably linked to GHG and EQ (Chu and Le 2021).

Many studies have found that GHG levels in many economies decreased during pandemics, which might help people breathe cleaner air (Tobias et al. 2020; Yazdani et al. 2021; Nicolini et al. 2022). In a recent study, Muhammad et al. (2020) analyzed the pandemic outbreak-EQ association using data from NASA[2] and ESA.[3] During COVID-19, the quality of air in Italy, Spain, Wuhan and the USA improved by almost 30%. In the same way, Menut et al. (2020) discovered that the pandemic outbreak had an inverse influence on the levels of PM[4] and N_2O in Western European nations. Tobias et al. (2020) discovered that black carbon and NO_2 were decreased by 50% in Spain throughout the lockdown time, whereas PM_{10} was lowered to some extent. During the lockdown in Barcelona, however, the amount of O_3 jumped by more than 50%. Abdullah et al. (2020) revealed that travel restrictions had a substantial influence on the minimization of $PM_{2.5}$ in Malaysia. The lockdown reduced air pollution by 30% while restricting mobility by nearly 90%. For Iran, Yazdani et al. (2021) observed the positive influence of the pandemic outbreak on EQ.

Syed et al. (2022) analyzed the heterogeneous influences of geopolitical and economic policy unpredictability on CO_2 in BRICS nations. Economic policy uncertainty reduced CO_2 at low and medium quantiles, while it surged emissions at upper quantiles. On the other hand, the geopolitical uncertainty increased CO_2 at low quartiles and plunged it at mid and high-level quantiles. Wang and Su (2020) indicated that the outburst of COVID-19 improved the environment of China and significantly contributed to global CO_2 reduction. Watts and Kommenda (2020) and Myllyvirta (2020) discovered that the level of GHG in China reduced during COVID-19 phase. Additionally, Liu et al. (2020) reported a 7.8% reduction in CO_2 owing to the consumption of fossil fuels in 2020 compared to 2019 because of COVID-19. Moreover, Zambrano-Monserrate et al. (2020) observed the indirect influence of travel restrictions and lockdowns regarding EQ in the form of reduced noise pollution, air pollution, and marine pollution. Similarly, Dantas et al. (2020) discovered that nitrogen dioxide, carbon monoxide, and particulate matter decreased significantly during COVID-19, while the level of ozone (O_3) increased during this period. Similarly, Nicolini et al. (2022) assessed the effectiveness of social restrictions on CO_2 in major European cities. The findings revealed reductions in CO_2 levels throughout the national lockdowns. Brzezinski (2021) examined the influence of several pandemics i.e. MERS, SARS, H3N2 (Flu), Ebola, Zika, and H1N1 (Swine Flu) on CO_2 for the panel of 174 economies. It was observed that past pandemics minimized the level of CO_2 by 3.4–3.7%. In the same way, Zscheischleret al. (2017), Gherheș et al. (2021), Hartono et al. (2021), and Cheval et al. (2020) also observed improved EQ during COVID-19.

In contrast to the research listed above, some economists have observed that pandemics or PU have a negative influence on EQ (Zuo 2020; Cheval et al. 2020; Robert 2020). According to Zambrano-Monserrat et al. 2020, hospitals in Wuhan produced 240 metric tons of wastage daily, as related to 50 tons daily before COVID-19. Similarly, domestic wastage has grown as a result of the growing reliance on home delivery and online shopping (Zambrano-Monserrate et al. 2020). For G7 economies, Chu and Le (2021) observed that pollution increased due to economic policy uncertainty during the period 1986–2016. In China, Zuo (2020) appraised the connection between COVID-19 pandemic and medical wastage. It was revealed that nearly 245 tons of medical waste were created per day that was 600% higher than the average value. Moreover, Robert (2020) and Benson et al. (2021) also observed that COVID-19 decreased EQ.

Finally, the existing literature contains a lot of awareness of the impacts of various pandemics on EQ, such as MERS-Cov, SARS, Covid-19, and Ebola. There has not been single research that looked at the impact of PU on GHG. In these circumstances, our research will reduce the discrepancy in

[2] National Aeronautics and Space Administration.

[3] European Space Agency.

[4] Particulate Matter.

Table 1 The taxonomy of symbol and abbreviation

Symbols or abbreviations	Narration	Symbols or abbreviations	Narration
PU	Pandemics-related health uncertainty	J-B	Jarque–Bera
WUI	World uncertainty index	ADF	Augmented Dickey-Fuller
WPUI	World pandemic uncertainty index	ρ_{ϕ}	quantile loss function
QQ	Quantile-on-Quantile Estimation	kt	Kiloton
QR	Quantile regression	μ_t^{θ}	Quantile's error term
QC	Quantile cointegration	τ	τth quantile of greenhouse gas emissions
OLS	Ordinary Least Squares	$\mathrm{Sup}_{\tau}\ \lvert V_n(\tau)\rvert$	Supremum norm value of parameters (α and γ)
GHG	Greenhouse gas emissions	h	Bandwidth parameter
EQ	Environmental quality	CO_2	Carbon dioxide emissions

the empirical findings by investigating the above-mentioned link.

Data along with Description

Our data set contains two variables. Pandemics-related health uncertainty (PU) is considered an explanatory variable. The dependent variable of this study is GHG, which serves as a proxy for EQ. We assess the association between PU and GHG for the top 10 emitter EU economies.[5] The research period spans from 1996 to 2019, according to the availability of data. The data for GHG is taken from the website of World Development Indicator. The dataset for PU is taken from (https://worlduncertaintyindex.com/) created by Ahir et al. (2018).

The WPUI is used to gauge the impact of PU on GHG. The WPUI fluctuates from the WUI in respect of its conceptual foundation and significance. The WUI examines cumulative uncertainty (social, economic, and political risk), while the WPUI solely considers the health uncertainty caused by pandemics (WPUI 2020; Ahir et al. 2018; WUI 2020). The WPUI keeps track of how frequently the official of the Economist Intelligence Unit (EIU) uses the phrase “uncertainty” in terms of pandemics. The WPUI especially estimates the amount of risk arising from universal pandemics like SARS, Avian flu, Ebola, and COVID-19. Table 1 includes the nomenclature for the acronyms and symbols used in this study.

Figure 1 indicates the PU pattern from 1996Q1 to 2021Q3. The trend line exhibits how WPUI fluctuates with time, reaching its topmost spot in 2021Q1 due to COVID-19 pandemic.

[5] Germany, Italy, France, Poland, Spain, Netherlands, Czech Republic, Belgium, Romania, and Greece.

Econometric Tool

The present section discusses the econometric technique employed in present paper. We utilize quantile-based cointegration test to look at the variables’ relationships in long-run with each other. We also use the QQ technique for econometric estimation.

