sustainability

MDPI

Article

The Role of Natural Gas in Mitigating Greenhouse Gas Emissions: The Environmental Kuznets Curve Hypothesis for Major Gas-Producing Countries †

Hussein Moghaddam [1,*] and Robert M. Kunst [2,3]

[1] Gas Exporting Countries Forum (GECF), Doha P.O. Box 23753, Qatar
[2] Department of Economics, University of Vienna, Oskar Morgenstern Platz 1, 1090 Vienna, Austria
[3] Institute for Advanced Studies, Josefstadter Strasse 39, 1080 Vienna, Austria
* Correspondence: hussein.moghaddam@gecf.org; Tel.: +974-404-84-24

† A first version of this paper has been presented at the 43rd IAEE International Conference in Tokyo, Japan, 31 July–4 August 2022.

Abstract: Since global warming has become a serious threat and GHG emissions are one of the main causes of it, analyzing the interactions between variables related to climate change has gained importance. This study investigates the nexus of per capita CO_2 emissions, per capita real GDP or income, per capita natural gas consumption, urban population, and trade openness by examining the validity of the environmental Kuznets curve (EKC) hypothesis for a panel of selected gas-producing countries over the period 1990–2020. To these data, slope homogeneity test, Granger causality in panels, stationarity tests, and cointegration tests are applied. A particular focus is on procedures that enable cross-sectional dependence. Admitting slope heterogeneity, the estimators provide mixed results. The findings, however, do provide evidence in favor of the EKC hypothesis in at least some of our sample countries. Furthermore, there are important policy implications that must be taken into consideration. This includes investing in clean technologies to reduce emissions and accelerating reform of fossil fuel subsidies.

Keywords: environmental Kuznets curve hypothesis; CO_2 emissions; natural gas consumption; second-generation econometric approaches; cross-sectional dependence

check for updates

Citation: Moghaddam, H.; Kunst, R.M. The Role of Natural Gas in Mitigating Greenhouse Gas Emissions: The Environmental Kuznets Curve Hypothesis for Major Gas-Producing Countries. *Sustainability* **2023**, *15*, 4266. https://doi.org/10.3390/su15054266

Academic Editor: Andrea Nicolini

Received: 4 January 2023
Revised: 12 February 2023
Accepted: 14 February 2023
Published: 27 February 2023

Copyright: © 2023 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Climate change and global warming are among the most discussed issues in the world, and they have important implications for the economy. Global energy-related carbon dioxide (CO_2) emissions have been growing substantially over recent decades. Between 1990 and 2020, CO_2 emissions increased by 51% from 2.1 gigatons (Gt) of CO_2 to over 3.2 Gt [1]. The largest sources of CO_2 emissions are power generation, transport, and the industrial sector. In 2020, these three sectors together comprised about 72% of the total CO_2 emissions in the world (see Figure 1).

The key climate-related objective agreed upon at the 2015 Paris Conference on Climate Change (COP21) was to restrict global warming to less than 2 °C, ideally 1.5 °C, by 2100 compared to pre-industrial levels. The Paris Agreement has served as the backdrop for most of today's greenhouse gas (GHG) emissions debate.

The main task for the Glasgow meeting (COP26)—held in November 2021—was to finalize the procedures for implementation of the COP21. The Glasgow Climate Pact asks countries to accelerate efforts towards phase-out of unabated coal power and inefficient fossil fuel subsidies. Although the COP26 appears to reinforce momentum toward deep decarbonization and clean energy transition, uncertainties loom large, affecting the ability to deliver on the announced pledges and achieve 1.5 °C compatible emissions pathways by mid-century.

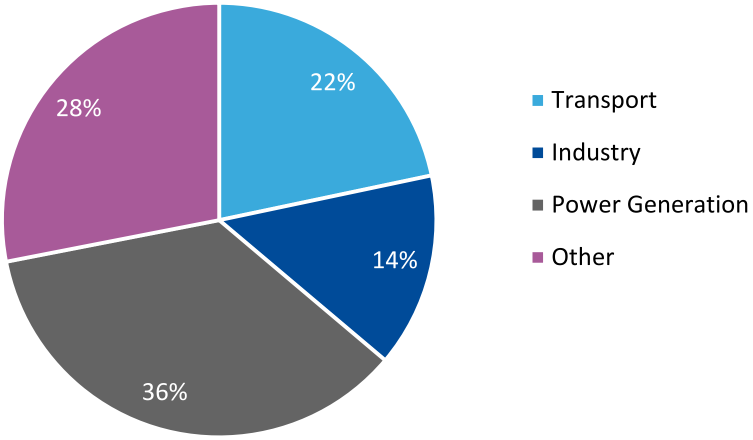

Figure 1. Global CO_2 emissions by sector in 2020. Source: GECF GGO 2050 [1].

That being said, abandoning use of all fossil fuels may seem like an ideal path toward 1.5 °C. Although cost of renewable energies is declining, renewables are still facing major obstacles, including but not limited to high capital costs, intermittency and variability, transmission infrastructure, affordability in many countries and regions, as well as lack of storage capacity [2].

In this context, natural gas as an affordable, reliable, and abundant source of energy represents an excellent alternative to reduce CO_2 emissions and help to combat global warming. Combustion of natural gas emits about half as much CO_2 as coal and 30% less than oil, as well as far fewer pollutants per unit of energy delivered. In addition, proven technology exists to reduce natural gas emissions, which ultimately could make natural gas even cleaner.

Moreover, natural gas exhibits complementary characteristics to address the drawbacks of renewables, namely a reliable, foreseeable production profile as gas is already part of the "baseload" production profile (displacing coal) in several countries. Furthermore, natural gas is becoming an important pillar of decarbonization and will increase its share in the global energy mix from 23% in 2020 to 27% in 2050 (see Figure 2) [1].

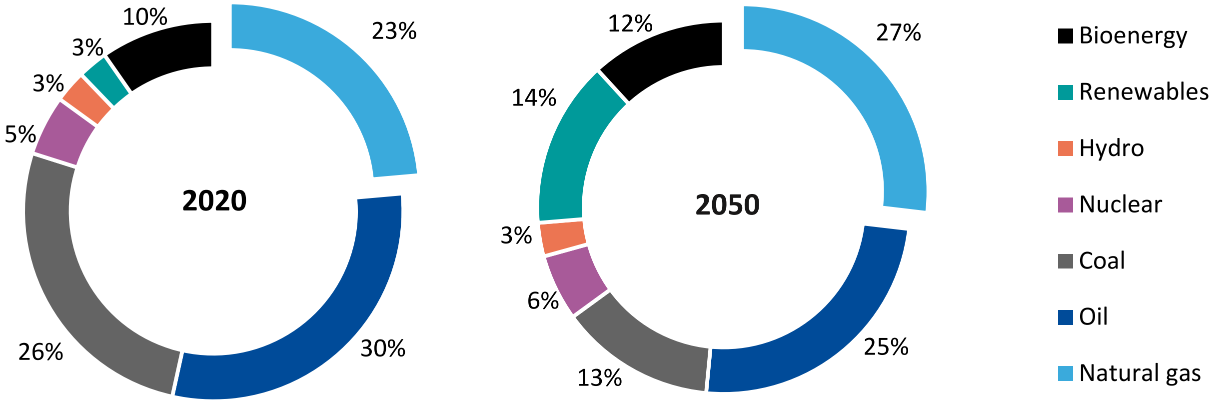

Figure 2. Global primary energy demand in 2020 and 2050. Source: GECF GGO 2050 [1].

Taking into consideration the above-mentioned aspects, adoption of suitable policies regarding energy and gas consumption, economic development, and environmental considerations is crucial for governments and policymakers. Therefore, it is vital to investigate the relationship between natural gas consumption and CO_2 emissions, which is important both for battling against CO_2 emissions and promoting natural gas demand.

In this context, the environmental Kuznets curve (EKC) hypothesis became popular among scholars as it represents an important tool for environmental policy. The EKC claims that, in the early stages of economic growth (determined by per capita), environmental degradation increases, but, beyond some level of economic growth, the trend will reverse, so, at high-income levels, economic growth leads to environmental improvement. This implies an inverted U-shaped relationship between economic growth and environmental degradation [3–5].

In the context of sustainability, the EKC suggests that, as countries become more economically developed, they will be better equipped to address environmental problems, leading to reduction in environmental damage. However, the relationship between economic growth and environmental damage is complex, and addressing sustainability challenges will require a multifaceted approach, including use of renewable energy sources, investment in clean technologies, and other mitigation strategies (e.g., changing customer behavior and increasing and enhancing energy efficiency in buildings).

This study addresses two main research questions: first, what is the role of natural gas consumption in mitigating CO_2 emissions in the sample of 12 major gas-producing and exporting countries? Second, does an inverted U-shaped reaction curve represent the relationship between economic growth (income) and CO_2 emissions?

In particular, the study aims to fill a gap in the EKC literature by focusing on two main objectives:

1. To the best of our knowledge, very few empirical studies have examined the validity of the EKC hypothesis with the impact of natural gas consumption on CO_2 emissions in the case of our sample countries.
2. Standard panel data techniques assume cross-sectional independence. However, this assumption is hard to satisfy due to the high degree of socioeconomic integration among countries, and this may create biased and inconsistent estimates in misleading conclusions [6–8]. Therefore, this analysis utilizes second-generation econometric approaches, such as the common correlated effects mean group (CCEMG) of Pesaran [9] and the augmented mean group (AMG) estimator of Eberhardt and Teal [10], assuming cross-sectional dependence to provide more robust analysis. Although there are many studies using either first- or second-generation panel data methods, there are few studies that use both methods.

