ISSN 2392-1641
e-ISSN 2450-0097

Economics and Business Review

Volume 10 (1) 2024

CONTENTS

Editorial introduction
Michał Pilc, Konrad Sobański

ARTICLES

Some implications of behavioral finance for international monetary analysis
Thomas D. Willett

Google Search intensity and stock returns in frontier markets: Evidence from the Vietnamese market
Dang Thi Viet Duc, Nguyen Thu Hoai, Van Phuoc Nguyen, Dang Phong Nguyen, Nguyen Huong Anh, Ho Hong Hai

The asset-backing risk of stablecoin trading: The case of Tether
Francisco Javier Jorcano Fernández, Miguel Ángel Echarte Fernández, Sergio Luis Náñez Alonso

Determinants of consumer adoption of biometric technologies in mobile financial applications
Anna Iwona Piotrowska

Central bank communication in unconventional times: Some evidence from a textual analysis of the National Bank of Poland communication during the COVID-crisis
Lada Voloshchenko-Holda, Paweł Niedziółka

Corporate governance and risk management: An evaluation of board responsibilities in western and Islamic banks
Bchr Alatassi, Rekha Pillai

Silver entrepreneurship: A golden opportunity for ageing society
Ivana Barković Bojanić, Aleksandar Erceg, Jovanka Damoska Sekuloska

Assessing the long-term asymmetric relationship between energy consumption and CO_2 emissions: Evidence from the Visegrad Group countries
Błażej Suproń

Poznań University of Economics and Business Press

Paper based publication

https://doi.org/10.18559/ebr.2024.1

ISSN 2392-1641
e-ISSN 2450-0097

POZNAŃ UNIVERSITY OF ECONOMICS AND BUSINESS PRESS
ul. Powstańców Wielkopolskich 16, 61-895 Poznań, Poland
phone +48 61 854 31 54, +48 61 854 31 55
https://wydawnictwo.ue.poznan.pl, e-mail: wydawnictwo@ue.poznan.pl
postal address: al. Niepodległości 10, 61-875 Poznań, Poland

Printed and bound in Poland by:
Poznań University of Economics and Business Print Shop

Circulation: 80 copies

Economics and Business Review

Volume 10 (1) 2024

CONTENTS

Editorial introduction
Michał Pilc, Konrad Sobański ... 3

ARTICLES

Some implications of behavioral finance for international monetary analysis
Thomas D. Willett ... 7

Google Search intensity and stock returns in frontier markets: Evidence from the Vietnamese market
Dang Thi Viet Duc, Nguyen Thu Hoai, Van Phuoc Nguyen, Dang Phong Nguyen, Nguyen Huong Anh, Ho Hong Hai ... 30

The asset-backing risk of stablecoin trading: The case of Tether
Francisco Javier Jorcano Fernández, Miguel Ángel Echarte Fernández, Sergio Luis Náñez Alonso ... 57

Determinants of consumer adoption of biometric technologies in mobile financial applications
Anna Iwona Piotrowska ... 81

Central bank communication in unconventional times: Some evidence from a textual analysis of the National Bank of Poland communication during the COVID-crisis
Lada Voloshchenko-Holda, Paweł Niedziółka ... 101

Corporate governance and risk management: An evaluation of board responsibilities in western and Islamic banks
Bchr Alatassi, Rekha Pillai ... 125

Silver entrepreneurship: A golden opportunity for ageing society
Ivana Barković Bojanić, Aleksandar Erceg, Jovanka Damoska Sekuloska ... 153

Assessing the long-term asymmetric relationship between energy consumption and CO_2 emissions: Evidence from the Visegrad Group countries
Błażej Suproń ... 179

Economics and Business Review
https://www.ebr.edu.pl

Vol. 10 (1), 2024: 179–198
https://doi.org/10.18559/ebr.2024.1.1082

Assessing the long-term asymmetric relationship between energy consumption and CO_2 emissions: Evidence from the Visegrad Group countries

Błażej Supron̈[1]

Abstract

This study investigates the impact of renewable (REW) and non-renewable (NREW) energy usage, along with economic growth (GDP), on carbon dioxide (CO_2) emissions in the Visegrad countries, which rely heavily on traditional energy sources. Using data from 1991 to 2021, the analysis employs a panel asymmetric regression with Driscoll-Kraay and FGLS standard errors. The latent cointegration test reveals long-term relationships with asymmetry among the variables. Real GDP fluctuations exhibit a negative impact on CO_2 emissions for both positive and negative shocks. A reduction in conventional energy source consumption leads to a greater CO_2 emission reduction, confirming asymmetry. Conversely, an increase in consumption positively impacts CO_2 reduction. However, non-conventional energy sources show no asymmetries. The OLS-based model proposed by Driscoll-Kraay showed reduced standard errors, but lower significance in the estimated parameters compared to the FGLS model. The findings recommend a sustainable energy transition for Visegrad countries by eliminating traditional sources and promoting renewable resources.

Keywords

- CO_2 emissions
- renewable energy
- asymmetric causality
- energy transition
- Visegrad Group
- asymmetric panel data

JEL codes: C32, C33, Q40, Q43

Article received 5 December 2023, accepted 15 March 2024.

This research was funded by the project within the framework of the Faculty of Economics, West Pomeranian University of Technology in Szczecin, Poland under the name "Green Lab. Research and Innovations". The 12th National Scientific Conference named after Professor Zbigniew Czerwiński "Mathematics and information technology at the service of economics".

[1] West Pomeranian University of Technology, Faculty of Economics, ul. Żołnierska 47, 72-210 Szczecin, Poland, bsupron@zut.edu.pl, https://orcid.org/0000-0002-7432-1670.

Suggested citation: Suproń, B. (2024). Assessing the long-term asymmetric relationship between energy consumption and CO_2 emissions: Evidence from the Visegrad Group countries. *Economics and Business Review*, *10*(1), 179–198. https://doi.org/10.18559/ebr.2024.1.1082

Introduction

At the 2015 Paris Conference, where climate change and global warming were discussed, the international community adopted the goal of concerted action to reduce greenhouse gases, including carbon dioxide. The main task emerging from the conference, as well as from subsequent events to lower global temperatures, was the need for an energy transition to low- and zero-emission sources (Flanker, 2016). Consequently, the energy transition has become a major challenge for both developed and developing countries in recent years (Pastukhova & Westphal, 2020). Meeting climate targets requires a change in the structure of energy production through significant financial investments. At the same time, this should be integrated into the pursuit of sustainable development, which will ensure existing or better economic living standards (Coy et al., 2021).

Many studies point to excessive CO_2 emissions from the burning of fossil fuels as a direct cause of global warming (Zoundi, 2017). Due to their large coal and lignite resources, a significant proportion of economies obtain their energy mainly from the combustion of these raw materials, thus contributing to environmental pollution (Antonakakis et al., 2017). Abandoning fossil fuels through the energy transition will therefore have a direct impact on economic development and pose a significant challenge for countries whose economies rely on cheap energy from coal combustion (Inglesi-Lotz & Dogan, 2018).

The 'Fit For 55' package adopted by the European Union in 2021, through which Europe aims to achieve climate neutrality by 2050, represents a further step in the fight against global warming. At the same time, this comprehensive package of reforms will have different social and economic impacts in different member states. The effects of Fit for 55 will differ from country to country, due to differences in energy mix and natural resources (LaBelle et al., 2022). Central European countries such as the Czech Republic, Hungary, Poland and Slovakia, which make up the Visegrad Group (V4) could experience very severe economic impacts of achieving climate neutrality due to their production structure and fossil fuel-based energy sector (Ambroziak et al., 2021).