Quantile Cointegration (QC) Test

Many usual tests of cointegration make use of constant cointegrating vectors, which might be the reason why correlations between variables are not always seen in the long-run (Yu et al. 2022). To avoid estimate-related bias, Xiao (2009) presented a quantile cointegration (QC) test, which incorporates time-based variations along with the influence of multiple explanatory variable’s quantiles on a dependent variable to study long-run relationships in conditionally distributed data. Since endogeneity affects typical cointegration tests, Xiao (2009) modified them to comply with the rules of Saikkonen (1991) by including fragmentary cointegrating residuals.

If α (τ) represents a fixed vector, then we can express the cointegration model as follows:

$$X_i = \alpha + \alpha' Y_i + \sum_{k=-s}^{k} \Delta Y'_{i-k} \Pi_k + v_i \tag{1}$$

and

$$Q_{\tau}^{X}(X_i M_i^X, M_i^y) = \beta(\tau) + \alpha(\tau)' Y_i + \sum_{k=-s}^{s} \Delta Y'_{i-k} \Pi_j + F_v^{-1}(\tau), \tag{2}$$

where $\beta(\tau)$ shows a drift term while $\alpha(\tau)$ signifies persistent parameters. $F_v^{-1}(\tau)$ shows residual for the conditional data series. The component of the cointegration model might be stated as follows:

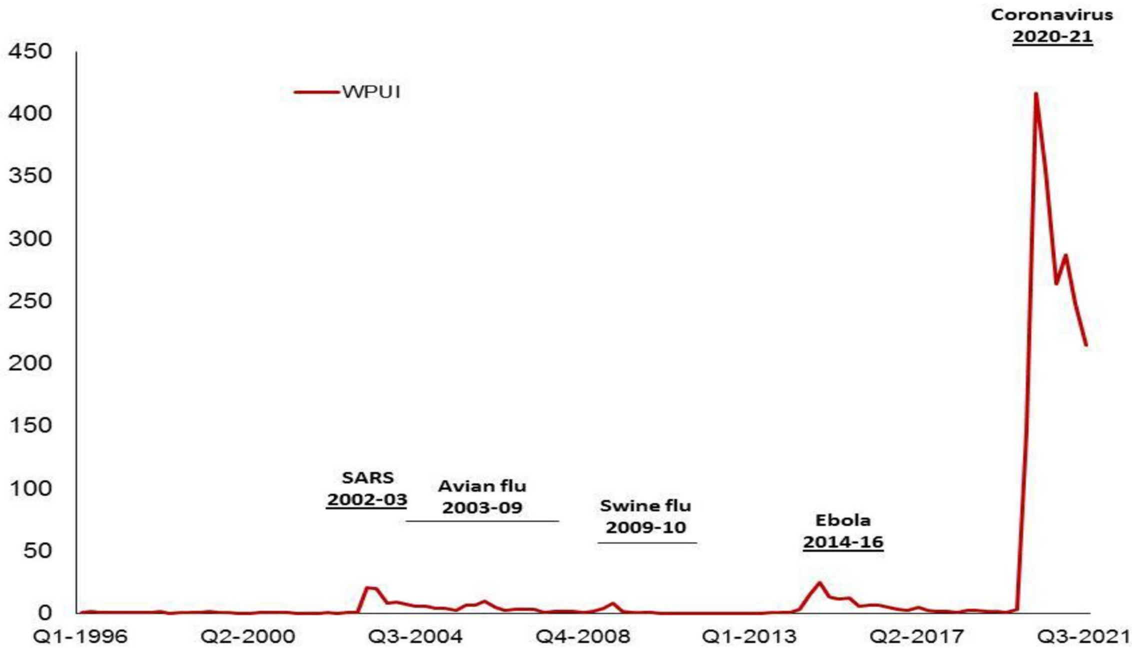


Fig. 1 Pandemics-related Health Uncertainty (1996Q1-2021Q3). Source: Author's own estimation on the basis of Ahir (2018) and WPUI (2020). The WPUI denotes to the simple mean of WPUI of 141 economies

$$Q_\tau^X(X_i M_i^X, M_i^y) = \beta(\tau) + \alpha(\tau)' Y_i + \delta(\tau)' Y_i^2 + \sum_{k=-s}^{s} \Delta Y_{i-k}' \Pi_k + \sum_{k=-s}^{s} \Delta Y_{i-k}^2 \Pi_k + F_v^{-1}(\tau) \tag{3}$$

For the QC test, H_0: α (π) = α is used as the default hypothesis acquired with the help of Eq. 3 to find the cointegration coefficients. $\hat{V}_n(\tau) = [\hat{\alpha}(\tau) - \hat{\alpha}]$ represents the null hypothesis (supermum rule) in our research. $Sup_\tau \left| V_n'(\tau) \right|$ is utilized as a test statistic throughout the whole quantile distribution in our study.

Quantile-on-Quantile (QQ) Method

Due to their non-linear distribution, the Quantile-on-Quantile (QQ) tool is taken as the most suitable evaluation for forming a connection between the two variables. The customary QR merely assesses the mean influence of the independent variable on the numerous dependent variables' quantiles. QQ tool, presented by Sim and Zhou (2015) is as an addition to the conventional QR method to address its limitations. QQ is an excellent choice for studying several aspects regarding association within explanatory and explained variable (Sim and Zhou 2015). This method combines standard QR with non-parametrical estimations. It appraises the effect of the quantiles of PU on the GHG quantiles in order to fix the interdependence concern. As a consequence, the QQ tool is adopted in the present research to ascertain complexities in the PU-EQ link that may be hard to investigate, picking other commonly utilized econometric techniques, like ordinary OLS or QR.

We use the non-parametrical model containing its simple version that is experimentally supported by Abdullah et al. (2020) and Wang and Su (2020) as follows:

$$GHG_t = \alpha^\theta(PU_t) + \mu_t^\theta, \tag{4}$$

where PU_t and GHG_t represent pandemics-related health uncertainty and greenhouse gas emissions, respectively, over t time period. θ^{th} GHG quantile of the conditional distribution is depicted by θ. Due to a lack of previous information on the PU-GHG association, factor load $\alpha^\theta(.)$ is not known to us. μ_t^θ denotes quantile error term along the θ quantile.