Based on the above-mentioned theorem, this study aims to examine the causal relationship between CO_2 emissions, economic growth, natural gas consumption, population, and trade openness for a panel of 12 major natural-gas-producing countries, spanning 1990 to 2020 in the context of EKC hypothesis modelling.

The remainder of this paper is structured as follows. Section 2 reviews the related literature. Section 3 details the methodology and data that have been used for analysis. Section 4 presents the empirical results. The final section concludes this study and proposes some energy policy implications.

2. Literature Review

The EKC was named for Kuznets [11], who argued that income inequality first increases with economic development and then falls as the economy develops to a certain extent. Grossman and Krueger [12] first proposed the hypothesis in the environmental context when they used three air pollutant measures for forty-two countries to study the relationship between air quality and economic growth. They found that sulfur dioxide and smoke first increase with per capita income but then decrease as per capita income reaches a certain level.

Following the seminal research, the EKC hypothesis was tested in plenty of studies. Different control variables were included in the EKC models to investigate the role of various kinds of energy in affecting carbon emissions. The results vary depending on the method and sample used. A summary of some of those studies is provided in Table 1.

To the best of our knowledge, however, very few studies examine the EKC hypothesis by analyzing effectiveness of natural gas consumption, especially in the case of natural-gas-producing countries. Among them, Zambrano-Monserrate et al. [13] examine the impact on emissions from electricity consumption from renewable sources as well as from petroleum and natural gas in Peru. The findings do not support the EKC hypothesis, but they show that gas and petroleum consumption have positive effects on CO_2 emissions, while electricity consumption from renewable sources has a negative impact.

Dong et al., [7] investigate effectiveness of natural gas consumption in a group of 14 Asia-Pacific nations from 1970 to 2016. They argue that the EKC will arise in any country regardless of whether it is a low-income or high-income country. Moreover, CO_2 emissions are negatively related to natural gas consumption over the long run. However, positive causality from natural gas consumption to CO_2 emissions might appear in some Asia-Pacific countries.

In another study, by employing the ARDL approach and a data span from 1995 to 2014, Dong et al., [8] explore the causal relationship between natural gas consumption and CO_2 emissions in the short- and long run in Beijing, China. They find that the move away from coal and petroleum to natural gas can reduce CO_2 emissions. However, the mitigation effect of natural gas consumption would be weakened over time.

Layachi [14] investigates the association between crude oil, natural gas, and heating oil prices and environmental pollution in Algeria from 1980 to 2017. The study finds that economic growth has a positive and significant impact on CO_2 emissions. Furthermore, all energy prices confirm a negative and significant impact on CO_2; however, no causal relationship between natural gas prices and CO_2 emissions is found.

Lotfalipour et al. [15] study the link between fossil fuel, natural gas, and petroleum products with CO_2 emissions in Iran. The study used data from the period of 1967 to 2007. Applying the method of Toda–Yamamoto Granger causality, the study shows unidirectional Granger causality running from GDP, petroleum products, and natural gas consumption to carbon emissions.

Li et al. [16] assess the impact of natural gas consumption on CO_2 emissions based on the panel data of 30 provinces in China from 1998 to 2016. The study realizes that per capita GDP is effective in controlling emissions. Moreover, in regions with low natural gas usage, unidirectional causality is established from natural gas consumption to CO_2 emissions. The different causalities support that use of natural gas has a negative impact on emissions.

Murshed et al. [17] notice that consumption of natural gas, liquefied petroleum gas (LPG), and hydropower tend to decrease CO_2 emissions. They suggest that natural gas and LPG could both function as transitionary fuels to mitigate environmental pollution in Bangladesh.

Solarin and Lean [18] examine the impact of natural gas consumption on CO_2 emissions in China and India for the period of 1965 to 2013. They find that natural gas has a long-run positive impact on emissions in both countries.

In a series of publications (see, for example, Müller-Fürstenberger and Wagner [19] and Wagner [20]), Martin Wagner and co-authors discuss several major econometric problems that have been ignored in the empirical EKC literature, including but not limited to use of nonlinear transformations of integrated regressors of potentially nonstationary regressors and cross-sectional dependence, as well as develop a FMOLS estimator for cointegrating polynomial regressions (CPRs). These are critical of cointegration methods that use a variable and its square, something characteristic of EKC. Thus, the problems are not just of academic interest but can lead to contrary conclusions concerning the prevalence of an EKC hypothesis.

For instance, Fürstenberger and Wagner [19] argue the implications of the nonlinear transformations of nonstationary regressors and of neglecting cross-sectional dependence in a nonstationary panel context in the econometric analysis of EKC. They conclude that, in estimating the EKCs, the literature should pay attention to the fact that Kuznets curve regressions involve nonlinear transformation of integrated regressors (i.e., GDP) and that almost all panels of economic time series are cross-sectionally dependent.

Employing empirical analysis for CO_2 and SO_2 emissions data of 19 countries, Wagner [20] clarifies some conceptual shortcomings of the empirical EKC literature that arise because of the hitherto inadequate application of unit root and cointegration techniques. He presents a methodology that is suited to analysis of CPRs and argues that the powers of integrated processes are themselves not integrated processes. Using appropriate methods leads to strongly reduced evidence for a cointegrating EKC compared to typical but conceptually not sound findings.

Based on annual data per capita of CO_2 emissions, energy consumption, and income of eight developed and developing countries, Moosa and Burns [21], suggest that an EKC can be estimated separately from the conventional environmental Kuznets curve as a quadratic function of income. By using a variable addition test, as well as the unobserved components model, they found that the quadratic function fits better than the linear function and demonstrated strong support for the Kuznets curves in developed but not developing countries.

Table 1. Summary of literature review (alphabetical order).

Authors	Period	Study Area	Variables	Method	Results
Alam and Adil [22]	1971–2016	India	CO_2, GDP, PES, FD, TO	ARDL	No credence to EKC
Apergis and Ozturk [23]	1990–2011	Asian countries	CO_2, GDP, LAND, POP, Industry Shares in GDP	GMM	Validity of EKC
Atasoy [24]	1960–2010	The US	CO_2, GDP, EC, POP	AMG, CCEMG	AMG validates the EKC. CCEMG provides only weak evidence on the EKC
Baek [25]	1980–2009	12 major nuclear-generating countries	CO_2, GDP, EC, NE	DOLS, FMOLS	CO_2 emissions tend to decrease monotonically with income growth, providing no evidence in support of EKC for CO_2 emissions
Jammazi and Aloui [26]	1980–2013	GCC countries	CO_2, EC, GDP	Wavelet Approaches	Bidirectional causality between EC and GDP, and unidirectional causality from EC to CO_2
Kohler [27]	1960–2009	South Africa	CO_2, GDP, EC, TO	ARDL, Johansen Cointegration, VECM	Positive bidirectional causality exists
Lin et al., [28]	1980–2011	Nigeria	CO_2, EI, POP, CI, IVD, GDP	VECM	An inverse significant relationship between IND and CO_2
El-Aasar and A. Hanafy [4]	1971–2012	Egypt	GHG, GDP, RE, TO	ARDL	EKC hypothesis does not exist for GHG emissions in Egypt for both short- and long term
Ozcan, B. [29]	1990–2008	Middle East countries	CO_2, GDP, EC	FMOLS, VECM	Unidirectional causality from economic growth to energy consumption in the short run
Paramati et al., [30]	1991–2012	G20 countries	CO_2, RE, NRE, POP, GDP, FDI, SMC	Panel Granger causality	Confirm a significant long run equilibrium relationship among the variables
Rafindadi [31]	1961–2012	Japan	CO_2, GDP, EX, IM	ARDL	Presence of EKC despite the deteriorating income of the country

Table 1. *Cont.*

Authors	Period	Study Area	Variables	Method	Results
Saboori et al., [32]	1977–2008	OPEC countries	CO_2, GDP, Labor, Capital, OC, OP	ARDL, TYDL	EKC approves. Oil prices reduce environmental damage by their negative effect on the ecological footprint
Saidi and Mbarek [33]	1990–2013	19 emerging economies	CO_2, NE, RE, GDP	ARDL	Invalidity of EKC
Ulucak et al., [34]	1992–2016	BRICS countries	GDP, RE, Urbanization, Natural Resource Rent, Ecological Footprint	FMOLS, DOLS	Approve of EKC in case of BRICS Countries
Wang et al., [35]	1990–2012	China	CO_2, EC, GDP	VECM	Shocks in CO_2 have a small effect on EC and GDP
Zoundi [36]	1980–2012	25 African countries	CO_2, GDP, RE	FMOLS, DOLS	No evidence of a total validation of EKC. However, CO_2 emissions increase with GDP

Source: authors' elaboration. Note: Carbon Dioxide (CO_2), Carbon Intensity (CI), Energy Consumption (EC), Energy Efficiency (EE), Energy Intensity (EI), Financial Development (FD), Foreign Direct Investment (FDI), Greenhouse Gas (GHG), Gross Domestic Product (GDP), Industrial Value-Added (IVD), Nuclear Energy (NE), Oil Consumption (OC), Oil Price (OP), Population (POP), Primary Energy Supply (PES), Real Exports (EX), Real Imports (IM), Renewable Energy (RE), Stock Market Capitalization (SMC), Trade Openness (TO), Augmented Mean Group (AMG), Autoregressive Distributed Lag (ARDL), Common Correlated Effects Mean Group (CCEMG), Dynamic Ordinary Least Squares Estimator (DOLS), Fully Modified OLS (FMOLS), Generalized Method Of Moments (GMM), Toda–Yamamoto–Dolado–Lutkepohl (TYDL), Vector Error Correction Model (VECM).

