DOI: 10.55643/fcaptp.1.54.2024.4280

# ANALYSIS OF COINTEGRATION AND CAUSALITY BETWEEN INDICATORS OF ECONOMIC GROWTH AND ENERGY EFFICIENCY OF EUROPEAN COUNTRIES

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Received: 09/12/2023
Accepted: 06/02/2024
Published: 29/02/2024



## ABSTRACT

In modern conditions, when European countries have set themselves an extremely ambitious goal of reducing greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels, it is important to analyze the cause-and-effect relationships between key indicators of energy efficiency of national economies and economic growth, the nature of their influence on each other. The article analyzes cointegration and causal relationships between panel data that determine the economic development and energy efficiency of 38 European countries for the period from 1995 to 2021. Stationary time series were analyzed for causality using the Dumitrescu Hurlin test, which, compared to the classical Granger test, more accurately takes into account the structure of panel data, namely cross-sectional relationships. The annual GDP growth rate has driven the intensity of CO2 emissions. For pairs of time series with the first level of integration, in the case of cointegration between them, a Vector Error Correction Model (VECM) was used to determine the type of long-term behaviour of the variables with their short-term feedback. Long-term causality was found from GDP per capita to the level of primary energy intensity of European countries. Exports of goods and services have proven to be a long-term cause of domestic consumption of natural gas and solid fossil fuels. Bidirectional long-term causality was found only between primary energy consumption and exports. It should be noted that in all short-term and long-term cause-and-effect relationships obtained in the article, economic development indicators are the cause for energy efficiency indicators. This signals that the level of energy efficiency of the European economy is determined to a large extent by the economic development of Europe in previous periods. ARDL models can be used to analyze causal relationships between time series that have different levels of integration.

**Keywords:** Causality, VECM, Granger causality, long-run equilibrium, energy intensity of the economy, economic development, co-integration, European countries

**JEL Classification:** F43, K32, C01, C32

## INTRODUCTION

The European Climate Law legally establishes the objective outlined in the European Green Deal, which aims to make the European economy carbon-neutral by 2050. Furthermore, this law mandates a significant reduction in greenhouse gas emissions, targeting a decrease of at least 55% by 2030 compared to 1990 levels. Achieving such ambitious targets necessitates the creation of effective programs aimed at enhancing the energy efficiency of European economies. In today's context, where discussions often revolve around how heightened energy efficiency requirements for national economies impact economic growth, it becomes crucial to analyze the cause-and-effect relationships between key indicators that characterize these processes and to discern the nature of their mutual influence.

In the last forty years, Europe's overall energy consumption has remained relatively stable, hovering at approximately 1,300 million tons per year. Nevertheless, the scenario undergoes a substantial transformation when examining the energy required to generate one unit of gross domestic product (GDP). This indicator has witnessed a remarkable decline of 43.3 per cent between 1980 and 2021 (Cevik et al.,2023). This is the result of the introduction of more energy-efficient production technologies and increased energy efficiency of consumer goods and services. The concern for ensuring an adequate level of energy supply to European countries and efforts to transition to a more efficient, safe and diversified energy system has created a very favourable context for the development of energy-efficient technologies. Although the situation looks favourable, there are still significant differences in the level of energy efficiency of different countries and Europe is no exception. Even countries with very high energy efficiency indicators may not fully realize their potential in this area. All this determines the need for a more detailed study of the problem of the relationship between economic development and energy efficiency of the national economies of European countries, determining cause-and-effect relationships between them, which would allow for the formation of long- and short-term programs for reforming the energy supply systems of European countries.

Many scientific papers have been devoted to answering this question. The findings of Almozaini et al. (2019) indicate the presence of both unidirectional and bidirectional Granger causality between the variables representing economic growth and energy consumption. Kirikkaleli et al. (2018) confirmed the inverse relationship between electricity consumption and Internet demand, as well as the one-way causality between economic growth and electricity consumption in OECD countries.

Shahateet et al. (2014) determined the relationship between economic growth and energy consumption in Jordan for the period 1970-2011 based on neoclassical productivity theory, which considers capital, labour and energy as separate factors of production. The analysis confirmed the existence of one-way Granger causality from GDP to energy consumption. According to the authors, this unidirectional causality provides empirical evidence that Jordan is a less energy-dependent economy and is consistent with government policies aimed at increasing energy prices and reducing public demand for energy consumption mainly to reduce government budget deficits and external debt. However, the Granger test will not be enough to draw such conclusions.