We evaluate Eq. 4 using local linear regression in the locality of PU as follows:

$$\alpha^\theta(PU_t) \approx \alpha^\theta(PU^\tau) + \alpha^{\theta'}(PU^\tau)(PU_t - PU^\tau) \tag{5}$$

In present situation, $\alpha^{\theta'}$ is a derivative of α^θ (PU_t) with respect of PU_t that is identified as partial impact. $\alpha^\theta(PU^\tau)$ and $\alpha^{\theta'}(PU^\tau)$ represents the function of θ and τ, individually. So, the altered form of the Eq. 5 might be specified as follows:

$$\alpha^\theta(PU_t) \approx \alpha_0(\theta, \tau) + \alpha_1(\theta, \tau)(PU_t - PU^\tau) \tag{6}$$

We derive the following QQ regression by substituting Eq. 4 in Eq. 6:

$$GHG_t = \frac{\alpha_0(\theta,\tau) + \alpha_1(\theta,\tau)\left(PU_t - \mathrm{PU}^{\tau}\right)}{(*)} + u_t^{\theta} \quad (7)$$

The QQ model's functional version is embodied with the help of Eq. (7), which explains the tie between the θ^{th} PU quantile and the τ^{th} GHG quantile. The conditional PU quantile is denoted by the term (*). The quantile-based linkage between PU and GHG is defined through parameters α_0 and α_1 and the said parameters are dually-indexed in θ and τ. α_0 and α_1 values might alter subject to the PU and GHG quantiles. By integrating their unique distributions, Eq. 7 exhibits the basic pattern of dependency between PU and GHG. As a bivariate QQ tool, it has no control variable except PU, but it outperforms other old time-series techniques. It is capable of forecasting the asymmetric link between PU and GHG at both the minimum and maximum quantiles, giving extra authentic and trustworthy results as compared to other frequently used tools (Yu et al. 2022).

The selection of bandwidth is vital as it contributes to understanding the PU-GHG linkage.

$$Min_{\delta_0\delta_1} \sum_{t=1}^{n} \rho_{\phi}\left[GHG_t - \delta_0 - \delta_1\left(PU_t - PU^{\tau}\right)\right] L\left[\frac{M_n(PU_t) - \tau}{h}\right], \quad (8)$$

where is the quantile loss function, while L (.) shows the Gaussian kernel function. The Gaussian kernel weighted parameters are not directly associated with the difference between the PU distribution function and the value of the PU quantile distribution function. h designates the bandwidth parameter. Small-bandwidth estimates exhibit considerable variation, whereas large-bandwidth estimates are skewed (Sim and Zhou 2015). So, it is crucial to strike the right balance between bias and variation. Hence, we agree to take $h = 0.05$ (5%) as the bandwidth's limit, followed by Sharif et al. (2020).

Robustness of the QQ Tool

The QQ model may propose us with typical QR estimations by allowing proper predictions for various quantiles of the PU. Despite the fact that its quantile-based coefficients are merely classified by θ, the QR model may anticipate the influence of θ^{th} quantile of PU on GHG. Unlike the method of QR, the QQ assesses the effect of the θ^{th} PU quantile on the τ^{th} GHG quantile and indexes the quantile constituents by both τ and θ, leading to further segmented data. In consequence, by taking the mean of the QQ parameters with τ yields the QR parameters. The QR regression's slope coefficients are represented by $\gamma_1(\theta)$, and it is applied to analyze the impact of PU on various GHG quantiles as follows:

$$\gamma_1(\theta) \equiv \overline{\hat{\alpha}}_1 = \frac{1}{s}\sum_{\tau}\hat{\alpha}_1(\theta,\tau) \quad (9)$$

In the present case, s = 19 embodies the number of quantiles, whereas τ = [0.05, 0.10, 0.15,…,0.95] represents the range quantile series. For this study, we might test the soundness of the QQ tool by relating the forecasted QR parameters to the QQ regression τ-averaged parameters.

Outcomes along with Discussion

The present section offers initial and key findings of the study.

Preliminary Findings

Table 2 shows the descriptive analysis of dependent variable (GHG) and independent variable (PU).

In terms of GHG, Germany has highest pollution, having an average value of 921245 kt changing from 806092 to 1083882 kt of GHG. Italy is ranked on second place, having GHG mean value of 488307 kt ranging from 3996001 to 559872 kt. France and Poland are rated third and fourth place containing mean GHG of 479638 and 385624 kt, respectively. Greece has the highest level of PU, with an average value of 5.34, falling between 0.52 and 47.12. Belgium ranks second with a mean or average PU score of 3.73, ranging from 0.11 to 28.31. Italy is positioned third, followed by Romania, Spain, and the Netherlands.

Excluding Spain, which has normal distribution of GHG, the results of the JB test reveal that PU and GHG have non-normal data distributions in our selected countries. Additionally, our selected countries' non-normal data distribution lends credibility to the rationality of the QQ tool that is the best fit for this situation (Razzaq et al. 2020). It is shown by ADF[6] test that the variables are stable at their first difference in most of the nations. As a consequence, a stationary data series is used, as suggested by Shahbaz et al. (2018), by transforming the variables into their first difference.

The correlation coefficients of PU and GHG are substantially interconnected with each other for entire countries, as displayed in Table 3. The probability values show that the coefficients are significant at 1% level. Italy and Germany have the biggest correlation coefficients (− 0.84), accompanied by the Netherlands (− 0.78), Poland (− 0.76), and Romania (− 0.75). PU and GHG are shown to be inversely associated with each other in all economies except the Czech Republic.

Table 2 Descriptive analysis of PU and GHG

Variable	Mean	Max	Min	Std. Dev	J-B Stats	ADF Level	ADFΔ
Panel A: Greenhouse Gas Emissions (kt of CO_2 equivalent)							
Germany	921245	1083882	806092	75007	2.05*	– 1.55	– 5.72*
Italy	488307	559872	399601	54197	2.09*	– 1.84	– 4.14*
France	479638	521880	423350	34386	2.52*	– 1.90	– 5.86*
Poland	385624	436365	362365	17628	5.98*	– 1.57	– 4.42*
Spain	358122	434660	296730	40164	1.76	– 1.73	– 7.65*
Netherlands	199802	230292	178642	13852	2.95*	– 1.68	– 4.48*
Czech Republic	135336	150742	120360	9274	2.67*	– 1.09	– 5.72*
Belgium	124528	142471	106460	12452	2.87*	– 1.13	– 5.72*
Romania	117832	160310	98570	16176	2.54*	– 1.98	– 7.82*
Greece	106934	125640	78500	14761	2.35*	– 5.70*	– 5.25*
Panel B: Pandemics-related Health Uncertainty (PU)							
Germany	2.13	16.21	0.00	4.09	80.11*	– 1.47	– 4.34*
Italy	2.81	20.20	0.21	4.16	172.05*	– 1.77	– 5.81*
France	2.07	16.05	0.00	3.67	77.86*	– 1.69	– 5.05*
Poland	1.80	7.57	0.00	1.80	24.87*	– 0.93	– 6.78*
Spain	2.38	17.51	0.16	4.36	79.21*	– 1.71	– 4.82**
Netherlands	2.36	9.50	0.00	2.67	5.97*	– 3.76*	– 5.56**
Czech Republic	1.24	7.97	0.10	2.12	51.42*	– 1.38	– 5.87*
Belgium	3.73	28.31	0.11	5.98	136.81*	– 1.49	– 4.62*
Romania	2.76	15.60	0.00	3.20	117.22*	– 1.97	– 5.81*
Greece	5.34	47.12	0.52	9.91	176.75*	– 1.54	– 5.64*

* and ** specify the rank of significance at 1% and 5%, correspondingly

Table 3 Correlation between PU and GHG

Country	Correlation	*t* statistics	*p* value
Germany	– 0.84	– 10.75*	0.00
Italy	– 0.84	– 11.27*	0.00
France	– 0.68	– 8.61*	0.00
Poland	– 0.76	– 5.34*	0.00
Spain	– 0.53	– 2.81*	0.00
Netherlands	– 0.78	– 20.32*	0.00
Czech Republic	0.73	7.43*	0.00
Belgium	– 0.74	– 4.15*	0.00
Romania	– 0.75	– 4.08*	0.00
Greece	– 0.66	– 7.83*	0.00

'*' shows the level of significance at 1%

Major Findings

Table 4 demonstrates the QC results. τ signifies the τ^{th} PU quantile. The supremum norm parameters (α and γ) indicate the stability of parameters.