This study aims to explore the relationship between renewable and non-renewable energy consumption, economic growth and CO_2 emissions in the

Visegrad countries using asymmetric panel econometric models. It also aims to determine whether there are any asymmetric effects of energy consumption and economic growth on CO_2 emissions. Additionally, the study investigates the impact of long-run shocks on CO_2 emissions in economies undergoing an energy transition. The text examines whether decreasing non-renewable energy usage and increasing renewable energy usage can lower CO_2 emissions while sustaining economic growth. It analyses the effects of positive and negative long-term economic shocks on CO_2 emissions in the countries under study.

The results can guide the harmonisation of climate and economic policies. The use of novel research methods can produce more accurate evidence. The study synthesises the methodology used in previous research on asymmetric relationships in environmental economics. Econometric techniques, including cointegration analysis for asymmetrical time series and data, modelling using the panel FGLS method, and testing for asymmetrical causality were employed.

Given these considerations, this study aims to fill the gap in the practical application of asymmetric panel econometric models by explaining how renewable and non-renewable energy consumption and economic growth affect CO_2 emissions in the Visegrad countries. In addition, the study synthesises the methodology used in previous research on asymmetric relationships in environmental economics. The research applied econometric techniques, including cointegration analysis for asymmetrical time series and data, modelling using the panel FGLS method, and testing for asymmetrical causality.

While there is extensive literature on the relationship between energy consumption, economic growth and CO_2 emissions, there is still a lack of research focusing specifically on the Visegrad countries, especially using asymmetric econometric models. The V4 countries are a particular example of a successful transition from centrally planned to market economies. They are also a model example of the economic success of European integration.

These countries are also playing an increasingly important economic role in Europe, becoming the site of many global economic investments (Brodny & Tutak, 2021)the issue of ensuring climate-neutral energy security is of great importance, especially in the “New” EU countries, where the energy transition began later than in the rest of the countries (the so-called Old EU. The Visegrad countries provide insights into the complex dynamics of energy transition. The example of the Visegrad countries can be used to draw conclusions about other countries that will one day embark on the path of economic integration, such as Ukraine and the Balkan countries, as well as countries pursuing a sustainable energy transition (Dzikuć et al., 2021).

The article is organised as follows: Section 1 reviews the recent empirical literature; Section 2 presents the range of data used and the methodology; Section 3 contains the results of the empirical analysis. The final part summarises the results of the study.

1. Literature review

The general basis for all considerations of the systematic and asymmetric determinants of CO_2 is the research on the Environmental Kuznets curve (EKC), which assumed a relationship between CO_2, energy production and economic growth (Apergis & Ozturk, 2015). In subsequent stages, other variables were added to the original model, such as renewable and non-renewable energy consumption (Adedoyin et al., 2021), urbanisation (Ahmad et al., 2021), industry (Rahman & Kashem, 2017), taxation and innovation (Sadiq et al., 2023), and the technical armament of labour (Alvarado et al., 2021). However, the vast majority of ECC-related studies in the European Union and other regions cite energy consumption as the main cause of environmental pollution (Al-mulali et al., 2014; Litavcová & Chovancová, 2021; Muço et al., 2021). The studies indicate that an increase in coal, electricity and oil usage leads to higher carbon dioxide emissions, while a reduction in coal, electricity, gas and oil usage results in lower carbon dioxide emissions in the long run (Abbasi et al., 2021; Adedoyin et al., 2021; Ito, 2017)among others. It is therefore essential to identify such factors that may play a constructive role in economic growth. In doing so, this study investigates the determinants of economic growth in Pakistan from 1972 to 2018. The dynamic autoregressive distributed lag (ARDL.

Additionally, the use of renewable energy has been found to reduce CO_2 emissions in the European Union region both in the short and long run (Azam et al., 2021; Deka et al., 2023; Grodzicki & Jankiewicz, 2022)panel unit root tests, panel heterogeneous co-integration method, panel Fully Modified Ordinary Least Square and the Granger causality method are employed. The primary outcomes of this study are as follows: (1. It is also observed that an increase in the share of renewable energy use leads to fewer CO_2 emissions (Rasheed et al., 2022). Most research indicated a negative, mostly U-shaped relationship between renewable energy consumption and CO_2 reduction, whether for Asian countries (Muhammad & Khan, 2019)energy use, CO_2 emissions and capital role in the economic growth. This study applies generalized method of moments (GMM, African (Inglesi-Lotz & Dogan, 2018), OECD (Bilgili et al., 2016), the European Union (Muço et al., 2021), United States (Ali et al., 2020), 150 countries of the world (Cialani, 2017), or all economies (Dissanayake et al., 2023).

The subject matter and scope of research conducted to date is so extensive that it has been the subject of numerous, comprehensive literature reviews (Haberl et al., 2020; Mardani et al., 2019). In the case of the Visegrad countries, which are the subject of this study, an overview of recent research and methods in the area of the EKC curve has so far been provided by Suproń and Myszczyszyn (2023) and Leitão et al. (2023). The symmetrical relationship between CO_2 emissions and energy consumption in the Visegrad countries was also analysed by Myszczyszyn and Suproń (2021). Previous studies of the relationship between CO_2 emissions and economic factors have used constantly improving methods, estimating symmetric single series models and panel data such as VECM, VAR, ARDL, NARDL, FMOLS, DOLS (Debone et al., 2021).

Recently, there have been a growing number of studies on the role of asymmetric effects of different factors on CO_2 emissions. Givens et al. (2019) analysed the theory of unequal ecological exchange. Recent advancements in econometric models and quantitative methods have sparked a surge of research into the asymmetric effects of various determinants on CO_2 emissions; Ullah et al. (2020) examined the asymmetric effect of deindustrialisation on pollution in Pakistan; Naseer et al. (2022) conducted a study of the asymmetric effect of education on CO_2 emissions in BRICS countries; Akram et al. (2020) using the asymmetric ARDL model, established the non-linear impact of energy efficiency and renewable energy on economic growth in the BRICS countries.

Mawejje (2023) also confirmed the asymmetric relationship between economic growth, CO_2 emissions and energy consumption in 19 Eastern and Southern African countries. Using an asymmetric model, Razzaq et al. (2023) provided new evidence that the development of international tourism drives economic growth and increases carbon emissions asymmetrically at different levels of economic growth and carbon emissions. McGee and York (2018), on the other hand, conducted a study of the asymmetric relationship between urbanisation and CO_2 emissions in less developed countries.

In conclusion, despite numerous studies on the subject, there is still a scarcity of research concerning the relationship between energy consumption, economic growth, and CO_2 emissions when using an asymmetric approach over a prolonged period. This is particularly the case for European countries, including the Visegrad countries. The literature review highlights a significant research gap in this field, particularly concerning the use of Feasible Generalized Least Squares (FGLS) models. So far, only sporadic research has been undertaken in this domain (Naqvi et al., 2022). Considering the foregoing, and given the current state of research, our study bridges the methodological gap.