Bayar et al. (2019) analyze the impact of energy efficiency and renewable energy on economic growth in emerging economies over the period 1992–2014 using a cointegration test and a Dumitrescu and Hurlin causality test. The existence test of cointegration shows that energy efficiency has a positive impact on economic growth in the long run, while renewable energy has no significant impact on economic growth in the long run. In addition, the causality analysis revealed a one-way causal relationship from both energy efficiency and renewable energy use to economic growth in the short term. Andrei et al. (2017) demonstrated that the existing trends in the growth of energy demand in the European Union are clearly expressed, which dictates the need to improve the concepts of energy supply to national economies and optimize energy efficiency. The factors that disturb the equilibrium of the system in the long term have been shown to be primary renewable energy production and, to a lesser extent, renewable energy. Ifa et al. (2022) confirmed the presence of cointegration between economic growth, renewable and non-renewable energy, public spending in eight Southern Mediterranean countries, which indicates the existence of a long-term relationship. Short-term causal relationships were found in all analyzed countries.

Taking into account, in addition, that the improvement of energy efficiency and the use of renewable energy sources have been identified as key measures to solve the problem of environmental and climate change, the problem of determining the nature of the cause-and-effect relationships between energy efficiency and economic development has significant theoretical and applied importance today.

## LITERATURE REVIEW

Many scientific publications are devoted to the problems of studying the nature of the relationship between indicators of economic development and energy efficiency. In scientific literature, economic development is typically linked to a rise in greenhouse gas emissions. Within this context, a common question arises: is it feasible to attain sustainable economic development while simultaneously enhancing the energy efficiency of the economy, which, in turn, is linked to a decrease in greenhouse gas emissions?

Bao-Linh Tran et al. (2022) and Hussain et al. (2021) examined the causal relationship between GDP and energy consumption in different countries by means of Granger causality tests on the base of the Vector Error Correction Model framework. The primary conclusion emphasized the presence of a GDP threshold, at which the influence of GDP on energy consumption and the direction of causality regarding energy consumption growth are contingent on the initial gross domestic product level. In Pakistan, for instance, economic growth is associated with increased energy consumption. The same result was obtained by Mohd et al. (2020), indicating that over an extended period, the utilization of renewable energy sources has the potential to decrease carbon dioxide ($CO_2$) emissions. Nevertheless, prolonged economic and population growth might lead to increased CO2 emissions in the long run. In the short term, the findings imply that increased overall economic growth may lead to higher CO2 emissions. Conversely, higher population growth and greater utilization of renewable energy could play a role in reducing CO2 emissions in the short term.

Alam et al. (2020) assert that economic growth, trade openness, and technological progress have a substantial influence on the long-term utilization of renewable energy in OECD countries. While the long-term relationship among these variables seems to be consistent across OECD countries, their short-term dynamics exhibit variation, that can be attributed to differing levels of economic openness and technological developments among OECD nations.

The results obtained by Kirikkaleli et al. (2018) indicate a positive relationship between electricity, Internet demand and economic growth in OECD countries in the long run. The DH causality results verified the causality between electricity consumption and Internet demand and the one-way causality from economic growth to electricity consumption.

Abbas et al. (2020) explore the relationship between energy consumption in agriculture and CO2 emissions in China. Based on China's annual data the study used the ARDL model. The analysis showed that there is a two-way causal relationship between agricultural production and CO2 emissions. The results indicate that the Chinese government should change its agricultural development strategy and focus more on energy-efficient technologies, which will improve the energy intensity of the economy.

Rajaguru et al. (2021) found compelling evidence of both long-term and short-term causal relationships between economic growth and energy consumption, specifically in terms of energy intensity. This causal link was confirmed in most of the countries included in their sample. The study also highlights the growing significance of energy efficiency policies on a global scale. The research outcomes indicate that, for the majority of these countries, there is a moderate decrease or increase in energy consumption as income levels rise. Consequently, reducing energy consumption plays a crucial role in diminishing the demand for available energy resources, including fossil fuels.