To compute the t-statistics for QC, a set of 19 quantiles ranging from 0.05 to 0.95 is utilized. The corresponding critical limits for the supremum norms at the 1%, 5%, and 10% significance levels are denoted as CR1, CR5, and CR10

The estimations of the QC test explains that the cointegration or long-run relationship between PU and GHG alters throughout the range of various quantiles. It is proved that α and γ (coefficients) have higher supremum norms as compared to related critical limits (CR1, CR5, and CR10), showing that PU and GHG hold a significant non-linear long-run association in whole economies (Fig. 2).

In Fig. 1, slope estimations $\alpha_1(\theta, \tau)$ are depicted to highlight the effect of the θ^{th} quantile of PU on the τ^{th} quantile of GHG by utilizing various values of θ and τ.

In Germany and Romania, the inverse effect of PU on GHG is powerful. A vigorous and inverse connection between PU and GHG is established between the zones, which joins overall PU quantiles having mid–low to high GHG quantiles (0.40–0.95) in Germany and medium to upper quantiles (0.50–0.95) in Romania. This significant negative bond specifies that the PU raises the EQ by decreasing GHG at rising pollution ranks. Though, a weak inverse PU-GHG association is established within the localities that join overall PU quantiles at the bottom to middle GHG quantiles (0.05–0.50) in Romania and lower to medium–low GHG quantiles (0.05–0.35) in Germany. In Italy, the inverse influence of PU on GHG is dominant. A robust and inverse link is established between PU and GHG across the areas that link the medium–low to high PU quantiles with all quantiles of GHG. This mainly significant

Table 4 Result of QC Test (PU and GHG)

Country	Coefficients	$\text{Sup}_\tau \|V_n(\tau)\|$	CR1	CR5	CR10
Germany PU vs. GHG	α	8318.22	5282.23	3137.08	2535.30
	γ	177.64	105.47	53.83	39.37
Italy PU vs. GHG	α	68591.87	58357.30	57318.28	54881.72
	γ	2455.67	1499.21	1437.47	1432.10
France PU vs. GHG	α	1241.79	939.72	544.09	207.73
	γ	786.81	587.92	499.90	379.74
Poland PU vs. GHG	α	9381.08	7206.07	5907.72	2625.09
	γ	253.65	167.46	129.58	99.17
Spain PU vs. GHG	α	8755.58	6711.19	4771.13	1476.89
	γ	398.18	202.69	103.07	99.19
Netherlands PU vs. GHG	α	539.46	326.35	295.72	239.57
	γ	287.90	198.85	126.73	99.38
Czech Republic PU vs. GHG	α	6238.61	5680.90	4688.52	3788.70
	γ	3272.93	2697.78	2186.70	1855.44
Belgium PU vs. GHG	α	7119.36	3494.13	3085.19	2226.36
	γ	607.41	302.86	217.17	119.13
Romania PU vs. GHG	α	3932.98	3767.24	249.59	203.95
	γ	160.79	159.82	48.09	45.77
Greece PU vs. GHG	α	1836.73	1541.76	1040.75	999.80
	γ	946.75	687.65	491.70	346.85

inverse correlation indicates that PU increases the EQ by reducing pollution at strong amounts of PU. Though, a positive and strong PU-GHG relationship exists in the localities that join medium–low PU quantiles (0.05–0.25) along with whole GHG quantiles. It defines that PU is a cause of increasing pollution by raising the levels of GHG at the lower ranks of PU. The domination of the inverse link of PU with GHG supports the works of Nicolini et al. (2022) and Menut et al. (2020), who noticed that COVID-19 increased EQ in EU region.

France shows the dominance of inverse ties between PU and GHG. An extremely inverse link between PU and GHG is noticed in the vicinity that integrates entire PU quantiles with bottom to medium–low and lower-mid to top GHG quantiles (0.05–0.35 and 0.45–0.95). This powerful inverse linkage specifies that the PU boosts the EQ by curtailing emissions at both bottom and higher pollution levels, though an inverse and weak PU-GHG bond is assessed in the locations that join overall PU quantiles with low-mid GHG quantiles. In Poland, the inverse influence of PU on GHG is eminent. A vigorous and inverse bond between PU and GHG is observed throughout the regions that join whole PU quantiles with bottom to medium–high GHG quantiles (0.05–0.75). This mainly powerful inverse bond entails that the PU improves the EQ by reducing GHG at upper pollution ranks. Though, a strong and positive PU-GHG link is witnessed in the vicinities that combine overall PU quantiles and mid-high GHG quantiles. Though, this powerful positive link turns into a weak inverse connection in the locations that join all PU quantiles with higher GHG quantiles (0.90–0.95). In Spain, there is a significant and inverse bond between PU and GHG among the areas that unite whole PU quantiles with bottom to middle and upper-middle to top GHG quantiles. This significant and inverse relationship implies as the PU raises the EQ by lessening GHG at both higher and lower ranks of pollution. Though, this linkage becomes powerful positive in the locations that join whole quantiles of PU with upper-middle quantiles of GHG (0.55–0.65). The findings are consistent with the study of Schulte-Fischedick et al. (2021), who observed that COVID-19 increased EQ in European nations.