2 Methodology and data

2.1. Methodology and econometric framework

Research on asymmetric time series estimation methods was initiated by Granger and Yoon (2002), who were the first to formulate the assumption of latent cointegration and to present a formula for partial cumulative sums for positive and negative components. Subsequently, the concept of asymmetric causality and cointegration tests was further developed by Hatemi-J (2012). Moreover, Shin et al. (2014), following on from earlier work, proposed the NARDL model to test both long- and short-run asymmetric relationships between variables. York and Light (2017) presented a method for estimating asymmetric models for panel data based on the Ordinary least squares (OLS) method with fixed effect. In contrast, Allison (2019), referring to previous studies, pointed out in his paper that standard fixed effects regression methods assume that the effects of variables are symmetric. At the same time, he stated that a GLS model is optimal. Furthermore, the concept of methods for modelling and testing asymmetric relationships for time series was developed by Hatemi-J (2022) and Hatemi-J and El-Khatib (2016).

In the methodological area, this study draws on the work of Granger and Yoon (2002), Hatemi-J (2012), Shin et al. (2014), York and Light (2017), Alison (Allison, 2019) in examining asymmetric relationships in time series and panel data. A basic model form was adopted to demonstrate asymmetric relationships between CO_2 emissions and economic growth, renewable and non-renewable energy consumption:

$$CO2_t = \beta_0 + \beta_{1t}\, GDP_t + \beta_{2t}\, REW_t + \beta_{3t}\, NREW_t + \varepsilon_t \tag{1}$$

The above equation (1) is a long-run model and allows estimation of the model parameters for the long run. In order to capture asymmetric effects, all variables were transformed based on the method developed by Granger and Yoon (2002) and developed by Hatemi-J (2012):

$$\begin{gathered}\sum_{n=1}^{t} \Delta x_{it}^{-} = \sum_{n=1}^{t} \min(\Delta x_{it}^{-}, 0) \\ \sum_{n=1}^{t} \Delta x_{it}^{+} = \sum_{n=1}^{t} \max(\Delta x_{it}^{+}, 0)\end{gathered} \tag{2}$$

The variables under consideration were transformed into a natural logarithm form and were assigned symbols: lnREW for renewable energy consumption, lnNREW for non-renewable energy consumption, lnGDP for gross domestic product and $\ln CO_2$ for carbon dioxide emissions. After transformation of the data to partial cumulative sums for positive and negative components and logarithmic transformation, the analytical form of the model under study was determined as follows:

$$\begin{aligned}\ln CO2_t = \beta_0 + \beta_{1t} \ln GDP_t^{+} + \beta_{2t} \ln GDP_t^{-} + \beta_{3t} \ln REW_t^{+} + \beta_{4t} \ln REW_t^{-} + \\ + \beta_{5t} \ln NREW_t^{+} + \beta_{3t} \ln NREW_t^{-} + \varepsilon_t\end{aligned} \tag{3}$$

Due to the fact that the study used panel data for 4 countries, the first step was to test for the presence of cross-sectional dependence (CSD) based on the Breusch-Pagan LM method (Baltagi et al., 2012). This method is applicable to panel data with a small number of cross-sectional units. In addition, multicollinearity tests were carried out (Daoud, 2017), along with serial correlation (Wooldridge, 2010) and heteroskedasticity (White, 1980), in order to determine the optimal estimation method. In the next stopper, the stationarity of the variables was tested at the level and for the first difference using the panel unit root test, second generation CIPS (Pesaran, 2007). To establish the asymmetric impact of energy consumption and economic growth, cointegration was examined using the Kao test (Hatemi-J, 2020; Kao, 1999).

In the present study, two models were estimated in line with previous research to compare their results. The Driscoll-Kraay model (Driscoll & Kraay, 1998), which is a modification of ordinary least squares (OLS) regression that is robust in terms of cross-sectional dependence and heteroskedasticity, and the FGLS model (Baum, 2001), which follows on from the findings presented by Allison (2019). The FGLS model itself is a regression model, appropriate for small panels with many observations over time ($T > N$), which is robust with regard to cross-sectional dependence and heteroskedasticity. The general form of the FGLS model is shown below:

$$\hat{\beta}_{FGLS} = (X'\hat{\Omega}^{-1}X)^{-1}X'\hat{\Omega}^{-1}y \tag{4}$$

In addition to model estimation, the study also conducted an asymmetric causality test to detect causal relationships between variables based on the Dumitrescu-Hurlin method (2012). This test considers the heterogeneity of the panel data, resulting in resilient outcomes. The null hypothesis posits that there is no causal relationship between the variables, whilst the alternative hypothesis proposes the existence of such a relationship.

2.2. Data and preliminary analysis

The proposed methodology was used to analyse the asymmetric, long-term relationship between renewable, non-renewable energy consumption (in tonnes of oil equivalent per capita) and economic growth (in constant 2015 USD per capita), and CO_2 emissions (in metric tonnes per capita) using the example of the Visegrad countries. All variables were extracted from the World Bank database and applied in a panel format. The data used in the study had an annual frequency and covered the period from 1991 to 2021 ($t = 31$). Table 1 presents the descriptive statistics for the variables CO2, GDP, NREW, and REW.

All four variables exhibit significant variability and deviations from normality. Skewness values indicate right-skewed distributions, while kurtosis values of 2 indicate moderate-to-strong leptokurtosis. The results of the Jarque-Bera test were significant for all four variables, further confirming that the data did not conform to a normal distribution. The variables under consideration are therefore asymmetric.

The correlation matrix is presented in Table 2, while Table 3 shows the results of the multicollinearity test for the time series studied. No multicollinearity problem was found for the variables tested, and the mean index for the Variance Inflation Factor (VIF) test was 1.68. Based on the descriptive statistics and preliminary analyses, non-parametric or robust econometric methods are necessary to achieve the research objectives.

Table 1. Descriptive statistics

Variable	CO_2	GDP	NREW	REW
Mean	125.24	11870.73	0.44	4.34
Median	82.57	11596.03	0.32	3.91
Maximum	362.71	20248.30	1.13	7.40
Minimum	23.38	4743.75	0.02	2.56
Standard deviation	107.97	3842.17	13.79	240.80
Skewness	0.94	0.20	0.71	2.23
Kurtosis	2.30	2.15	1.93	8.06
Jarque-Bera	20.92	4.54	16.26	234.77
Probability	0.00	0.03	0.00	0.00
Observations	124	124	124	124

Source: own calculations.

Table 2. Correlation matrix

Variables	$lnCO_2$	$lnGDP^+$	$lnGDP^-$	$lnNREW^+$	$lnNREW^-$	$lnREW^+$	$lnREW^-$
$lnCO_2$	1.000	–0.261	0.535	–0.369	0.543	–0.370	0.429
$lnGDP^+$	–0.261	1.000	–0.418	0.730	–0.690	0.657	–0.681
$lnGDP^-$	0.535	–0.418	1.000	–0.781	0.852	–0.702	0.793
$lnNREW^+$	–0.369	0.730	–0.781	1.000	–0.836	0.893	–0.948
$lnNREW^-$	0.543	–0.690	0.852	–0.836	1.000	–0.794	0.842
$lnREW^+$	–0.370	0.657	–0.702	0.893	–0.794	1.000	–0.843
$lnREW^-$	0.429	–0.681	0.793	–0.948	0.842	–0.843	1.000

Source: own calculations.

Table 3. Multicollinearity VIF Test

Variable	VIF	1/VIF
lnGDP+ –	1.94	0.515
lnNREW+ –	1.89	0.529

Source: own calculations.

3. Research results

Table 4 shows the results of the initial diagnostics for the asymmetric panel data. These results indicate that there is a problem with autocorrelation, heteroskedasticity and cross-sectional dependence in the series under investigation. The results are in line with expectations presented for asymmetric data by Allison (Allison, 2019). In view of the above, standard OLS models cannot be used in the estimation process.