3. Methodology and Data

3.1. Empirical Model

We examine the relationship between CO_2 emissions per capita as a dependent variable, GDP per capita (income), natural gas consumption per capita, urban population (urbanization), and trade openness as the explanatory variables.

In this study, the following linear/logarithmic model is employed to investigate the validity of the EKC hypothesis and determinants of carbon emissions for a sample of 12 major gas-producing countries:

$$CO2_{it} = \propto_0 + \beta_1 GDP_{it} + \beta_2 GDP_{it}^2 + \beta_3 GC_{it} + \beta_4 U_{it} + \beta_5 TO_{it} + \varepsilon_{it} \tag{1}$$

Here, $\propto_0$ and ε_{it} are the intercept and error term representing other factors affecting CO_2 emissions, respectively. In the sample, i indexes the country $(i = 1, 2, \ldots 12)$ and t indicates the time index in years (t = 1990, . . . , 2020).

A quadratic function of GDP is used to capture decreasing marginal income effect on CO_2 emissions. If $\beta_1 = \beta_2 = 0$, this indicates no relationship between economic growth and pollution. If $\beta_1 > 0$ and $\beta_2 < 0$, the relationship between economic growth and pollution is inverted U-shaped, supporting the EKC hypothesis. This means the CO_2 emissions tend to rise with an increase in income up to a certain level, beyond which CO_2 emissions decline with higher income levels. Once the EKC hypothesis is confirmed, interest focuses on the position of the turning point in GDP per capita, beyond which level of pollution declines [4,13,25,37,38].

The coefficient β_3, the partial effect of natural gas demand on CO_2 emissions, is of interest. If an increase in natural gas demand leads to a decrease in CO_2 emissions, then β_3 will be negative. Finally, the signs of β_4 and β_5 are expected to be mixed according to the level of economic development of the country. Nonetheless, in general, a higher level of urbanization means a higher level of economic development, and, consequently, a higher level of CO_2 emissions. Therefore, a bidirectional causal relationship is expected between economic growth, urbanization, and CO_2 emissions. Furthermore, the relationship between economic activities and environmental degradation can be through trade. According to Sobrinho [39], some economists believe that trade brings economic growth, which helps to protect the environment through raised incomes. Conversely, others think that trade increases environmental damage by raising unsustainable consumption and production patterns (e.g., increasing water and air pollution, land and forest degradation, and waste generation). Thus, there could be a bidirectional causal link between economic growth and environmental pollution [40].

Similar to Li et al. [16], Murshed et al. [17], Dong et al. [7,8], Zambrano-Monserrate et al. [13], and Atasoy [24], the estimation methodology in this study contains the following steps:

- Cross-sectional dependence tests to check interdependencies between cross-sectional units (countries) (Section 4.1)
- Slope heterogeneity tests for slope homogeneity in large panels (Section 4.2)
- Panel unit root tests to check the stationarity of the variables (Section 4.3)
- Cointegration tests to check the validity of a cointegration relationship between the variables (Section 4.4)
- Estimate the long-run parameters of explanatory variables (Section 4.5)
- The Dumitrescu and Hurlin (D–H) method to reveal the causal relationships between the variables (Section 4.6)

3.2. Data and Descriptive Statistics

We use annual data from 1990 to 2020 for a sample of 12 gas-producing countries as follows: Algeria, Azerbaijan, Egypt, Iran, Malaysia, Nigeria, Oman, Qatar, Russia, Saudi Arabia, Turkmenistan, and the United Arab Emirates (UAE). According to the GECF [1], as of 2021, these countries together approximately hold 71% (134 tcm) of the world proven gas reserves, 41% (1,610 bcm) of the world dry gas production, and 30% (1150 bcm) of world gas consumption. Furthermore, these countries were responsible for 12% (4030 mt CO_2) of the global CO_2 emissions in 2020 (see Figure 3).

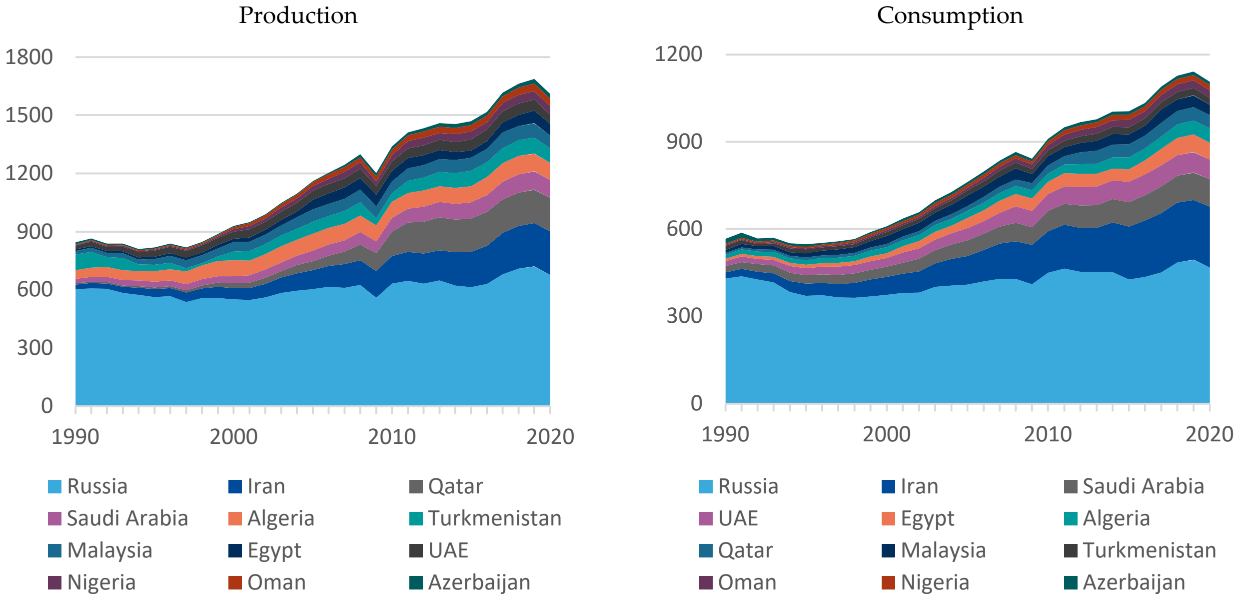

Figure 3. Dry natural gas production and consumption (bcm). Source: GECF GGO 2050 [1].

For estimation, all variables are expressed in logarithmic form. The dataset contains a strongly balanced panel composed of 2232 observations (N = 12 and T = 31). After eliminating periods with no data, the sample was reduced to 2220 observations. Table 2 shows definition of variables, data sources, and descriptive statistics.

Table 2. Data: definition, sources, and descriptive statistics, 1990–2020.

Variables.	Definition	Source	Unit	Obs.	Mean	Std. Dev.	Min	Max
$\ln CO_2$	Energy-related CO_2 emissions	GECF	Million ton CO_2 (Mt CO_2)/person	372	1.9021	1.1877	−0.9790	3.9279
lnGDP	Real GDP	GECF	Real 2020 US$/person	372	8.8399	1.1701	6.8237	11.0257
$\ln GDP^2$	Quadratic GDP	GECF	Real 2020 US$/person	372	79.5100	21.2761	46.5637	121.567
lnGC	Natural gas consumption	GECF	Million Cubic Meters (MCM)/person	372	7.5359	1.3254	4.1875	10.0420
lnU	Urbanization	United Nations	Share of total population	372	−0.4577	0.2797	−1.2146	−0.0076
lnTO	Trade openness	World Bank	Trade (% of GDP)	360	4.2714	0.4830	3.0312	5.3954

4. Estimation Techniques and Results

4.1. Cross-Sectional Dependence Test

Cross-sectional dependence is an important issue that should be investigated before estimating any panel data models. Due to the high degree of socioeconomic and political integration among countries, cross-sectional dependence is a *priori* likely to exist. Ignoring this cross-sectional dependence may create biased estimates and mislead conclusions.

There are a variety of tests for cross-sectional dependence in the literature. In this study, we use the Breusch and Pagan [41] LM test, Pesaran scaled LM test, and the Pesaran CD test [42]. However, according to the literature [7,8,24,42], the Breusch–Pagan LM test is not appropriate for large cross-section dimension (N) or time dimension (T). Since N and T in this study are both rather moderate (12 and 31, respectively), the Pesaran CD test is applied to examine the potential common correlation effects between the variables that use the following statistic that is asymptotically normal under the null hypothesis of cross-section independence:

$$CD = \sqrt{\frac{2T}{N(N-1)}} \left(\sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{\rho}_{ij} \right) => N(0,1) \tag{2}$$

Here, $\hat{\rho}_{ij}$ indicates the sample estimate of the pairwise correlation of the residuals obtained by OLS. The correlation coefficients are obtained from the residuals of the model, and the CD statistic is asymptotically standard normal for $T \to \infty$ and $N \to \infty$ in any order. As shown in Table 3, the null hypothesis of no cross-sectional dependence is rejected at a 1% level, and thus a possible shock in any of the sample countries may affect others.

Table 3. Cross-sectional dependence test results.

Test	Value
Breusch–Pagan LM	565.4625 ***
Pesaran scaled LM	43.4726 ***
Pesaran CD	5.2719 ***

Note: *** indicates that statistics are significant at a 1% level of significance. H_0: no cross-section dependence (correlation).