The Netherlands shows a significant negative link between PU and GHG. There is a strong correlation across all GHG quantiles and the medium to higher PU quantiles (0.50–0.95), and this correlation is negative. According to this incredibly strong negative link, the PU improves environment by reducing the volume of GHG at significant quantiles of PU and GHG. A weak inverse bond exists among the areas that join bottom to medium–low PU quantiles with the lower to medium–low GHG quantiles. Though, this weak inverse tie becomes a positive and powerful among the locations that unite low to lower-middle PU quantiles along with medium to upper GHG quantiles (0.50–0.95). There is supremacy of strong inverse PU-GHG association in Belgium. A strong inverse bond between PU and GHG is observed within the regions that join low to higher-middle PU quantiles (0.05–0.80) with all GHG quantiles. This predominantly powerful inverse association entails as the PU

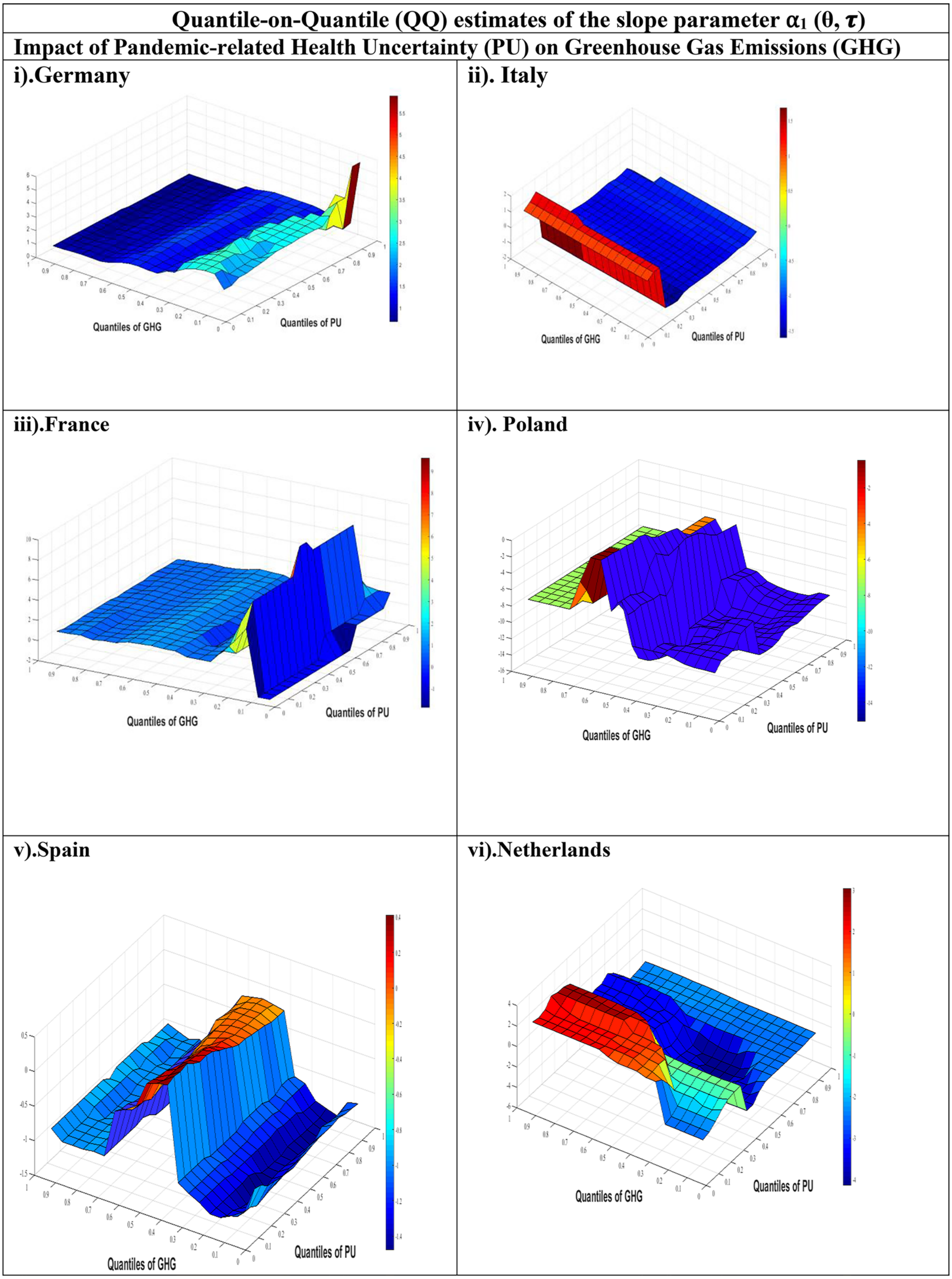
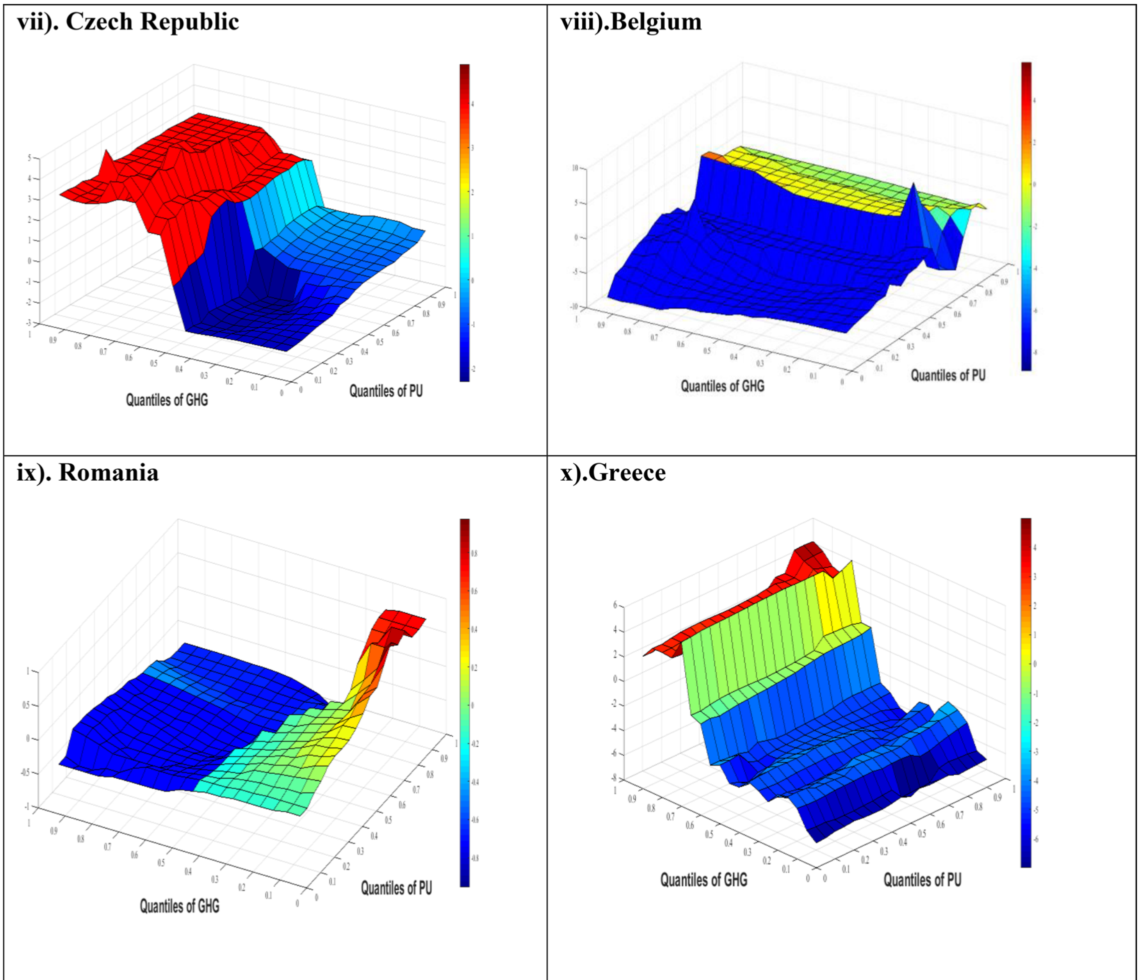