Table 4. Asymmetric panel data tests

Test	Statistic	Value	***p*-value**
Wooldridge test for autocorrelation	F	30.364	0.012
Heteroskedasticity White Test	$\chi 2$	33.560	0.001
Breusch-Pagan LM Residual Cross-Section Dependence Test	$\chi 2$	15.447	0.017

Source: own calculations.

In the initial stage of this study, the unit root tests were conducted using the second-generation CIPS test, which considers the issue of cross-sectional dependence and is known for its high statistical power. The results of the test are shown in Table 5. The test performed confirms that all variables are stationary at first difference I (1).

Building on previous work by Hatemi-J, a cointegration test procedure for asymmetric series was carried out in the next step by applying tests to Kao panel data. Cointegration analysis was applied in pairs and jointly. All tests confirmed the presence of cointegration in the asymmetric series, but not in the symmetrical pairs test. This indicates the presence of latent cointegration. The results of the cointegration tests are shown in Table 6.

Based on the obtained preliminary results, an OLS model with fixed effect and robust standard errors was estimated based on the Driscoll-Kraay method for panel data with heteroskedasticity and autocorrelation problems. The

Table 5. Panel data CIPS unit root tests

Variable	Level	First difference
$\ln CO_2$	–2.294*	–5.210***
$\ln CO_2^+$	2.042	–5.291***
$\ln CO_2^-$	–2.025	–4.628***
$\ln GDP$	–1.457	–3.490***
$\ln GDP^+$	–1.316	–3.325***
$\ln GDP^-$	–0.924	–4.902***
$\ln NREW$	–2.060	–4.760***
$\ln NREW^+$	–1.213	–4.178***
$\ln NREW^-$	1.186	–4.204***
$\ln REW$	–2.930***	–4.192***
$\ln REW^+$	–3.354***	–4.368***
$\ln REW^-$	–2.685***	–5.717***

Note: The significance of the coefficients is indicated by an asterisk in the tables, where *, **, *** denotes 10%, 5%, and 1% significance level, respectively.

Source: own calculations.

Table 6. The results of panel hidden cointegration tests

Variables	ADF	*p*-value
$\ln CO_2$, $\ln REW$	–0.026	0.490
$\ln CO_2$, $\ln NREW$	0.728	0.233
$\ln CO_2$, $\ln GDP$	–0.013	0.495
$\ln CO_2^+$, $\ln GDP^+$, $\ln REW^+$, $\ln NREW^+$	–1.761	0.039
$\ln CO_2^-$, $\ln GDP^-$, $\ln REW^-$, $\ln NREW^-$	–2.146	0.016
$\ln CO_2$, $\ln GDP^+$, $\ln REW^+$, $\ln NREW^+$	–1.284	0.009
$\ln CO_2$, $\ln GDP^-$, $\ln REW^-$, $\ln NREW^-$	–2.041	0.021
$\ln CO_2^+$, $\ln REW^-$, $\ln REW^+$, $\ln NREW^+$, $\ln REW^-$, $\ln GDP^+$, $\ln GDP^-$	–2.761	0.003
$\ln CO_2^-$, $\ln REW^-$, $\ln REW^+$, $\ln NREW^+$, $\ln REW^-$, $\ln GDP^+$, $\ln GDP^-$	–2.556	0.005
$\ln CO_2$, $\ln REW^-$, $\ln REW^+$, $\ln NREW^+$, $\ln REW^-$, $\ln GDP^+$, $\ln GDP^-$	–3.023	0.001
$\ln CO_2^+$, $\ln CO^-$, $\ln REW$, $\ln REW^+$, $\ln NREW^+$, $\ln REW^-$, $\ln GDP^+$, $\ln GDP^-$	–3.245	0.001

Source: calculations.

estimation results are presented in Table 7. The lnREW variable and lnGDP had a statistically significant effect on the dependent variable. The model coefficients reveal that a 1% increase in renewable energy consumption causes a 0.02% drop in CO_2 emissions in the countries under study. Conversely, if there is a negative change in lnGDP by 1%, CO_2 emissions decrease by 2.39%.

Table 7. Asymmetric Model Estimated with fixed effect (robust)

Variables	Coefficient	Standard error	*t*-statistics	*p*-value
$\ln REW^{+}$	–0.024	0.003	–7.570	0.005
$\ln REW^{-}$	–0.159	0.147	–1.080	0.359
$\ln NREW^{+}$	0.272	0.313	0.870	0.448
$\ln NREW^{-}$	0.109	0.063	1.740	0.181
$\ln GDP^{+}$	0.057	0.146	0.390	0.721
$\ln GDP^{-}$	2.390	0.866	2.760	0.070
Const.	2.173	0.033	65.090	0.000

Note: *F*-statistics of the model is 26.681 with *p*-value 0.000, R^2 of 0.723.

Source: own calculations.

In the next stage of the study, a long-term asymmetric model was estimated using the FGLS method. The estimation results are presented in Table 8. Based on the results obtained, it can be concluded that the GLS model showed a larger number of statistically significant variables and a different value of the estimated parameters. In contrast, the model estimated by the Driscoll-Kraay method has about ¼ smaller standard errors compared to the GLS model. At the same time, the standard errors of the GLS model are similar in their magnitude to those obtained by Şanlı et al. (2023)population density and sources of energy supply is critical in assessing environmental quality. Recent empirical studies paid limited attention to the role of renewable (RE for the NARDL model.

According to the results obtained for the FGLS model, an increase in renewable energy consumption in the countries studied contributes to a decrease in CO_2 of 0.23%. At the same time, the results of the Wald test for the joint significance of the coefficients did not confirm a significant asymmetry for renewable energy consumption. In the case of non-renewable energy consumption, the model tested indicates that a 1% increase in non-renewable energy consumption leads to a 0.34% increase in CO_2, while a decrease leads to a 0.71% reduction in CO_2. Wald tests simultaneously confirmed for these two variables a significant asymmetry at a significance level of 10%.

The final variable studied was GDP. The results showed statistically significant coefficients for both positive and negative changes. It should be noted that in the countries investigated, a 1% increase in GDP results in a 1.19% decline in CO_2 emissions, while a decrease leads to a long-term reduction of

Table 8. Asymmetric Model Estimated with generalized least squares

Variables	Coefficient	Standard error	*z*-statistics	*p*-value
$lnREW^{+}$	–0.233	0.054	–4.290	0.000
$lnREW^{-}$	–0.390	0.448	–0.870	0.383
$lnNREW^{+}$	0.339	0.299	–1.970	0.071
$lnNREW^{-}$	0.713	0.414	1.720	0.085
$lnGDP^{+}$	–1.186	0.234	–5.060	0.000
$lnGDP^{-}$	5.665	1.604	3.530	0.000
Const.	2.267	0.109	20.830	0.000
Wald asymmetry test results				
Variables		**Statistic**	**Value**	***p*–value**
lnGDP		$\chi2$	8.30	0.004
lnNREW		$\chi2$	2.58	0.098
lnREW		$\chi2$	1.94	0.164
Diagnostics Wald $\chi2$		$\chi2$	189.64	0.002

Source: own calculations.

5.66% in CO_2 emissions. The asymmetry observed in this variable is also statistically significant.