4.2. The Slope Homogeneity Test

Even though many researchers assumed homogeneous slope coefficients in panel data models across individual units, the slope homogeneity assumption often fails to hold in panels with large N and T observations. Therefore, in this section, the slope homogeneity tests proposed by Pesaran and Yamagata [43], and Blomquist and Westerlund [44], which are based on the early work of Swamy [45], are employed. The Blomquist and Westerlund test is valid in the presence of cross-sectional dependence. Moreover, the assumptions of homoscedasticity and serial independence of the Pesaran and Yamagata test can be dropped. The proposed version is consistent with heteroscedasticity and autocorrelation consistent (HAC) counterpart and formed two delta test statistics as follows:

$$\Delta_{HAC} = \sqrt{N}\left(\frac{N^{-1}S_{HAC} - k}{\sqrt{2k}}\right) \tag{3}$$

$$(\Delta_{HAC})_{adj} = \sqrt{N}\left(\frac{N^{-1}S_{HAC} - k}{v(T,k)}\right) \tag{4}$$

Here, N denotes the number of cross-section units, S denotes the Swamy test statistic, and k denotes the number of explanatory variables. As listed in Table 4, the null hypothesis of slope homogeneity is rejected.

Table 4. Slope heterogeneity test results.

Test	Value
Pesaran and Yamagata	
Δ	12.696 ***
$\Delta_{adj.}$	14.500 ***
Blomquist and Westerlund	
Δ	11.081 ***
$\Delta_{adj.}$	12.656 ***

Note: *** indicates that statistics are significant at a 1% level of significance. H_0: slope coefficients are homogenous.

4.3. Testing for Stationarity

Since there is cross-sectional dependence in the data, imposing homogeneity when coefficient heterogeneity is present can result in misleading conclusions [46]. In order to investigate stationarity, determine integration level of variables, and overcome spurious regression, in this study, the Levin–Lin–Chu test (LLC test) proposed by Levin et al. [47], the Fisher–ADF panel unit root test developed by Maddala and Wu [48], and the Im, Pesaran, and Shin (IPS test) proposed by Im et al. [49] are employed.

According to the literature [7,8,21,30,50], however, the first-generation panel unit root tests are not valid in the presence of cross-sectional dependence. Therefore, we also employed the second-generation panel unit root test proposed by Pesaran [50], namely the CIPS test, to identify the order of integration as follows:

$$CIPS(N,T) = N^{-1}\sum_{i=1}^{N} t_i(N,T) \tag{5}$$

Here, $t_i(N,T)$ is the cross-sectionally augmented Dickey–Fuller statistic for the ith cross-section unit given by the t-ratio of the coefficient of $y_{i,t-1}$ in the CADF regression defined as follows:

$$\Delta y_{it} = \alpha_i + b_i y_{i,t-1} + c_i \overline{y}_{t-1} + d_i \Delta \overline{y}_t + \varepsilon_{it} \tag{6}$$

Here, $\overline{y}_t$ is the average at time T of all N countries, and Δ is the first difference operator.

As indicated in Table 5, the LLC, the Fisher–ADF, the IPS, and the CIPS tests show that the series are integrated of order one I(1) when a time trend is included. Therefore, variables become stationary after applying first differences. These results provide evidence for a possible cointegration relationship between the variables.

4.4. Cointegration Tests

After concluding that the series are first-order integrated (in symbols, I(1)), in this section, three panel cointegration tests, namely the Kao [51], the Pedroni [52], and the Westerlund [53] tests, are applied to control for the validity of the long-run equilibrium relationship among the variables.

Table 5. Results of panel unit root tests.

Variable	Level		1st Difference	
LLC Test	Intercept	Intercept and Trend	Intercept	Intercept and Trend
lnCO$_2$	−4.5124 ***	−0.4769	−4.1597 ***	−3.0191 ***
lnGDP	−1.0392	−1.5491 *	−3.3349 ***	−2.0718 *
lnGDP^2	−0.9070	−1.5123 *	−3.3014 ***	−2.0293 *
lnGC	−3.8289 ***	−1.3094 *	−11.275 ***	−10.6326 ***
lnU	−8.7882 ***	−6.8910 ***	−8.6010 ***	−52.3669 ***
Fisher–ADF test	Intercept	Intercept and trend	Intercept	Intercept and trend
lnCO$_2$	2.4906 **	1.2074	37.1258 ***	35.7304 ***
lnGDP	−1.8509	−0.1505	12.7983 ***	10.9182 ***
lnGDP^2	−1.9454	−0.1126	12.7340 ***	10.8641***
lnGC	1.2259	0.4684	43.5791 ***	39.4963 ***
lnU	41.9397	14.5531	2.4923 **	10.1618 ***
lnTO	4.2778 ***	2.1929 **	35.9704 ***	30.6290 ***
IPS test	Intercept	Intercept and trend	Intercept	Intercept and trend
lnCO$_2$	−1.1238	−0.9496	−9.9337 ***	−10.4638 ***
lnGDP	2.8790	0.3618	−5.2711 ***	−5.8034 ***
lnGDP^2	3.0644	0.3481	−5.2458 ***	−5.7710 ***
lnGC	−1.4087 *	−1.3933 *	−10.1395 ***	−10.6683 ***
lnU	1.9344	1.1152	1.5460	−2.5687 **
lnTO	−1.9039 **	−2.1075 **	−9.4524 ***	−9.9113 ***
CIPS test	Intercept	Intercept and trend	Intercept	Intercept and trend
lnCO$_2$	−2.861 ***	−2.698	−5.475 ***	−5.989 ***
lnGDP	−2.444 ***	−2.536	−3.745 ***	−4.198 ***
lnGDP^2	−2.492 ***	−2.512	−3.690 ***	−4.114 ***
lnGC	−2.845 ***	−2.694 *	−4.955 ***	−5.383 ***
lnU	−2.034	−2.372	−1.852	−2.686 **
lnTO	−2.110	−2.395	−4.618 ***	−4.797 ***

Note: *, **, *** indicate that statistics are significant at 10%, 5%, and 1% level of significance, respectively. H_0: panels contain unit roots.

By applying two variance ratio statistics, namely panel variance ratio statistic and group mean variance ratio statistic, Westerlund takes cross-sectional dependence into account (see also [7,8,21,30]) as follows:

$$VR_G \equiv \sum_{i=1}^{N} \sum_{t=1}^{T} \hat{E}_{it}^2 \hat{R}_i^{-1} \tag{7}$$

$$VR_P \equiv \sum_{i=1}^{N} \sum_{t=1}^{T} \hat{E}_{it}^2 \left(\sum_{i=1}^{N} \hat{R}_i \right)^{-1} \tag{8}$$

Here, $\hat{E}_{it} \equiv \sum_{j=1}^{t} \hat{e}_{ij}$ and $\hat{R}_i \equiv \sum_{t=1}^{T} \hat{e}_{it}^2$ and $\hat{e}_{it}^2$ are the model residuals.

As specified in Table 6, the results reject the null hypothesis of no cointegration, which reveals that the variables in the panel of 12 gas-producing countries have a long-run association over the 1990 to 2020 period. In other words, even though the variables may contain stochastic trends (i.e., be nonstationary), they nonetheless tend to move closely together over time and the difference between them is stationary [25].

Table 6. Panel cointegration test results.

Test	Value
Kao	
Modified Dickey–Fuller	−4.3886 ***
Dickey–Fuller	−5.6569 ***
Augmented Dickey–Fuller	−3.9340 ***
Unadjusted modified Dickey–Fuller	−6.2985 ***
Unadjusted Dickey–Fuller	−6.2220 ***
Pedroni	
Modified Phillips–Perron	1.3345 *
Phillips–Perron	−2.8852 ***
Augmented Dickey–Fuller	−2.4163 **
Westerlund	
[1] Variance ratio	−1.8754 **
[2] Variance ratio	−3.2259 ***

Note: *, **, *** indicate that statistics are significant at 10%, 5%, and 1% level of significance, respectively. H_0: no cointegration. [1] Include one lag on lCO_2. [2] ΔCO_2 is considered.

4.5. Estimate the Long-Run Parameters

In order to test for validity of an EKC and calculate Equation (1), this study employs panel cointegration techniques, such as panel fully modified ordinary least squares (FMOLS), dynamic ordinary least squares (DOLS), common correlated effects mean group (CCEMG), and augmented mean group (AMG), for the full panel and individual countries.

The FMOLS estimator is a non-parametric approach and does not consider cross-sectional dependence, while the DOLS estimator is a parametric approach where lagged first-differenced terms are explicitly estimated. However, both approaches incorporate corrections for endogeneity and serial correlation and have been widely used in the EKC literature to estimate long-run coefficients [7,8,17,25,54].

The CCEMG estimator holds under slope homogeneity, particularly even in the presence of cross-sectional dependence, as well as endogeneity and serial correlation. The AMG estimator is also robust to parameter heterogeneity and cross-sectional dependence. It employs a two-stage method to estimate the unobserved common dynamic effect and allows for cross-sectional dependence by including the common dynamic effect parameter [7,8,10,25] as follows:

$$\text{Stage I } \; \Delta y_{it} = \alpha + \beta_i \Delta x_{it} + \varphi_i f_t + \sum_{t=2}^{T} d_t \Delta D_t + \varepsilon_{it} \tag{9}$$

$$\text{Stage II } \; AMG = N^{-1} \sum_{i=1}^{N} \hat{\beta}_i \tag{10}$$

Here, Δ is the first difference operator, y_{it} and x_{it} represent observables, a_i represents the intercept, $\hat{\beta}_i$ is country-specific coefficient, f_t is unobserved common factor with heterogeneous factor loadings, φ_i and d_t are coefficients of time dummies, and ΔD_t and ε_{it} are error terms. In Stage I, Equation (9) is estimated by OLS. In Stage 2, the estimates are averaged.

Table 7 presents the estimation results using FMOLS, DOLS, CCEMG, and AMG. Accordingly, the four mentioned estimation methodologies provide mixed results.

Table 7. Panel cointegration coefficients for 12 natural-gas-producing countries, 1990–2020.