Fig. 2 Quantile-on-Quantile (QQ) estimates of the slope parameter $\boldsymbol{\alpha_1}$ ($\boldsymbol{\theta}$, $\boldsymbol{\tau}$). The slope parameter estimates $\boldsymbol{\alpha_1}$ ($\boldsymbol{\sigma}$, $\boldsymbol{\tau}$) are provided along z-axis while the PU quantiles are given along x-axis and GHG quantiles along y-axis



Note: The slope parameter estimates $\boldsymbol{\alpha}_1(\boldsymbol{\sigma},\boldsymbol{\tau})$ are provided along z-axis while the PU quantiles are given along x-axis and GHG quantiles along y-axis.

Fig. 2 (continued)

boosts the EQ by reducing the amount of GHG in phases of both bottom and medium–high PU levels. Both weak negative and weak positive bonds prevail among the regions that link top PU quantiles with whole GHG quantiles. The domination of the inverse link of PU with GHG is in corroboration with the investigations of Menut et al. (2020) and Nicolini et al. (2022), who observed that COVID-19 enhanced EQ in EU economies.

In Greece, the powerful and inverse correlation prevails between PU and GHG. A persistent inverse tie is established among the locations that integrate whole PU quantiles with the lower to moderately high GHG quantiles (0.05–0.65). This mainly strong negative connection indicates that the PU increases the EQ by reducing GHG at lowest to higher-middle level of pollution. A mixed PU-GHG nexus exists in the areas that bind all PU quantiles along with high-middle GHG quantiles (0.70–0.85). Additionally, this mixed connection turns into a strong positive link within the localities that joins whole quantiles of PU with upper quantiles of GHG (0.90–0.95). It entails that PU deteriorates the environment by enhancing the amount of GHG during periods of higher pollution.

There is a diverse link between PU and GHG in the Czech Republic. A substantial inverse association between PU and GHG is realized in the locations that join whole PU quantiles with the low to medium GHG quantiles (0.05–0.50). This predominantly powerful inverse connection entails that the PU uplift the EQ by lessening the amount of GHG during the phase when GHG is at low to medium ranks. A strong positive bond holds among the regions that join whole PU quantiles along with high-middle to top GHG quantiles (0.55–0.95), which means that PU considerably raises pollution during upper ranks of GHG. The mixed PU–GHG link is endorsed by the finding of Syed et al. (2022), who discovered that economic policy uncertainty decreased CO_2 at

Table 5 Summarized Findings regarding (Relation b/w Various Quantiles of PU and GHG)

Country	Quantiles of PU	Quantiles of GHG	Association b/w Quantiles	Dominant Linkage
Germany	All quantiles	Mid-low to high quantiles	Powerful and inverse	Powerful and inverse
	All quantiles	Lowest to lower-middle quantiles	Weak and negative	
Italy	Medium–low to top quantiles	Whole quantiles	Powerful and inverse	Powerful and inverse
	Lower-middle quantiles	Whole quantiles	Powerful and positive	
France	Whole quantiles	Bottom to lower-middle and lower-middle to top quantiles	Strong and inverse	Powerful and inverse
	Whole quantiles	Lower-middle quantiles	Weak negative	
Poland	Whole quantiles	Bottom to high-middle quantiles	Powerful and inverse	Powerful and inverse
	Whole quantiles	Medium–high quantiles	Powerful and positive	
	Whole quantiles	Higher quantiles	Weak and negative	
Spain	Whole quantiles	Bottom to medium and higher-middle to top quantiles	Powerful and inverse	Powerful and inverse
	Whole quantiles	Higher middle quantiles	Strong and positive	
Netherlands	Middle to higher quantiles	Whole quantiles	Powerful and inverse	Powerful and inverse
	Bottom to lower–middle quantiles	Low to lower-middle quantiles	Weak and inverse	
	Lower to lower-middle quantiles	Middle to higher quantiles	Powerful and positive	
Czech Republic	Whole quantiles	Low to medium quantiles	Powerful and inverse	Mixed relationship
	Whole quantiles	High-middle to top quantiles	Powerful and positive	
Belgium	Low to medium–high quantiles	Whole quantiles	Powerful and inverse	Powerful and inverse
	Top quantiles	Whole quantiles	Mixed relationship	
Romania	Whole quantiles	Medium to high quantiles	Strong and inverse	Strong and inverse
	Whole quantiles	Bottom to medium quantiles	Weak and inverse	
Greece	All quantiles	Low to higher-middle quantiles	Powerful and inverse	Strong and inverse
	All quantiles	High-middle quantiles	Mixed relationship	
	All quantiles	High quantiles	Powerful and positive	

low and medium quantiles while it surged CO_2 at higher quantiles.

Table 5 identifies the link between numerous PU and GHG quantiles for our selected economies based on Fig. 1. Most of the economies we looked at had a high negative correlation between PU and GHG, indicating that PU enhances EQ. In the Czech Republic, however, there is a mixed linkage between PU and GHG.

Verification of the Robustness of the QQ Method

The QQ estimated values may be analyzed to check if they are the same. The QQ technique's prior findings are supported by Fig. 3. The graphs demonstrate that for every nation under consideration, the average QQ and QR estimated values of the slope coefficients reveal a similar trend.

Figure 3 displays the PU and GHG heterogeneity in our sample vicinities. Confirming the extent of the coefficients, the influence of PU on GHG is significantly higher in the Netherlands, Italy, Belgium, and Greece, while substantially lower in Spain and France.

Discussion of Results

In most of the sample economies, the outcomes demonstrate an inverse correlation between PU and GHG. The findings of the study corroborate our hypothesis, as do those of other empirical investigations like Abdullah et al. (2020) and Wang and Su (2020), which imply that pandemics improve EQ. The detection of significant and negative PU coefficients gives credit to past policy comments regarding the Paris agreement (COP21), underlying the significance of minimizing GHG. We can compare our results with preliminary estimations of how the pandemics affect pollution levels, as well as strict government measures imposed in response to these pandemics.[6] Global emissions declined by 6.2 percent in 2020, according to Carbon Monitor Programs,[7] with substantial nation-specific heterogeneity (Nicolini et al. 2022). Watts & Kommenda (2020), Myllyvirta (2020) Yazdani et al. (2021) also support the findings. The outcomes are moderately coherent with those of Nicolini

[6] See Menut et al. (2020) and Nicolini et al. (2022).