To confirm whether changes in the structure of energy production can have a significant impact on CO_2 reduction, as well as to establish their asymmetric impact, a causality test was conducted in the final stage of the study. For this purpose, a paired test based on the Dumitrescu & Hurlin panel data test was applied (2012) in conjunction with the method discussed by Hatemi-J (2012). The results indicate that there is bidirectional causality between lnCO2 $\leftrightarrow$ lnREW, $lnREW^{-} \leftrightarrow lnCO2^{-}$, $lnREW^{+} \leftrightarrow lnCO2^{-}$, $lnNREW^{-} \leftrightarrow lnCO2^{+}$, $lnGDP^{-} \leftrightarrow lnCO2^{+}$. Unidirectional causality, on the other hand, has been demonstrated for the variables: $lnCO2^{-} \rightarrow lnREW^{-}$, $lnNREW^{-} \rightarrow lnCO2^{-}$, lnGDP $\rightarrow$ lnCO2, $lnCO2^{+} \rightarrow lnGDP^{+}$, $lnCO2^{-} \rightarrow lnGDP^{-}$ (Table 9).

The findings suggest a feedback loop between positive and negative interactions of CO_2 and renewable energy consumption. Causality tests establish that a reduction in non-renewable energy leads to a decrease in CO_2 emissions. However, results imply that economic growth has a non-linear impact on CO_2 emissions in the countries studied. Emissions initially increase, but then decline after a certain point.

The presence of multiple bidirectional and unidirectional asymmetric causality suggests that the relationships between variables are intricate and necessitate a comprehensive approach. In determining energy production strat-

Table 9. Results of pairwise Dumitrescu-Hurlin panel causality tests

Causality	*Z*-bar statistics	*p*-value	Causality	*Z*-bar statistics	*p*-value
$lnCO2 \rightarrow lnREW$	1.936	0.053	$lnCO2^{-} \rightarrow lnNREW^{-}$	–0.420	0.674
$lnREW \rightarrow lnCO2$	2.870	0.004	$lnNREW^{-} \rightarrow lnCO2^{+}$	4.489	0.000
$lnREW^{+} \rightarrow lnCO2^{+}$	1.082	0.279	$lnCO2^{+} \rightarrow lnNREW^{-}$	23.575	0.000
$lnCO2^{+} \rightarrow lnREW^{+}$	16.156	0.000	$lnNREW^{-} \rightarrow lnCO2^{-}$	2.137	0.033
$lnREW^{-} \rightarrow lnCO2^{-}$	2.325	0.020	$lnCO2^{-} \rightarrow lnNREW^{+}$	0.908	0.364
$lnCO2^{-} \rightarrow lnREW^{-}$	12.417	0.000	$lnGDP \rightarrow lnCO2$	2.111	0.035
$lnREW^{-} \rightarrow lnCO2^{+}$	–0.071	0.943	$lnCO2 \rightarrow lnGDP$	–0.789	0.430
$lnCO2^{+} \rightarrow lnREW^{-}$	1.368	0.171	$lnGDP^{+} \rightarrow lnCO2^{+}$	0.571	0.568
$lnREW^{+} \rightarrow lnCO2^{-}$	2.567	0.010	$lnCO2^{+} \rightarrow lnGDP^{+}$	1.720	0.086
$lnCO2^{-} \rightarrow lnREW^{+}$	2.137	0.033	$lnGDP^{-} \rightarrow lnCO2^{-}$	–0.937	0.349
$lnCO2 \rightarrow lnNREW$	0.785	0.433	$lnCO2^{-} \rightarrow lnGDP^{-}$	3.303	0.001
$lnNREW \rightarrow lnCO2$	0.816	0.414	$lnGDP^{-} \rightarrow lnCO2^{+}$	3.912	0.000
$lnNREW^{+} \rightarrow lnCO2^{+}$	1.333	0.183	$lnCO2^{+} \rightarrow lnGDP^{-}$	4.432	0.000
$lnCO2^{+} \rightarrow lnNREW^{+}$	–0.482	0.630	$lnGDP^{+} \rightarrow lnCO2^{-}$	4.755	0.000
$lnNREW^{-} \rightarrow lnCO2^{-}$	8.843	0.000	$lnCO2^{-} \rightarrow lnGDP^{+}$	–0.063	0.950

Source: own calculations.

egies, a range of factors should be considered, including the energy source type, economic growth, and greenhouse gas emissions. Transforming the energy mix has the potential to affect CO_2 emissions, but it requires a balanced approach that considers various factors to tackle climate change effectively.

The results obtained for the asymmetric effect of economic growth on CO_2 emissions in the long term are consistent with those presented by Toumi & Toumi (2019). The results for GDP are at the same time different from those obtained by Iqbal et al. (2022), who showed no significant asymmetry in the long term. Both studies in question simultaneously confirm the long-term asymmetry for the relationship between renewable energy and CO_2 emissions, which could not be confirmed for the V4 countries. In contrast, the result obtained is consistent with the study by Şanlı et al. (2023), who only confirmed the positive impact of renewable energy on the decrease in CO_2 emissions, while indicating the presence of a statistically significant asymmetry in the relationship between non-renewable energy and CO_2 emissions.

Conclusions

The objective of this paper was to examine the enduring and uneven influence of renewable and non-renewable energy consumption, as well as economic growth, on CO_2 emissions, with a case study focussing on the Visegrad countries from 1991 to 2021. The study used the Driscoll-Kraay and FGLS models to address challenges arising from serial correlation, panel group heteroskedasticity, cross-sectional dependence, and the heterogeneity of asymmetrically modified data. The findings indicate the presence of cointegration for all variables, encompassing various combinations, in the asymmetrically transformed series. The OLS-based model proposed by Driscoll-Kraay showed reduced standard errors, but lower significance in the estimated parameters compared to the FGLS model.

These differences are due to different estimation rules, in particular the distribution of model residuals and the accuracy of these methods. However, the results tend to converge to some extent in terms of the strength and direction of the effects. It is important to emphasise the need for further research in this area, particularly on panels with more observations per unit of time, to develop optimal estimation techniques for an asymmetric effect.

Research also indicates that a rise in renewable energy consumption has a direct and proportional negative impact on CO_2 levels, thereby contributing to the mitigation of greenhouse gases. In contrast, a decrease in non-renewable energy consumption brings about a significant decrease in CO_2 emissions in the long term. Moreover, GDP was found to have an asymmetric effect on CO_2, where a decrease in GDP induces a greater decrease in GHG emissions than an increase in GDP. Thus, the research confirms that economic development, combined with increasing the share of renewable energy, is a source of stable and sustainable socio-economic development, while also being environmentally friendly. Furthermore, the application of asymmetric Dumitrescu-Hurlin causality tests confirms the existence of bidirectional causality between an increase in renewable energy consumption and a reduction in CO_2, a decrease in GDP and a decrease in CO_2, and a unidirectional relationship between a decrease in non-renewable energy consumption and a decrease in CO_2.

The study's findings may inform energy policy decisions. The estimation results obtained suggest that economic growth can be sustained during an energy transition. To achieve this, it is essential to develop renewable energy sources in a sustainable and well-considered manner. This goal can be achieved both through the involvement of domestic resources and foreign funds, including European funds and loans from institutions such as the World Bank.

The policy implications of the research suggest that the Visegrad governments should implement robust incentive programmes and subsidies to encourage investment in renewable energy projects. To fully realize the potential of renewable energy, a two-pronged approach is essential: providing financial incentives to encourage its adoption, and modernizing the energy infrastructure to ensure efficient integration of different energy sources. To accelerate the transition to clean energy, policymakers should focus on two key areas: Firstly, investing in smart grid technologies to improve the flexibility and reliability of existing infrastructure, enabling efficient integration of renewable energy sources. Secondly, increasing government support for renewable energy research and development (R&D) to unlock the full potential of these technologies and pave the way for a sustainable energy future. Collaboration between academia, industry and research institutions can lead to breakthroughs that make renewable energy more accessible and cost-effective.