	FMOLS						DOLS					
Country/Panel	**lnGDP**	**lnGDP2**	**lnGC**	**lnU**	**lnTO**	**EKC**	**lnGDP**	**lnGDP2**	**lnGC**	**lnU**	**lnTO**	**EKC**
Algeria	−1.2288 *** (−5.9797)	0.1704 *** (8.7982)	0.2211 ** (2.3972)	−0.3165 (−1.3744)	−0.4560 *** (−7.7259)	No	−15.393 ** (−3.5182)	1.4098 ** (3.5430)	4.9374 ** (3.3886)	−24.264 ** (−4.1054)	−2.0256 (−2.7508)	No
Azerbaijan	−1.2615 *** (−3.4049)	0.0671 ** (2.5410)	1.0003 *** (9.5615)	−0.4274 (−0.3257)	−0.0415 (−0.4075)	No	41.465 *** (10.294)	−2.6830 *** (−10.343)	1.0319 *** (10.822)	−51.410 *** (−7.7455)	−2.0599 *** (−10.393)	Yes
Egypt	−0.3622 (−0.6790)	0.0599 (1.6943)	0.1611 (2.7494)	1.5249 (0.6564)	0.0423 (0.8654)	No	21.293 *** (6.3334)	−1.2946 *** (−6.0513)	−0.3288 *** (−4.8434)	6.6936 ** (4.0557)	0.2155 ** (4.1834)	Yes
Iran	−0.6704 ** (−2.1706)	0.0816 *** (4.3929)	0.3051 * (1.9981)	0.5521 (0.8515)	−0.0211 (−0.4547)	No	−0.6020 (−1.6941)	0.0707 *** (3.2700)	0.3192 * (1.8277)	0.6528 (0.8695)	−0.0017 (−0.0315)	No
Malaysia	−0.3162 (−1.6903)	0.0249 (1.4895)	0.3802 *** (5.9629)	0.9330 *** (3.7757)	0.0723 (1.0705)	No	115.75 ** (3.0992)	−6.6645 ** (−3.0717)	1.4602 ** (2.9340)	−3.5419 (−0.4345)	−0.9107 (−1.0625)	Yes
Nigeria	−1.0181 *** (−6.6289)	0.0996 *** (5.2751)	0.2085 ** (2.1291)	−0.0523 (−0.3171)	0.0952 (2.3188)	No	−2.4275 *** −4.8910	0.2815 *** 4.9065	−0.0791 −0.4680	−1.1132 ** −2.5698	0.4273 ** 3.1881	No
Oman	−0.3397** (−2.6795)	−0.0040 (−0.2317)	0.7260 *** (10.941)	−1.1016 ** (−2.6799)	−0.0246 (−0.1265)	No	−0.6881 *** (−4.9179)	0.0475 ** (2.5027)	0.6106 *** (9.6642)	−0.7520 ** (−2.1586)	−0.1182 (−0.8884)	No
Qatar	−0.9110*** (−8.3222)	0.0518 *** (7.6562)	0.8254 *** (12.661)	2.8573*** (3.6693)	−0.1169 (−1.0005)	No	−48.725 ** (−2.8378)	2.2822 ** (2.8486)	1.2324 *** (9.1319)	5.2539 ** (2.9818)	−0.7066 ** (−2.8119)	No
Russia	−2.2301 *** (3.0560)	0.1112 *** (3.0361)	1.4610 *** (3.6776)	−7.2650 ** (−2.1191)	−0.0947 * (−1.7235)	No	7.8218 * (2.1907)	−0.4318 * (−2.1465)	0.3443 ** (3.1545)	−32.424 ** (−4.7310)	−0.0903 * (−2.3112)	Yes
Saudi Arabia	−0.4266 (−1.0652)	0.0273 (1.1866)	0.5075 (2.2187)	2.4701 ** (1.2033)	0.1844 (2.3497)	No	−134.88 *** (−3.4987)	6.8013 *** (3.4984)	−0.7370 * (−1.8678)	12.574 ** (3.6900)	0.6735 *** (5.1091)	No
Turkmenistan	−1.8434 *** (−3.2464)	0.1341 *** (3.2073)	0.7543 ** (7.2875)	−4.0372 ** (−2.2264)	−0.1797 *** (−3.4626)	No	5.2139 *** (3.8249)	−0.3124 *** (−3.5168)	0.5137 *** (8.7780)	3.6680 (1.0454)	−0.0598 * (−1.9807)	Yes
UAE	−1.0595 ** (−2.7761)	0.0709 *** (5.0749)	0.5177 * (1.7813)	−2.4160 ** (−2.4237)	0.2863 ** (2.4562)	No	7.2298 * (2.0479)	−0.3216 * (−1.9233)	0.1097 (0.8257)	−896.24 *** (−13.362)	0.2226 ** (2.7583)	Yes
Panel	−0.8244 *** (−8.0283)	0.0553 *** (7.9496)	0.5500 *** (11.919)	0.6150 *** (2.7656)	0.2314 *** (3.0264)	No	1.2793 ** (1.9678)	−0.0758 ** (−1.9115)	0.5720*** (10.476)	−2.0604 (−1.6648)	0.0655 * (1.7201)	Yes

Table 7. *Cont.*

	CCEMG						AMG					
Country/Panel	lnGDP	lnGDP2	lnGC	lnU	lnTO	EKC	lnGDP	lnGDP2	lnGC	lnU	lnTO	EKC
Algeria	−11.867	0.77533 *	0.27069 **	−3.2029 **	−0.05258	No	−4.7723	0.354167	0.32699 ***	−6.1451 ***	−0.03408	No
	(7.4538)	(0.46404)	(0.09984)	(1.3386)	(0.08540)		(6.9398)	(0.43681)	(0.09197)	(1.1084)	(0.08720)	
Azerbaijan	1.5779 *	−0.08666 *	0.58224 ***	1.179	0.09036	Yes	1.8295 *	−0.11959 *	0.1879 *	6.084 ***	−0.04665	**Yes**
	(1.1611)	(0.07217)	(0.14506)	(2.2351)	(0.08493)		(1.3394)	(0.08684)	(0.11131)	(1.0645)	(0.06744)	
Egypt	17.825 ***	−1.142 ***	−0.30615 *	−5.4118 *	0.13315 ***	Yes	0.01985 *	−0.02829 *	−0.15847 *	0.00456	0.07530	**Yes**
	(4.6707)	(0.29807)	(0.07743)	(3.0150)	(0.04511)		(4.8554)	(0.31241)	(0.09565)	(3.3778)	(0.05247)	
Iran	−15.218	0.95094	0.21741	7.888 ***	0.04094	No	−14.278 *	0.92122	0.11887	5.8451 ***	0.05257	No
	(10.512)	(0.66042)	(0.22734)	(2.822)	(0.06781)		(7.9859)	(0.50195)	(0.17451)	(2.0571)	(0.05308)	
Malaysia	−1.4256	0.11849	0.26896 ***	1.5536	0.10239	No	3.0977 *	−0.14973 *	0.33804 ***	1.3683	−0.03291	**Yes**
	(6.1761)	(0.34923)	(0.08147)	(1.4143)	(0.19701)		(4.4858)	(0.25632)	(0.06912)	(1.0732)	(0.11823)	
Nigeria	−0.11140	0.06602	0.15508	−7.0383 **	0.08922 **	No	−3.5440	0.29778	0.14090	−8.7369 **	0.08727 **	No
	(6.466)	(0.43450)	(0.1161)	(3.577)	(0.04479)		(4.0513)	(0.28314)	(0.08919)	(3.6017)	(0.04079)	
Oman	−28.704 *	1.5138 **	0.43629 ***	0.82887	−0.05435	No	−35.393	1.8563	0.60413 ***	1.4387 *	0.15523	No
	(14.8379)	(0.7698)	(0.08034)	(0.51818)	(0.12376)		(26.550)	(1.3832)	(0.09085)	(0.82057)	(0.21913)	
Qatar	7.2400	−0.33891	0.81448 ***	4.4507	−0.2076 *	No	−12.776	0.59990	0.88759 ***	6.0296 **	−0.2349 *	No
	(12.262)	(0.57281)	(0.10300)	(3.2361)	(0.11161)		(10.2767)	(0.48071)	(0.06580)	(2.4841)	(0.12212)	
Russia	−3.084	0.20159	0.76187 ***	0.86321	0.03424	No	−2.6678	0.15814	0.49916 ***	14.0736 ***	0.01631	No
	(2.4501)	(0.13777)	(0.13946)	(3.7644)	(0.0241)		(1.8526)	(0.10502)	(0.12431)	(1.4684)	(0.01710)	
Saudi Arabia	−119.938 **	6.047 **	0.21178	21.576 **	0.36412 **	No	−120.67 **	6.0912 **	0.44535	1.3027	0.23492 **	No
	(60.691)	(3.0649)	(0.34282)	(9.2040)	(0.15958)		(60.606)	(3.0593)	(0.27792)	(4.5649)	(0.11221)	
Turkmenistan	2.5294 *	−0.18008 *	0.49317 ***	10.210 ***	0.05224	Yes	5.7003 ***	−0.3650 ***	0.52460 ***	10.504 ***	0.03902	**Yes**
	(2.553)	(0.15502)	(0.1140)	(3.1237)	(0.03959)		(1.0965)	(0.0719)	(0.04696)	(3.0939)	(0.03055)	
UAE	−60.562 ***	2.8956 ***	0.8187 ***	−117.6 ***	0.33227 **	No	−6.6305	0.33175	0.28101	−25.039 *	0.32465	No
	(14.971)	(0.71250)	(0.25212)	(36.680)	(0.15561)		(7.7767)	(0.36864)	(0.31964)	(13.674)	(0.19975)	
Panel	−3.1452	0.27606	0.4314 ***	2.2542	0.04972	No	−4.3443	0.26488 *	0.36269 ***	2.7435	0.05191	No
	(4.6954)	(0.30010)	(0.08371)	(2.3309)	90.03755)		(2.7246)	(0.15916)	(0.0670)	(2.3925)	(0.04219)	

Note: *, **, *** indicate that statistics are significant at 10%, 5%, and 1% level of significance, respectively. The values in parentheses represent *t*-statistics. DOLS: Algeria: including fixed leads (2) and lag specification (1). Azerbaijan, Malaysia, Russia, and the panel: the quadratic model has been considered, including fixed lead (1) and lag specification (1). Egypt: the linear model has been considered, including fixed lead (1) and lag specification (1). Nigeria: including fixed lead (1) and lag specification (1). Oman, Qatar, Saudi Arabia: including lag specification (1). Turkmenistan: the linear model has been considered. UAE: the quadratic model has been considered.