[7] https://carbonmonitor.org/.

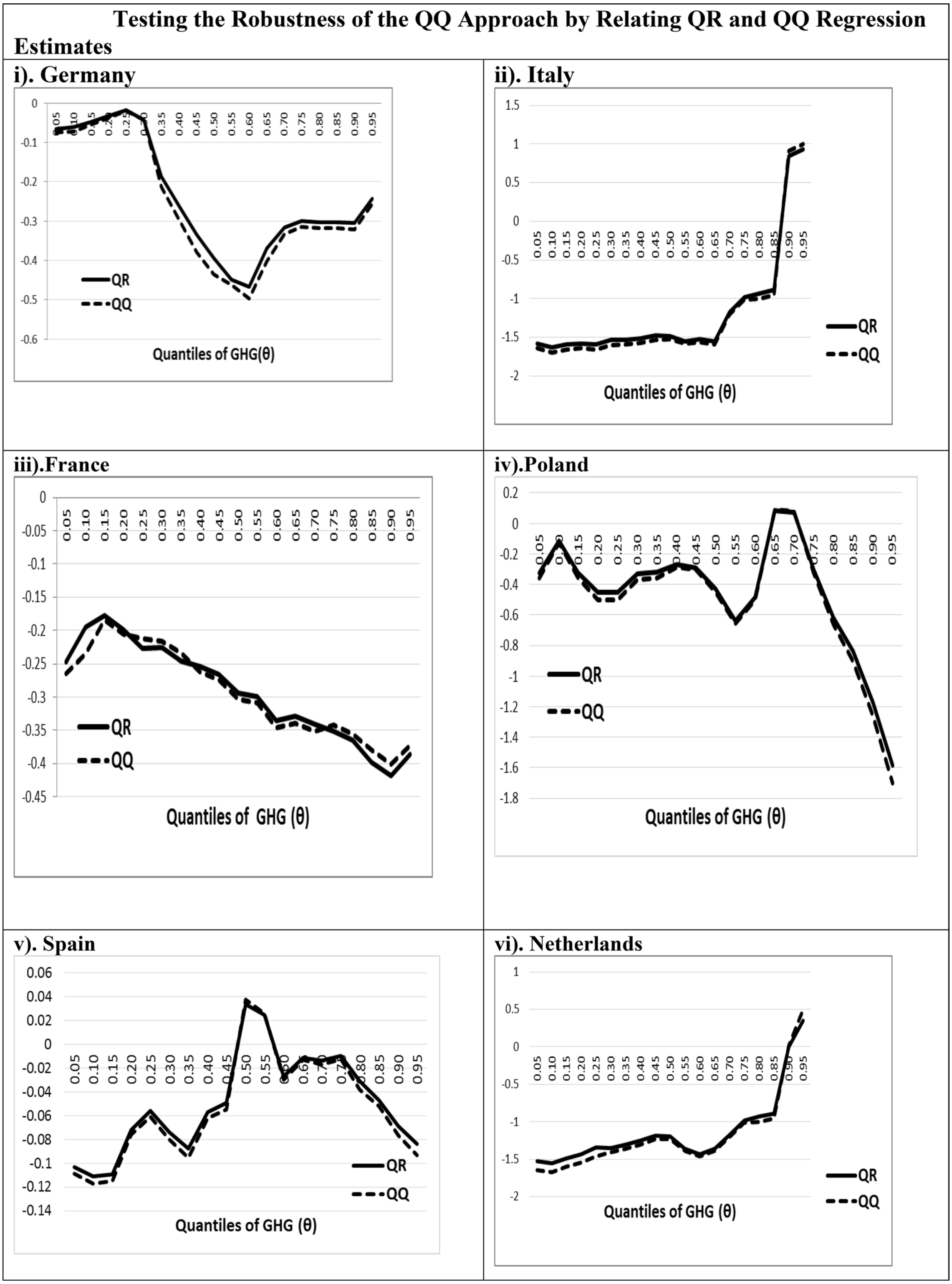
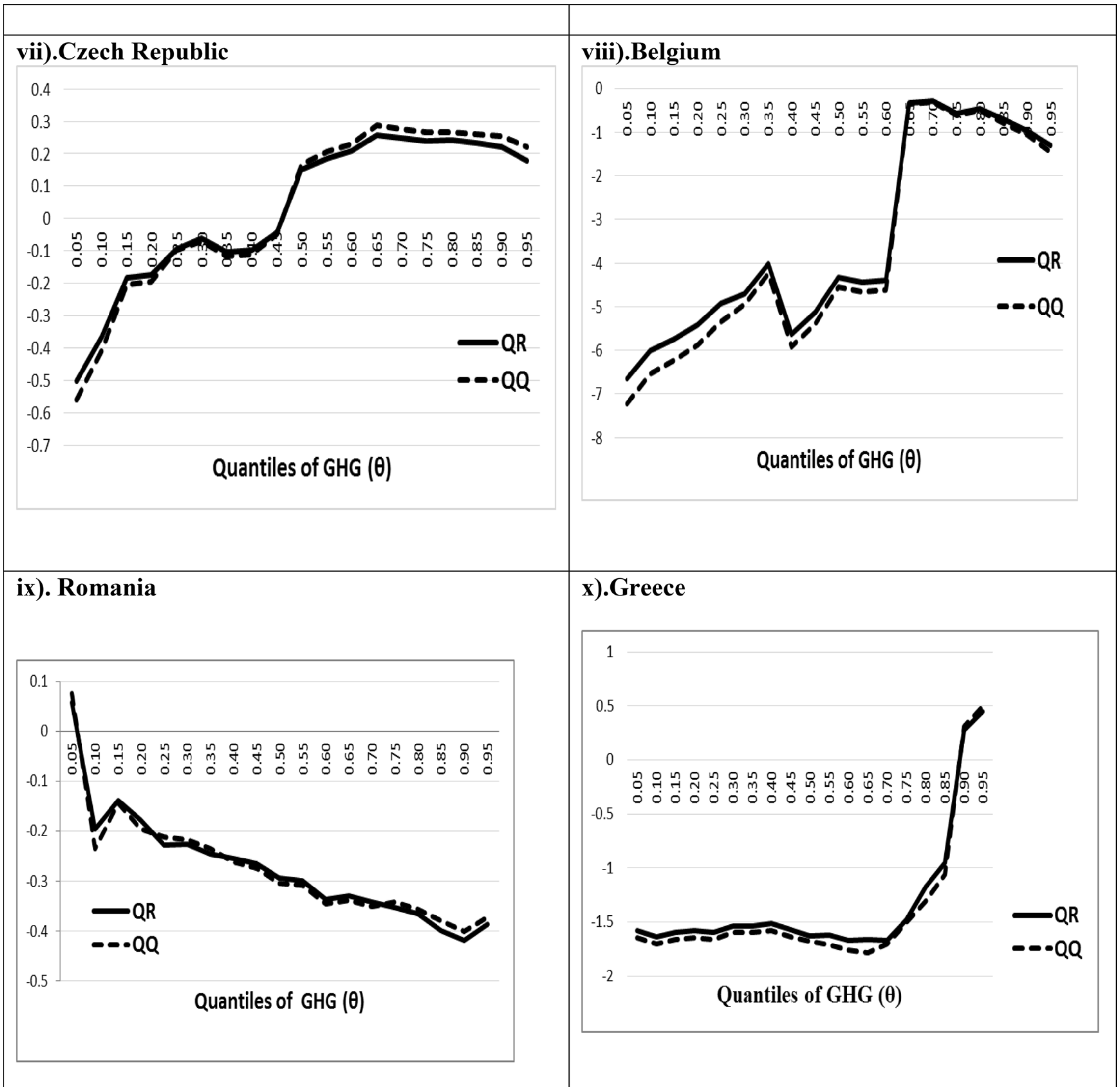