In line with the latest initiatives from the European Union aimed at reducing CO_2 emissions, it is essential to enhance human capital. Therefore, implementing training schemes and educational programmes is necessary to develop a skilled workforce capable of effectively managing, sustaining, and innovating within the renewable energy sector. Incorporating vocational training, academic programmes, and collaborations with industries can ensure a smooth transition in the labour market.

The Visegrad countries should actively participate in global collaboration, recognizing the interdependence of environmental concerns. Accelerating the transition and effectively tackling worldwide climate challenges can be achieved by exchanging best practices, technological advancements, and policy insights with other nations. It would be beneficial for the group to establish a collective fund and attract investors through a public-private partnership.

The study has some limitations that could be addressed in future research. For instance, the sample size is relatively small, with only four participants from Central and Eastern Europe (CEE), which may limit the generalizability of the findings to other regions. While economic growth and energy use are often seen as the primary drivers of CO_2 emissions, a singular focus on these factors overlooks potentially influential contributors such as green taxes, innovative climate solutions, population trends, and urban planning. To equip policymakers with deeper insights into effective plans for curbing CO_2 emissions and fostering sustainable economic growth in CEE economies, future research should expand its reach to encompass a broader range of countries and delve deeper into the influence of additional factors, along with examining potential interactions between them. Moreover, conducting research utilizing innovative estimation methods like Fourier ARDL or ARDL CS could yield compelling insights.

References

Abbasi, K. R., Shahbaz, M., Jiao, Z., & Tufail, M. (2021). How energy consumption, industrial growth, urbanization, and CO_2 emissions affect economic growth in Pakistan? A novel dynamic ARDL simulations approach. *Energy*, *221*, 119793. https://doi.org/10.1016/j.energy.2021.119793

Adedoyin, F. F., Ozturk, I., Bekun, F. V., Agboola, P. O., & Agboola, M. O. (2021). Renewable and non-renewable energy policy simulations for abating emissions in a complex economy: Evidence from the novel dynamic ARDL. *Renewable Energy*, *177*, 1408–1420. https://doi.org/10.1016/j.renene.2021.06.018

Ahmad, M., Işık, C., Jabeen, G., Ali, T., Ozturk, I., & Atchike, D. W. (2021). Heterogeneous links among urban concentration, non-renewable energy use intensity, economic development, and environmental emissions across regional development levels. *Science of The Total Environment*, *765*, 144527. https://doi.org/10.1016/j.scitotenv.2020.144527

Akram, R., Majeed, M. T., Fareed, Z., Khalid, F., & Ye, C. (2020). Asymmetric effects of energy efficiency and renewable energy on carbon emissions of BRICS economies: Evidence from nonlinear panel autoregressive distributed lag model. *Environmental Science and Pollution Research*, *27*(15), 18254–18268. https://doi.org/10.1007/s11356-020-08353-8

Ali, F., Huang, S., & Cheo, R. (2020). Climatic Impacts on Basic Human Needs in the United States of America: A Panel Data Analysis. *Sustainability*, *12*(4), Article 4. https://doi.org/10.3390/su12041508

Allison, P. D. (2019). Asymmetric Fixed-effects Models for Panel Data. *Socius*, *5*, 2378023119826441. https://doi.org/10.1177/2378023119826441

Al-mulali, U., Fereidouni, H. G., & Lee, J. Y. M. (2014). Electricity consumption from renewable and non-renewable sources and economic growth: Evidence from Latin American countries. *Renewable and Sustainable Energy Reviews*, *30*, 290–298. https://doi.org/10.1016/j.rser.2013.10.006

Alvarado, R., Deng, Q., Tillaguango, B., Méndez, P., Bravo, D., Chamba, J., Alvarado-Lopez, M., & Ahmad, M. (2021). Do economic development and human capital decrease non-renewable energy consumption? Evidence for OECD countries. *Energy*, *215*, 119147. https://doi.org/10.1016/j.energy.2020.119147

Ambroziak, Ł., Chojna, J., Miniszewski, M., Strzelecki, J., Aleksander, S., Śliwowski, P., Święcicki, I., & Wąsiński, M. (2021). *Visegrad Group—30 years of transformation, integration and development*. Polish Economic Institute. https://pie.net.pl/wp-content/uploads/2021/02/Wyszechrad-ENG.pdf

Antonakakis, N., Chatziantoniou, I., & Filis, G. (2017). Energy consumption, CO_2 emissions, and economic growth: An ethical dilemma. *Renewable and Sustainable Energy Reviews*, *68*, 808–824. https://doi.org/10.1016/j.rser.2016.09.105

Apergis, N., & Ozturk, I. (2015). Testing Environmental Kuznets Curve hypothesis in Asian countries. *Ecological Indicators*, *52*, 16–22. https://doi.org/10.1016/j.ecolind.2014.11.026

Azam, A., Rafiq, M., Shafique, M., Zhang, H., Ateeq, M., & Yuan, J. (2021). Analyzing the relationship between economic growth and electricity consumption from renewable and non-renewable sources: Fresh evidence from newly industrialized countries. *Sustainable Energy Technologies and Assessments*, *44*, 100991. https://doi.org/10.1016/j.seta.2021.100991

Baltagi, B. H., Feng, Q., & Kao, C. (2012). A Lagrange Multiplier test for cross-sectional dependence in a fixed effects panel data model. *Journal of Econometrics*, *170*(1), 164–177. https://doi.org/10.1016/j.jeconom.2012.04.004

Baum, C. F. (2001). Residual Diagnostics for Cross-section Time Series Regression Models. *The Stata Journal*, *1*(1), 101–104. https://doi.org/10.1177/1536867X0100100108

Bilgili, F., Koçak, E., & Bulut, Ü. (2016). The dynamic impact of renewable energy consumption on CO_2 emissions: A revisited Environmental Kuznets Curve approach. *Renewable and Sustainable Energy Reviews*, *54*, 838–845. https://doi.org/10.1016/j.rser.2015.10.080

Brodny, J., & Tutak, M. (2021). The comparative assessment of sustainable energy security in the Visegrad countries. A 10-year perspective. *Journal of Cleaner Production*, *317*, 128427. https://doi.org/10.1016/j.jclepro.2021.128427

Cialani, C. (2017). CO_2 emissions, GDP and trade: A panel cointegration approach. *International Journal of Sustainable Development & World Ecology*, *24*(3), 193–204. https://doi.org/10.1080/13504509.2016.1196253

Coy, D., Malekpour, S., Saeri, A. K., & Dargaville, R. (2021). Rethinking community empowerment in the energy transformation: A critical review of the definitions, drivers and outcomes. *Energy Research & Social Science*, *72*, 101871. https://doi.org/10.1016/j.erss.2020.101871

Daoud, J. I. (2017). Multicollinearity and Regression Analysis. *Journal of Physics: Conference Series*, *949*(1), 012009. https://doi.org/10.1088/1742-6596/949/1/012009

Debone, D., Leite, V. P., & Miraglia, S. G. E. K. (2021). Modelling approach for carbon emissions, energy consumption and economic growth: A systematic review. *Urban Climate*, *37*, 100849. https://doi.org/10.1016/j.uclim.2021.100849

Deka, A., Ozdeser, H., & Seraj, M. (2023). The effect of GDP, renewable energy and total energy supply on carbon emissions in the EU-27: New evidence from panel GMM. *Environmental Science and Pollution Research*, *30*(10), 28206–28216. https://doi.org/10.1007/s11356-022-24188-x

Dissanayake, H., Perera, N., Abeykoon, S., Samson, D., Jayathilaka, R., Jayasinghe, M., & Yapa, S. (2023). Nexus between carbon emissions, energy consumption, and economic growth: Evidence from global economies. *PLOS ONE*, *18*(6), e0287579. https://doi.org/10.1371/journal.pone.0287579

Driscoll, J. C., & Kraay, A. C. (1998). Consistent Covariance Matrix Estimation with Spatially Dependent Panel Data. *The Review of Economics and Statistics*, *80*(4), 549–560.