Among four full panel estimates of the long-run relationship, the only models that have statistically significant variables are the FMOLS and DOLS. With FMOLS, the estimated effect of income on CO_2 emissions is negative and statistically significant at a 1% level. Nonetheless, the estimated coefficient on the quadratic income term is positive, providing presence of the U-shaped EKC hypothesis. On the other hand, the DOLS model shows that the coefficient on the income and squared income term supports the evidence of the EKC hypothesis. However, in this model, no significant relationship is found between urbanization and CO_2 emissions.

The CCEMG and AMG models neither have significant variables, nor do they support the EKC hypothesis. Inevitably, we accept the fact that the evidence does not support the EKC hypothesis for the full panel of 12 major gas-producing countries. This finding of no evidence in the full panel is consistent with the results of Destek et al. [55], Liddle [56], and partially Erdogan et al. [3], Destek and Sarkodie [57], and Acaravci and Akalin [58].

As for the relationship between natural gas consumption and CO_2 emissions, in all the outcomes of individual estimators (except Egypt), natural gas consumption has a significantly positive effect on CO_2 emissions. Similarly, according to the full panel regression results, natural gas consumption is the singular variable among four models, which is statistically significant at the 1% level. That is, a 1% increase in natural gas consumption causes CO_2 emissions to increase by 0.36% to 0.57% in different models. Therefore, natural gas consumption will not decrease CO_2 emissions, but we can argue that, by increasing consumption of gas in the energy mix, the speed and slope of CO_2 emissions are slowing.

Regarding the relationship between income and CO_2 emissions, only in the FMOLS estimator is the coefficient of GDP significant and negative, while the coefficient of squared GDP is positive and significant, meaning that GDP does not contribute to reduction in CO_2 emissions in the full panel. Moreover, population growth has a significant positive coefficient only under FMOLS, implying that a 1% increase in population growth increases CO_2 emissions by around 0.61%. Finally, the effect of trade openness on CO_2 emissions in the FMOLS and DOLS estimators is significant and positive, while, in the CCEMG and AMG, it is insignificant. Therefore, in the full panel, trade openness plays a role in increasing CO_2 emissions.

As mentioned, one thing that can be instantly noticed is that the results depend dramatically on the method used. The country-specific results of the individual FMOLS estimator indicate that the EKC does not hold in the sample countries, while the individual DOLS estimator shows that the EKC holds in six of twelve countries, namely Azerbaijan, Egypt, Malaysia, Russia, Turkmenistan, and the UAE. Moreover, the CCEMG results specify that the EKC hypothesis is maintained in Azerbaijan, Egypt, and Turkmenistan, while the individual AMG estimator results propose that the EKC holds in Azerbaijan, Egypt, Malaysia, and Turkmenistan. Accordingly, we can conclude that the EKC hypothesis is valid in Azerbaijan, Egypt, Turkmenistan, and to some extent in Malaysia. This means that income levels have increased environmental degradation at the initial stages of economic development, but it declined after attaining a specific turning point in income level in these countries.

Concerning the relationship between natural gas consumption and CO_2 emissions, Egypt's energy policy prioritizes natural gas usage as a substitute for oil products. The country is implementing reforms aimed at encouraging competition and the opening of its gas sector, and it has accelerated the bidding rounds for gas exploration and development, specifically in deep waters and western areas. In 2020, natural gas constituted more than 50% of the country's energy mix. Moreover, 79% of the power generation mix is supplied by natural gas. Natural gas is also being encouraged in the transport sector by incentivizing vehicle conversions and building gas-refueling stations. Last but not least, Egypt has paid a great deal of attention to countering climate change in the past few years. The country is to host the UN climate change conference COP27 in 2022. The mentioned energy policies in Egypt support our modelling results. Accordingly, a 1% increase in natural gas consumption causes a decline in CO_2 emissions by 0.32%, 0.30%, and 0.15% in the DOLS, CCEMG, and AMG models, respectively.

4.6. Panel Causality Test

Additional to the reported cointegration tests, the direction of causality among CO_2 emissions, income, natural gas consumption, urbanization, and trade openness variables helps to develop specific energy policies to tackle CO_2 emissions. Therefore, the D–H panel causality test proposed by Dumitrescu and Hurlin [59] is employed to determine the direction of causality based on an average Wald statistic of Granger [60]. The D–H test with the linear regression model can be described as follows:

$$y_{i,t} = \alpha_i + \sum_{k=1}^{p} \gamma_i^{(k)} y_{i,t-k} + \sum_{k=1}^{p} \beta_i^{(k)} x_{i,t-k} + \varepsilon_{i,t} \tag{11}$$

Here, α_i, $\gamma_i^{(k)}$, and $\beta_i^{(k)}$ represent the constant term, the autoregressive parameters, and the regression coefficient slopes, respectively, and they differ across groups. The null hypothesis of D–H states that no causal relationship exists for all individuals, whereas the alternative hypothesis claims that the causal relationship occurs at least once for the panel.

As indicated in Table 8 and Figure 4, the panel causality test reveals a strong bidirectional causal link between CO_2 emissions and trade openness, CO_2 emissions and income, income and urbanization, as well as urbanization and trade openness for the panel of 12 major gas-producing countries. The results also indicate unidirectional panel causality running from CO_2 emissions toward urbanization and natural gas consumption, from income to natural gas consumption and trade openness, and from urbanization to natural gas consumption. These relationships support the argument that natural gas consumption may not be a limiting driver of CO_2 emissions in the panel of sample countries.

Table 8. Results of D–H panel causality test.

Null Hypothesis	**Wald Statistics**
LGDP = LCO_2	6.7533 ***
LCO_2 = LGDP	7.3271 ***
LGC $\neq$ LCO_2	3.0876
LCO_2 = LGC	3.5557 **
LUR $\neq$ LCO_2	5.6659 ***
LCO_2 = LUR	4.7675 ***
LTO = LCO_2	5.2695 ***
LCO_2 = LTO	3.6270 **
LGC $\neq$ LGDP	2.9962
LGDP = LGC	6.5912 ***
LUR = LGDP	7.3501 ***
LGDP = LUR	4.4033 ***
LTO $\neq$ LGDP	2.3198
LGDP = LTO	4.7253 ***
LUR = LGC	9.1723 ***
LGC $\neq$ LUR	3.1961
LTO $\neq$ LGC	2.4157
LGC $\neq$ LTO	3.1662
LTO = LUR	3.4838 *
LUR = LTO	7.0099 ***

Note: *, **, *** indicate that statistics are significant at 10%, 5%, and 1% level of significance, respectively. H_0 ($\neq$): A does not homogeneously cause B.

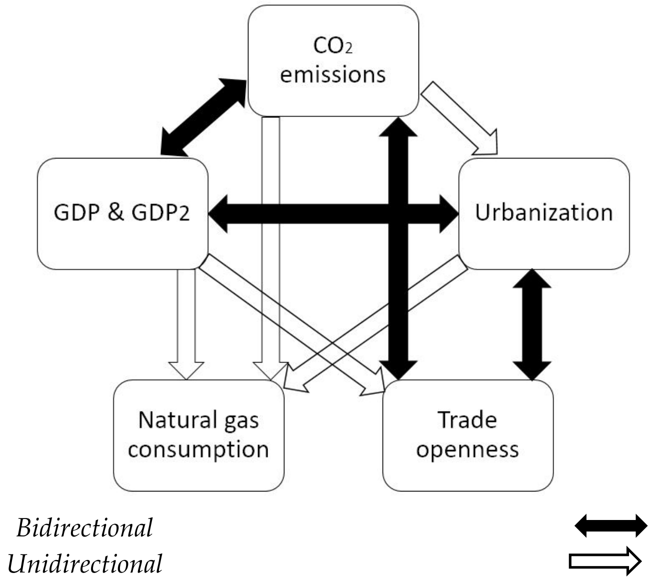

Figure 4. Causality relationship flow.

Furthermore, bidirectional causality between urbanization and income and urbanization and trade openness suggests that urbanization is an instrument of economic development and is associated with industrialization. Moreover, the bidirectional causal relationship between CO_2 emissions and income and CO_2 emissions and trade openness approves the hypothesis that not only does level of economic growth have an impact on CO_2 emissions but CO_2 emissions can also have an impact on economic growth and level of development. This implies that more economic activities are likely to be associated with CO_2 emissions.

5. Conclusions

Using robust methods, this study aims to provide consistent and unbiased answers to its main research questions regarding the validity of the EKC hypothesis for the sample of 12 major gas-producing countries during 1990–2020 and the role of natural gas consumption in mitigating CO_2 emissions in these countries.