Fig. 3 Testing the Robustness of the QQ Approach by Relating QR and QQ Regression Estimates. The estimates of the typical QR parameters and the averaged QQ parameters are shown against various GHG quantiles



Note: The estimates of the typical QR parameters and the averaged QQ parameters are shown against various GHG quantiles.

Fig. 3 (continued)

et al. (2022) and Menut et al. (2020) for the EU, Tobias et al. (2020) for Spain, and similarly Chu and Le (2021) for the G-7 countries, who claim that PU improves EQ. The data further corroborate the notion that Covid-19-related reductions of GHG are driven by a reduction in economic activity, which might be induced by the health disasters themselves or the measures by the government that limit human and industrial actions to fight the epidemic.

We, however, detect a diverse link between PU and GHG in a significant number of quantiles in the Czech Republic, which might be attributable to distinguishing traits such as population, growth trends, business cycles, and technology. This corresponds to the conclusions of Syed et al. (2022), who revealed that economic policy uncertainty decreased CO_2 at low and medium quantiles, while it surged CO_2 at higher quantiles. Overall, current projections of PU-GHG are relatively comparable to past pandemic estimations. The cumulative GHG reduction associated with COVID-19 is expected to be transitory and will dissipate in the near future, although pandemic-linked uncertainty is expected to have slightly wider exposure than prior pandemics analyzed individually in many prior studies. Our estimates are quite related to those observed for the effect of pandemics on economic performance (Goswami et al. 2021), financial market (Sharif et al. 2020), economic growth (Salisu et al. 2020), energy usage (Li et al. 2022), and investment (Sharma et al. 2020).

On several grounds, the influence of PU fluctuates significantly among quantiles and throughout the sample localities. For instance, high GHG quantiles show a powerful negative bond with PU (for Spain, Germany, Romania, and France). The differences in the PU impact amongst sample economies might be determined by the economic situations of economies picked by us. In the context of population, technology, and potential for economic growth, France and Germany, for instance, stand out among the other chosen economies. In a locality, overlooking this sort of heterogeneity could lead to erroneous findings. PU and GHG slope coefficients differ among vicinities, showing that the PU-Environment relationship is not persistent along discrete high and low data quantiles but rather linked to the frequency and severity of economic shocks as well as the specific economic stage that has an influence on PU.

Concluding Remarks and Policy Implications

We observed the non-linear bond between PU and GHG in the topmost emitter localities of the EU (Germany, Italy, France, Poland, Spain, Netherlands, Czech Republic, Belgium, Romania, and Greece). Using panel data from 1996 to 2019, the 'QQ' method is employed that permits researchers to autonomously explore dependency in every economy in terms of offering international but locality-specific evidence on the bond between the variables. Estimates reveal that PU expands EQ by reducing GHG in most of our chosen economies at certain quantiles of data distribution.

Pandemic outbreaks have major implications, which might be utilized to reconsider individual and communal decisions and objectives. Most modern architecture demonstrates how people have adapted to contagious illnesses by changing their workspaces. During the COVID-19 outbreak, the utilization of media and webinars for information dissemination and skills gained significant use. When we increasingly work from home, study and update skills online, and buy essentials on e-commerce sites, we replace conventional physical venues with virtual ones that can be visited from smart/digital devices, resulting in less transportation and hence less GHG. The growing dependence on digital platforms in the built environment might persist for a long time after the pandemic, affecting all aspects of the layout and urban planning. Human civilization is facing a worldwide crisis, maybe the worst of our generation. Many pandemic-related measures will become a part of everyday life, influencing behaviors and routines, and may have a beneficial effect on EQ. The pandemics have exposed our inability to govern our environment and have provided some lessons from this forced experiment. One of the most significant lessons we will learn is the importance of having a network of streets for cycling and walking. Walking has been demonstrated to be ecologically friendly as well as beneficial to humans' physical and mental betterment as a major form of transportation and physical activity. Streets may need to be modified to meet the needs of multi-modal mobility, resulting in healthier, safer, and greener societies. While public transportation is a good choice for decreasing pollution, it is not appropriate during a pandemic because it may contribute to the transmission of illness among passengers.

National decision-makers and international organizations are being encouraged to take action in order to reverse the growing tendency in worldwide GHG and to break the relationship between growth and GHG. International collaboration is crucial for managing pandemic crises like COVID-19. Depending on their national conditions, various nations actively react to pandemics. Developed and developing nations must exchange information, as well as learn from complementing each other's capabilities. Countries may pool their pandemic and environmental research abilities and resources to form a robust and worldwide scientific research coordination force able to respond to pandemic issues and boost EQ. To promote long-term growth, governments should emphasize policies with multilateral environmental limitations, as well as R&D investment and severe environmental laws. Nobody can be completely protected from the indirect effects of these disasters in any part of the world since humans share the same planet (Gu et al. 2019). Meanwhile, until quick coordinated action is taken, no country will be spared from the disastrous effects of climate change.

Last, this study has a few shortcomings that would set the stage for potential researchers. Due to the limitations of the QQ model, we have taken just the total GHG while neglecting its various sub-components (like N_2O, CO_2, CH_4, SO_2, and CH_4). These metrics could be utilized in upcoming research to evaluate how the results vary across different environmental factors. In addition, future studies might see at the impact of different forms of uncertainties on EQ, such as policy uncertainty, trade uncertainty, and overall uncertainty. Another prominent disadvantage of this research is the utilization of the bivariate QQ technique that precludes the addition of other control elements that alter the effect of PU on GHG. As a consequence, in future research, we might improve our model by using multivariate quantile-based approaches (like Quantile ARDL) to well perceive the relationship with extra independent variables.

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Data Availability The data that support the findings of this study are available on request from the corresponding author.

Declarations

Conflict of Interest The corresponding author declares that there is no conflict of interest with this work on behalf of all coauthors.

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