Dumitrescu, E.-I., & Hurlin, C. (2012). Testing for Granger non-causality in heterogeneous panels. *Economic Modelling*, *29*(4), 1450–1460. https://doi.org/10.1016/j.econmod.2012.02.014

Dzikuć, M., Wyrobek, J., & Popławski, Ł. (2021). Economic Determinants of Low-Carbon Development in the Visegrad Group Countries. *Energies*, *14*(13), Article 13. https://doi.org/10.3390/en14133823

Flanker, R. (2016). The Paris Agreement and the new logic of international climate politics. *International Affairs*, *92*(5), 1107–1125. https://doi.org/10.1111/1468-2346.12708

Givens, J. E., Huang, X., & Jorgenson, A. K. (2019). Ecologically unequal exchange: A theory of global environmental injustice. *Sociology Compass*, *13*(5), e12693. https://doi.org/10.1111/soc4.12693

Granger, C. W. J., & Yoon, G. (2002). *Hidden Cointegration* (SSRN Scholarly Paper 313831). https://doi.org/10.2139/ssrn.313831

Grodzicki, T., & Jankiewicz, M. (2022). The impact of renewable energy and urbanization on CO_2 emissions in Europe – Spatio-temporal approach. *Environmental Development*, *44*, 100755. https://doi.org/10.1016/j.envdev.2022.100755

Haberl, H., Wiedenhofer, D., Virág, D., Kalt, G., Plank, B., Brockway, P., Fishman, T., Hausknost, D., Krausmann, F., Leon-Gruchalski, B., Mayer, A., Pichler, M., Schaffartzik, A., Sousa, T., Streeck, J., & Creutzig, F. (2020). A systematic review of the evidence on decoupling of GDP, resource use and GHG emissions, part II: Synthesizing the insights. *Environmental Research Letters*, *15*(6), 065003. https://doi.org/10.1088/1748-9326/ab842a

Hatemi-J, A. (2012). Asymmetric causality tests with an application. *Empirical Economics*, *43*(1), 447–456. https://doi.org/10.1007/s00181-011-0484-x

Hatemi-J, A. (2020). Hidden panel cointegration. *Journal of King Saud University - Science*, *32*(1), 507–510. https://doi.org/10.1016/j.jksus.2018.07.011

Hatemi-J, A. (2022). Dynamic Asymmetric Causality Tests with an Application. *Engineering Proceedings*, *18*(1), Article 1. https://doi.org/10.3390/engproc2022018041

Hatemi-J, A., & El-Khatib, Y. (2016). An extension of the asymmetric causality tests for dealing with deterministic trend components. *Applied Economics*, *48*(42), 4033–4041. https://doi.org/10.1080/00036846.2016.1150950

Inglesi-Lotz, R., & Dogan, E. (2018). The role of renewable versus non-renewable energy to the level of CO_2 emissions a panel analysis of sub- Saharan Africa's Big 10 electricity generators. *Renewable Energy*, *123*, 36–43. https://doi.org/10.1016/j.renene.2018.02.041

Iqbal, S., Wang, Y., Shaikh, P. A., Maqbool, A., & Hayat, K. (2022). Exploring the asymmetric effects of renewable energy production, natural resources, and economic progress on CO_2 emissions: Fresh evidence from Pakistan. *Environmental Science and Pollution Research*, *29*(5), 7067–7078. https://doi.org/10.1007/s11356-021-16138-w

Ito, K. (2017). CO_2 emissions, renewable and non-renewable energy consumption, and economic growth: Evidence from panel data for developing countries. *International Economics*, *151*, 1–6. https://doi.org/10.1016/j.inteco.2017.02.001

Kao, C. (1999). Spurious regression and residual-based tests for cointegration in panel data. *Journal of Econometrics*, *90*(1), 1–44. https://doi.org/10.1016/S0304-4076(98)00023-2

LaBelle, M. C., Tóth, G., & Szép, T. (2022). Not Fit for 55: Prioritizing Human Well-Being in Residential Energy Consumption in the European Union. *Energies*, *15*(18), Article 18. https://doi.org/10.3390/en15186687

Leitão, N. C., Dos Santos Parente, C. C., Balsalobre-Lorente, D., & Cantos Cantos, J. M. (2023). Revisiting the effects of energy, population, foreign direct investment, and economic growth in Visegrad countries under the EKC scheme. *Environmental Science and Pollution Research*, *30*(6), 15102–15114. https://doi.org/10.1007/s11356-022-23188-1

Litavcová, E., & Chovancová, J. (2021). Economic Development, CO_2 Emissions and Energy Use Nexus-Evidence from the Danube Region Countries. *Energies*, *14*(11), Article 11. https://doi.org/10.3390/en14113165

Mardani, A., Streimikiene, D., Cavallaro, F., Loganathan, N., & Khoshnoudi, M. (2019). Carbon dioxide (CO_2) emissions and economic growth: A systematic review of two decades of research from 1995 to 2017. *Science of The Total Environment*, *649*, 31–49. https://doi.org/10.1016/j.scitotenv.2018.08.229

Mawejje, J. (2023). Renewable and nonrenewable energy consumption, economic growth, and CO_2 emissions in Eastern and South African countries: The role of informality. *Environmental Science and Pollution Research*, *30*(28), 72575–72587. https://doi.org/10.1007/s11356-023-27549-2

McGee, J. A., & York, R. (2018). Asymmetric relationship of urbanization and CO_2 emissions in less developed countries. *PLOS ONE*, *13*(12), e0208388. https://doi.org/10.1371/journal.pone.0208388

Muço, K., Valentini, E., & Lucarelli, S. (2021). The Relationships between GDP growth, Energy Consumption, Renewable Energy Production and CO_2 Emissions in European Transition Economies. *International Journal of Energy Economics and Policy*, *11*(4), Article 4.