Considering cross-sectional dependence, the slope homogeneity test, as well as the Granger causality framework, including stationarity tests, cointegration tests, and causality tests, are employed, enabling cross-sectional dependence. Moreover, the D–H panel causality test is used for causality analysis. The main findings of this study are as follows:

First, among four full panel estimates (i.e., panel FMOLS, DOLS, CCEMG, and AMG estimators), the only procedures that yield statistically significant variables are FMOLS and DOLS. However, in FMOLS, the estimated coefficient on the quadratic income term is positive, failing to support the U-shaped EKC hypothesis. The results of DOLS support the EKC hypothesis. No significant relationship is found between urbanization and CO_2 emissions. The CCEMG and AMG models neither have significant variables nor support the EKC hypothesis. Therefore, we conclude that the evidence does not favor the EKC hypothesis for the full panel.

Second, regarding country-specific results, four estimators provided mixed results. Accordingly, the FMOLS estimator shows that the EKC does not hold in sample countries, while the individual DOLS estimator shows that the EKC holds in six of twelve countries. The CCEMG and AMG estimators specify that the EKC hypothesis holds in three and four countries, respectively. Therefore, we conclude that the EKC hypothesis is valid in four countries, namely Azerbaijan, Egypt, Turkmenistan, and Malaysia. Accordingly, environmental degradation increases as income levels increase with economic development. Beyond a certain level of income per capita, however, the trend reverses. Therefore, economic growth leads to environmental improvement at high-income levels in the above-mentioned countries.

In this connection, Stern [61] proposes that the ambiguity surrounding the EKC is because the EKC theory ignores thermodynamic laws. According to the first law, energy cannot be created or destroyed, but it can be transferred. Economic activity requires utilization of resources, and use of resources implies production of waste. Therefore, transforming pollution from one form to another is not the same as mitigating it.

Furthermore, Panyotou [62] provides a few explanations for inversion of pollution patterns that may not have been observed yet in our sample countries. He argues that the turning point for pollution is the result of more affluent, prosperous, and progressive societies placing greater emphasis on environmental issues and thus putting into place institutional and non-institutional measures to effect change. Furthermore, in the early phase of a country's industrialization, due to rudimentary technology, pollution increases. When industrialization achieves more advanced levels, pollution will stop increasing and start to take a U-turn. In addition, service industries will gain prominence, resulting in even more pollution reduction.

Our third conclusion is that natural gas consumption—neither in the full panel nor in the individual countries' estimators (except in the case of Egypt)—has not decreased level of CO_2 emissions. However, as natural gas is the lowest-carbon hydrocarbon compared to other fossil fuels, substituting gas with oil and coal (e.g., in the power generation sector) would reduce speed and slope of CO_2 emissions, and, most probably, if we include other fossil fuel variables, such as oil and coal, we could see the positive effect of natural gas on reducing CO_2 emissions. Furthermore, the feature of gas as "easy-to-store energy" stands out as a type of the best option to support intermittent renewable generation output when the sun does not shine and the wind does not blow. Moreover, the existing natural gas infrastructure and abundant and affordable supply of gas resources make gas a driver of energy transition in scaling up of blue hydrogen.

6. Policy Implications

Adoption of suitable policies regarding energy consumption, economic development, and environmental considerations is crucial for governments and policymakers. Governments should implement energy policies to reduce energy intensity and increase energy efficiency in order to keep CO_2 emissions under control. The findings of this study also highlight important policy implications:

(i) To invest in technologies to prevent emissions from the entire gas value-chain: considering the impact of natural gas production and exports and economic development on CO_2 emissions, policymakers should consider measures to not only develop their natural resources but also employ technologies to prevent release of CO_2 and methane emissions generated through conventional production facilities. Today, proven technology exists to reduce gas flaring, methane venting, and even to capture, use, or store CO_2 emissions (i.e., CCS/CCUS). Accordingly, the natural gas industry is capital-intensive, with long lead times and payback periods that require policy and regulatory stability. Sufficient investments through the entire gas value-chain, as well as in clean technologies, including CCS/CCUS capacity, are required to attain the UN Sustainable Development Goals and for the very battle of mitigating and adapting to climate change.

(ii) To accelerate the reform of fossil fuel subsidies: the implicit subsidies typically occur in countries with relatively rich oil and gas reserves, where state-owned oil and gas companies can be mandated to sell refined products for the domestic market at lower prices than production costs (e.g., in the mentioned 12 sample countries). Fossil fuel subsidies that are offered for a long period are not only inefficient but also dangerous due to gradual increases in energy demand and consequent increases in CO_2 emissions. Furthermore, as energy cost is artificially lower due to the subsidies, this will drive continued dependence on fossil-based fuels. As a result, subsidies may allow governments to build or develop new fossil fuel infrastructure, extending use of fossil fuels and, as a result, delaying economic transition to cleaner energies. Further, low domestic fossil fuel prices have led to immense oil and gas demand growth that cannot continue if oil- and gas-exporting countries wish to continue exporting. Only very high price jumps can stop this development, but, politically, these price jumps are very costly for many governments [63]. Thus, it is recommended that countries gradually remove fossil fuel subsidies, introduce true energy pricing, and promote mechanisms and policies, such as tax changes, feed-in tariffs, carbon pricing, and renewable portfolio standards.

Author Contributions: Methodology, H.M.; Software, H.M.; Validation, R.M.K.; Formal analysis, H.M.; Writing—original draft, H.M.; Writing—review & editing, R.M.K.; Supervision, R.M.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: World Bank Open Data available at: https://data.worldbank.org/.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Gas Exporting Countries Forum. Available online: https://www.gecf.org/gas-data/environment.aspx (accessed on 1 March 2021).
2. Moghaddam, H. *Electric Vehicle Growth to Lead to Higher Gas Demand*; Petroleum Exploration Society of Australia: Beaumaris, VIC, Australia, 2021.
3. Erdogan, S.; Okumus, I.; Guzel, A.E. Revisiting the Environmental Kuznets Curve hypothesis in OECD countries: The role of renewable, non-renewable energy, and oil prices. *Environ. Sci. Pollut. Res.* **2020**, *27*, 23655–23663. [CrossRef] [PubMed]
4. El-Aasar, K.M.; Hanafy, S.A. Investigating the environmental Kuznets curve hypothesis in Egypt: The role of renewable energy and trade in mitigating GHGs. *Int. J. Energy Econ. Policy* **2018**, *8*, 177–184.
5. Stern, D.I. The environmental Kuznets curve after 25 years. *J. Bioecon.* **2017**, *19*, 7–28. [CrossRef]
6. Dong, K.; Sun, R.; Hochman, G. Do natural gas and renewable energy consumption lead to less CO_2 emission? Empirical evidence from a panel of BRICS countries. *Energy* **2017**, *141*, 1466–1478. [CrossRef]
7. Dong, K.; Sun, R.; Li, H.; Liao, H. Does natural gas consumption mitigate CO_2 emissions: Testing the environmental Kuznets curve hypothesis for 14 Asia-Pacific countries. *Renew. Sustain. Energy Rev.* **2018**, *94*, 419–429. [CrossRef]
8. Dong, K.; Sun, R.; Dong, C.; Li, H.; Zeng, X.; Ni, G. Environmental Kuznets Curve for $PM_{2.5}$ emissions in Beijing, China: What role can natural gas consumption play? *Ecol. Indic.* **2018**, *93*, 591–601. [CrossRef]
9. Pesaran, M.H. Estimation and inference in large heterogeneous panels with a multifactor error structure. *Econometrica* **2006**, *74*, 967–1012. [CrossRef]
10. Eberhardt, M.; Teal, F. *Productivity Analysis in Global Manufacturing Production*; University of Oxford: Oxford, UK, 2010.
11. Kuznets, S. Economic growth and income inequality. *Am. Econ. Rev.* **1955**, *45*, 1–28.
12. Grossman, G.M.; Krueger, A.B. *Environmental Impacts of a North American Free Trade Agreement*; National Bureau of Economic Research, Inc.: Cambridge, MA, USA, 1991.
13. Zambrano-Monserrate, M.A.; Silva-Zambrano, C.A.; Davalos-Penafiel, J.L.; Zambrano-Monserrate, A.; Ruano, M.A. Testing environmental Kuznets curve hypothesis in Peru: The role of renewable electricity, petroleum and dry natural gas. *Renew. Sustain. Energy Rev.* **2018**, *82*, 4170–4178. [CrossRef]
14. Layachi, O.B. Effects of energy prices on environmental pollution: Testing environmental Kuznets curve for Algeria. *Int. J. Energy Econ. Policy* **2019**, *9*, 401–408. [CrossRef]
15. Lotfalipour, M.R.; Falahi, M.A.; Ashena, M. Economic growth, CO_2 emissions, and fossil fuels consumption in Iran. *Energy* **2010**, *35*, 5115–5120. [CrossRef]
16. Li, H.; Shahbaz, M.; Jiang, H.; Dong, K. Is natural gas consumption mitigating air pollution? Fresh evidence from national and regional analysis in China. *Sustain. Prod. Consum.* **2021**, *27*, 325–336. [CrossRef]
17. Murshed, M.; Alam, R.; Ansarin, A. The environmental Kuznets curve hypothesis for Bangladesh: The importance of natural gas, liquefied petroleum gas, and hydropower consumption. *Environ. Sci. Pollut. Res.* **2021**, *28*, 17208–17227. [CrossRef] [PubMed]
18. Solarin, S.A.; Lean, H.H. Natural gas consumption, income, urbanization, and CO_2 emissions in China and India. *Environ. Sci. Pollut. Res.* **2016**, *23*, 18753–18765. [CrossRef] [PubMed]
19. Müller-Fürstenberger, G.; Wagner, M. Exploring the environmental Kuznets hypothesis: Theoretical and econometric problems. *Ecol. Econ.* **2007**, *62*, 648–660. [CrossRef]

20. Wagner, M. The environmental Kuznets curve, cointegration and nonlinearity. *J. Appl. Econom.* **2015**, *30*, 948–967. [CrossRef]
21. Moosa, I.A.; Burns, K. The Energy Kuznets Curve: Evidence from Developed and Developing Economies. *Energy J.* **2022**, *43*. Available online: https://www.google.com.hk/search?q=%E2%80%8EThe+Energy+Kuznets+Curve%3A+Evidence+from+Developed+and+Developing+Economies&ei=DCP8Y__lDeDu2roPiMq6kAY&ved=0ahUKEwj_m6Xu4LT9AhVgt1YBHQilDmIQ4dUDCA4&uact=5&oq=%E2%80%8EThe+Energy+Kuznets+Curve%3A+Evidence+from+Developed+and+Developing+Economies&gs_lcp=Cgxnd3Mtd2l6LXNlcnAQAzoKCAAQRxDWBBCwA0oECEEYAFCFAViFAWD2BmgBcAF4AIABfogBfpIBAzAuMZgBAKABAqABAcgBCMABAQ&sclient=gws-wiz-serp (accessed on 1 March 2021). [CrossRef]
22. Alam, R.; Adil, M.H. Validating the environmental Kuznets curve in India: ARDL bounds testing framework. *OPEC Energy Rev.* **2019**, *43*, 277–300. [CrossRef]
23. Apergis, N.; Ozturk, I. Testing environmental Kuznets curve hypothesis in Asian countries. *Ecol. Indic.* **2015**, *52*, 16–22. [CrossRef]
24. Atasoy, B.S. Testing the environmental Kuznets curve hypothesis across the US: Evidence from panel mean group estimators. *Renew. Sustain. Energy Rev.* **2017**, *77*, 731–747. [CrossRef]
25. Baek, J. A panel cointegration analysis of CO_2 emissions, nuclear energy and income in major nuclear generating countries. *Appl. Energy* **2015**, *145*, 133–138. [CrossRef]
26. Jammazi, R.; Aloui, C. RETRACTED: On the interplay between energy consumption, economic growth and CO_2 emission nexus in the GCC countries: A comparative analysis through wavelet approaches. *Renew. Sustain. Energy Rev.* **2015**, *51*, 1737–1751. [CrossRef]
27. Kohler, M. CO_2 emissions, energy consumption, income and foreign trade: A South African perspective. *Energy Policy* **2013**, *63*, 1042–1050. [CrossRef]
28. Lin, B.; Omoju, O.E.; Okonkwo, J.U. Impact of industrialisation on CO_2 emissions in Nigeria. *Renew. Sustain. Energy Rev.* **2015**, *52*, 1228–1239. [CrossRef]
29. Ozcan, B. The nexus between carbon emissions, energy consumption and economic growth in Middle East countries: A panel data analysis. *Energy Policy* **2013**, *62*, 1138–1147. [CrossRef]
30. Paramati, S.R.; Mo, D.; Gupta, R. The effects of stock market growth and renewable energy use on CO_2 emissions: Evidence from G20 countries. *Energy Econ.* **2017**, *66*, 360–371. [CrossRef]
31. Rafindadi, A.A. Revisiting the concept of environmental Kuznets curve in period of energy disaster and deteriorating income: Empirical evidence from Japan. *Energy Policy* **2016**, *94*, 274–284. [CrossRef]
32. Saboori, B.; Al-Mulali, U.; Bin Baba, M.; Mohammed, A.H. Oil-induced environmental Kuznets curve in organization of petroleum exporting countries (OPEC). *Int. J. Green Energy* **2016**, *13*, 408–416. [CrossRef]
33. Saidi, K.; Mbarek, M.B. Nuclear energy, renewable energy, CO_2 emissions, and economic growth for nine developed countries: Evidence from panel Granger causality tests. *Prog. Nucl. Energy* **2016**, *88*, 364–374. [CrossRef]
34. Ulucak, R.; Khan, S.U.D. Determinants of the ecological footprint: Role of renewable energy, natural resources, and urbanization. *Sustain. Cities Soc.* **2020**, *54*, 101996.
35. Wang, S.; Li, Q.; Fang, C.; Zhou, C. The relationship between economic growth, energy consumption, and CO_2 emissions: Empirical evidence from China. *Sci. Total Environ.* **2016**, *542*, 360–371. [CrossRef] [PubMed]
36. Zoundi, Z. CO_2 emissions, renewable energy and the Environmental Kuznets Curve, a panel cointegration approach. *Renew. Sustain. Energy Rev.* **2017**, *72*, 1067–1075. [CrossRef]
37. Mahmood, N.; Wang, Z.; Hassan, S.T. Renewable energy, economic growth, human capital, and CO_2 emission: An empirical analysis. *Environ. Sci. Pollut. Res.* **2019**, *26*, 20619–20630. [CrossRef] [PubMed]
38. Narayan, P.K.; Narayan, S. Carbon dioxide emissions and economic growth: Panel data evidence from developing countries. *Energy Policy* **2010**, *38*, 661–666. [CrossRef]
39. Sobrinho, V.G. Trade and environmental policy strategies in the north and south negotiation game. *Int. J. Environ. Stud.* **2005**, *62*, 147–161. [CrossRef]
40. Demissew Beyene, S.; Kotosz, B. Testing the environmental Kuznets curve hypothesis: An empirical study for East African countries. *Int. J. Environ. Stud.* **2020**, *77*, 636–654. [CrossRef]
41. Breusch, T.S.; Pagan, A.R. The Lagrange multiplier test and its applications to model specification in econometrics. *Rev. Econ. Stud.* **1980**, *47*, 239–253. [CrossRef]
42. Pesaran, M.H. *General Diagonist Tests for Cross Section Dependence in Panels*; University of Cambridge: Cambridge, UK, 2004.
43. Pesaran, M.H.; Yamagata, T. Testing slope homogeneity in large panels. *J. Econom.* **2008**, *142*, 50–93. [CrossRef]
44. Blomquist, J.; Westerlund, J. Testing slope homogeneity in large panels with serial correlation. *Econ. Lett.* **2013**, *121*, 374–378. [CrossRef]
45. Swamy, P.A. Efficient inference in a random coefficient regression model. *Econometrica* **1970**, *38*, 311–323. [CrossRef]
46. Barreira, A.P.; Rodrigues, P.M. Unit root tests for panel data: A survey and an application. *Estud. II* **2005**, *26*, 665–685.
47. Levin, A.; Lin, C.F.; Chu, C.S.J. Unit root tests in panel data: Asymptotic and finite-sample properties. *J. Econom.* **2002**, *108*, 1–24. [CrossRef]
48. Maddala, G.S.; Wu, S. A comparative study of unit root tests with panel data and a new simple test. *Oxf. Bull. Econ. Stat.* **1999**, *61*, 631–652. [CrossRef]
49. Im, K.S.; Pesaran, M.H.; Shin, Y. Testing for unit roots in heterogeneous panels. *J. Econom.* **2003**, *115*, 53–74. [CrossRef]

50. Pesaran, M.H. A simple panel unit root test in the presence of cross-section dependence. *J. Appl. Econom.* **2007**, *22*, 265–312. [CrossRef]
51. Kao, C. Spurious regression and residual-based tests for cointegration in panel data. *J. Econom.* **1999**, *90*, 1–44. [CrossRef]
52. Pedroni, P. Purchasing power parity tests in cointegrated panels. *Rev. Econ. Stat.* **2001**, *83*, 727–731. [CrossRef]
53. Westerlund, J. New simple tests for panel cointegration. *Econom. Rev.* **2005**, *24*, 297–316. [CrossRef]
54. Harris, R.; Sollis, R. *Applied Time Series Modelling and Forecasting*; Wiley: Chichester, UK, 2003.
55. Destek, M.A.; Ulucak, R.; Dogan, E. Analyzing the environmental Kuznets curve for the EU countries: The role of ecological footprint. *Environ. Sci. Pollut. Res.* **2018**, *25*, 29387–29396. [CrossRef]
56. Liddle, B. What are the carbon emissions elasticities for income and population? Bridging STIRPAT and EKC via robust heterogeneous panel estimates. *Glob. Environ. Change* **2015**, *31*, 62–73. [CrossRef]
57. Destek, M.A.; Sarkodie, S.A. Investigation of environmental Kuznets curve for ecological footprint: The role of energy and financial development. *Sci. Total Environ.* **2019**, *650*, 2483–2489. [CrossRef] [PubMed]
58. Acaravci, A.; Akalin, G. Environment–economic growth nexus: A comparative analysis of developed and developing countries. *Int. J. Energy Econ. Policy* **2017**, *7*, 34.
59. Dumitrescu, E.I.; Hurlin, C. Testing for Granger non-causality in heterogeneous panels. *Econ. Model.* **2012**, *29*, 1450–1460. [CrossRef]
60. Granger, C.W.J. Investigating causal relations by econometric models and cross-spectral methods. *Econometrica* **1969**, *37*, 424–438. [CrossRef]
61. Stern, D.I. The rise and fall of the environmental Kuznets curve. *World Dev.* **2004**, *32*, 1419–1439. [CrossRef]
62. Panayotou, T. Economic growth and the environment. In Proceedings of the Spring Seminar of the United Nations Economic Commission for Europe, Geneva, Swtitzerland, 3 March 2003; pp. 45–72. Available online: https://digitallibrary.un.org/record/488313?ln=en (accessed on 1 March 2021).
63. Moghaddam, H.; Wirl, F. Determinants of oil price subsidies in oil and gas exporting countries. *Energy Policy* **2018**, *122*, 409–420. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.