Muhammad, B., & Khan, S. (2019). Effect of bilateral FDI, energy consumption, CO_2 emission and capital on economic growth of Asia countries. *Energy Reports*, *5*, 1305–1315. https://doi.org/10.1016/j.egyr.2019.09.004

Myszczyszyn, J., & Suproń, B. (2021). Relationship among Economic Growth (GDP), Energy Consumption and Carbon Dioxide Emission: Evidence from V4 Countries. *Energies*, *14*(22), Article 22. https://doi.org/10.3390/en14227734

Naqvi, S., Wang, J., & Ali, R. (2022). Towards a green economy in Europe: Does renewable energy production has asymmetric effects on unemployment? *Environmental Science and Pollution Research*, *29*(13), 18832–18839. https://doi.org/10.1007/s11356-021-17093-2

Naseer, S., Song, H., Chupradit, S., Maqbool, A., Hashim, N. A. A. N., & Vu, H. M. (2022). Does educated labor force is managing the green economy in BRCS? Fresh evidence from NARDL-PMG approach. *Environmental Science and Pollution Research*, *29*(14), 20296–20304. https://doi.org/10.1007/s11356-021-16834-7

Pastukhova, M., & Westphal, K. (2020). Governing the Global Energy Transformation. In M. Hafner & S. Tagliapietra (Eds.), *The Geopolitics of the Global Energy Transition* (pp. 341–364). Springer International Publishing. https://doi.org/10.1007/978-3-030-39066-2_15

Pesaran, M. H. (2007). A simple panel unit root test in the presence of cross-section dependence. *Journal of Applied Econometrics*, *22*(2), 265–312. https://doi.org/10.1002/jae.951

Rahman, M. M., & Kashem, M. A. (2017). Carbon emissions, energy consumption and industrial growth in Bangladesh: Empirical evidence from ARDL cointegration and

Granger causality analysis. *Energy Policy*, *110*, 600–608. https://doi.org/10.1016/j.enpol.2017.09.006

Rasheed, M. Q., Haseeb, A., Adebayo, T. S., Ahmed, Z., & Ahmad, M. (2022). The long-run relationship between energy consumption, oil prices, and carbon dioxide emissions in European countries. *Environmental Science and Pollution Research*, *29*(16), 24234–24247. https://doi.org/10.1007/s11356-021-17601-4

Razzaq, A., Fatima, T., & Murshed, M. (2023). Asymmetric effects of tourism development and green innovation on economic growth and carbon emissions in top 10 GDP countries. *Journal of Environmental Planning and Management*, *66*(3), 471–500. https://doi.org/10.1080/09640568.2021.1990029

Sadiq, M., Chau, K. Y., Ha, N. T. T., Phan, T. T. H., Ngo, T. Q., & Huy, P. Q. (2023). The impact of green finance, eco-innovation, renewable energy and carbon taxes on CO_2 emissions in BRICS countries: Evidence from CS ARDL estimation. *Geoscience Frontiers*, 101689. https://doi.org/10.1016/j.gsf.2023.101689

Şanlı, D., Muratoğlu, Y., Songur, M., & Uğurlu, E. (2023). The asymmetric effect of renewable and non-renewable energy on carbon emissions in OECD: New evidence from non-linear panel ARDL model. *Frontiers in Environmental Science*, *11*. https://www.frontiersin.org/articles/10.3389/fenvs.2023.1228296

Shin, Y., Yu, B., & Greenwood-Nimmo, M. (2014). Modelling Asymmetric Cointegration and Dynamic Multipliers in a Nonlinear ARDL Framework. In R. C. Sickles & W. C. Horrace (Eds.), *Festschrift in Honor of Peter Schmidt: Econometric Methods and Applications* (pp. 281–314). Springer. https://doi.org/10.1007/978-1-4899-8008-3_9

Supron, B., & Myszczyszyn, J. (2023). Impact of Renewable and Non-Renewable Energy Consumption and CO_2 Emissions on Economic Growth in the Visegrad Countries. *Energies*, *16*(20), Article 20. https://doi.org/10.3390/en16207163

Toumi, S., & Toumi, H. (2019). Asymmetric causality among renewable energy consumption, CO_2 emissions, and economic growth in KSA: Evidence from a non-linear ARDL model. *Environmental Science and Pollution Research*, *26*(16), 16145–16156. https://doi.org/10.1007/s11356-019-04955-z

Ullah, S., Ozturk, I., Usman, A., Majeed, M. T., & Akhtar, P. (2020). On the asymmetric effects of premature deindustrialization on CO_2 emissions: Evidence from Pakistan. *Environmental Science and Pollution Research*, *27*(12), 13692–13702. https://doi.org/10.1007/s11356-020-07931-0

White, H. (1980). A Heteroskedasticity-Consistent Covariance Matrix Estimator and a Direct Test for Heteroskedasticity. *Econometrica*, *48*(4), 817–838. https://doi.org/10.2307/1912934

Wooldridge, J. M. (2010). *Econometric Analysis of Cross Section and Panel Data*. The MIT Press. https://www.jstor.org/stable/j.ctt5hhcfr

York, R., & Light, R. (2017). Directional Asymmetry in Sociological Analyses. *Socius*, *3*, 2378023117697180. https://doi.org/10.1177/2378023117697180

Zoundi, Z. (2017). CO_2 emissions, renewable energy and the Environmental Kuznets Curve, a panel cointegration approach. *Renewable and Sustainable Energy Reviews*, *72*, 1067–1075. https://doi.org/10.1016/j.rser.2016.10.018

Aims and Scope

The **Economics and Business Review** is a quarterly journal focusing on theoretical, empirical and applied research in the fields of Economics and Corporate and Public Finance. The Journal welcomes the submission of high quality articles dealing with micro, mezzo and macro issues well founded in modern theories and relevant to an international audience. The EBR's goal is to provide a platform for academicians all over the world to share, discuss and integrate state-of-the-art Economics and Finance thinking with special focus on new market economies.

The manuscript

1. Articles submitted for publication in the **Economics and Business Review** should contain original, unpublished work not submitted for publication elsewhere.
2. Manuscripts intended for publication should be written in English, edited in Word in accordance with the **APA editorial** guidelines and sent to: secretary@ebr.edu.pl**.** Authors should upload two versions of their manuscript. One should be a complete text, while in the second all document information identifying the author(s) should be removed from papers to allow them to be sent to anonymous referees.
3. Manuscripts are to be typewritten in **12' font in A4 paper** format, one and half spaced and be aligned. Pages should be numbered. Maximum size of the paper should be up to 20 pages.
4. Papers should have an abstract of about 100-150 words, keywords and the Journal of Economic Literature classification code (**JEL Codes**).
5. Authors should clearly declare the aim(s) of the paper. Papers should be divided into numbered (in Arabic numerals) sections.
6. **Acknowledgements** and references to grants, affiliations, postal and e-mail addresses, etc. should appear as a separate footnote to the author's name a, b, etc and should not be included in the main list of footnotes.
7. **Footnotes** should be listed consecutively throughout the text in Arabic numerals. Cross-references should refer to particular section numbers: e.g.: See Section 1.4.
8. **Quoted texts** of more than 40 words should be separated from the main body by a four-spaced indentation of the margin as a block.
9. **References** The EBR 2022 editorial style is based on the **7th editio**n of the Publication Manual of the American Psychological Association (**APA**). For more information see APA Style used in EBR guidelines.
10. **Copyrights** will be established in the name of the **EBR publisher**, namely the Poznań University of Economics and Business Press.

More information and advice on the suitability and formats of manuscripts can be obtained from:

Economics and Business Review
al. Niepodległości 10
61-875 Poznań
Poland
e-mail: secretary@ebr.edu.pl
www.ebr.edu.pl

Subscription

Economics and Business Review (EBR) is published quarterly and is the successor to the Poznań University of Economics Review. The EBR is published by the Poznań University of Economics and Business Press.

Economics and Business Review is indexed and distributed in Scopus, Claritave Analytics, DOAJ, ERIH plus, ProQuest, EBSCO, CEJSH, BazEcon, Index Copernicus and De Gruyter Open (Sciendo).

Subscription rates for the print version of the EBR: institutions: 1 year – €50.00; individuals: 1 year – €25.00. Single copies: institutions – €15.00; individuals – €10.00. The EBR on-line edition is free of charge.