Gholizadeh et al. (2020) showed that GDP has a direct relationship with all variables, namely, capital, labour and energy consumption, and an increase in these independent variables entails an increase in each of the dependent variables. Kyshakevych et al. (2023) on the basis of constructed panel regression models for 38 European countries, generally confirmed the modern-day thesis that economic development can be achieved while reducing greenhouse gas emissions.

Küçüksakarya (2021) examines the relationship between financial development and economic growth of OECD countries. The outcomes of the causality test demonstrated that, even among countries with a high level of development within the examined panel, financial development remains a fundamental factor for their economic growth. The study's findings offer compelling evidence of the connection between economic growth and financial development, considering the diverse range of countries in the sample, which had varying degrees of financial development and GDP per capita growth.

## AIMS AND OBJECTIVES

In this research, we aim to analyze the existence of long- and short-run relationships and causality between indicators of economic growth and energy efficiency of European countries.

Objectives of the article are the following:

- verification of the existence of causality between pairs of stationary indicators of economic development and energy efficiency of European countries;
- checking the presence of cointegration between indicators of economic development and energy efficiency;
- construction of VECM models to check the existence of a long- and short-run relationship between co-integrated indicators of economic development and energy efficiency.

## METHODS

To establish the nature of the relationship between energy efficiency indicators and economic growth, we will use the Granger causality test. This test of causality between time series was developed in 1969 (Granger, 1969). The Granger test implements the idea that the time series will cause changes in the time series if changes in values precede changes in the values of the time series, and in addition, makes a significant contribution to forecasting values. The Granger causality test is performed in relation to stationary time series. In the case of panel data, the Granger test will involve estimating the parameters of the following pair of regressions:


DOI: 10.55643/fcaptp.1.54.2024.4280

$$x_{lt} = \sum_{i=1}^{n} a_l^i x_{lt-i} + \sum_{j=1}^{n} b_l^j y_{lt-j} + u_{lt}, \quad (1)$$

$$y_{lt} = \sum_{i=1}^{n} c_l^i y_{lt-i} + \sum_{j=1}^{n} d_l^j x_{lt-j} + u_{lt}, \quad (2)$$

*where* $x_{lt}$ *and* $y_{lt}$ *- observations of two stationary variables for country l in time period t.*

The null hypothesis will be that the coefficients at the lags of the second variable will all be equal to zero at the same time. Mutual independence is also possible when both groups of coefficients are statistically insignificant.

EViews offers two approaches to causality testing for panel data. The first approach treats the panel data as one large stacked data set and then performs a Granger causality test in the standard way, except that data from one cross-section are not included in the lagged values of data from subsequent cross-sections. This method assumes that all coefficients are the same for all cross sections, that is:

$$a_l^i = a_m^i \quad (3)$$

$$b_l^i = b_m^i \quad (4)$$

The second approach, developed by Dumitrescu-Hurlin (2012), is based on a completely opposite assumption, allowing all coefficients to be different in different cross-sections: and . The lag n is assumed to be the same for all cross-sections and the panel should be balanced (Lopez et al., 2017). This test is implemented by conventional estimation of standard regression parameters and Granger causality analysis for each cross-section (country) separately.

The prerequisite for applying the Granger test is the stationarity of time series. Statistical data describing the energy efficiency and macroeconomic indicators of 38 European countries for the period from 1995 to 2021 were used to construct panel regression models (see Table 1). For this, statistical resources such as Enerdata, World Bank, World Energy & Climate Statistics – Yearbook 2023, Eurostat were used.

**Table 1. Variables used to build VECM models.**

| **Energy efficiency indicators** | |
|---|---|
| EI | Energy intensity (Megajoules per 2017 purchasing power parity gross domestic product in USD). |
| EL_PC | Per capita production of gross electricity. (Kilotonnes of oil equivalent) |
| ELS | Final consumption of Electric power per capita (GWh) |
| CO_GDP | Intensity carbon dioxide emissions (Kilograms per Purchasing Power Parity USD of GDP) |
| C_ENER | Primary energy consumption (Mtoe) |
| C_ENER_PC | Primary energy consumption per capita (Mtoe) |
| C_ENER_ALL_PC | Total available energy per capita (kgoe) |
| GAS_PC | Domestic gas consumption (TJ/capita) |
| S_PC | Solid fossil energy sources domestic consumption (kT/capita) |
| **Indicators of economic development** | |
| GDP_PC | GDP per capita (USD) |
| EMP | Overall unemployment rate |
| EXP_GDP | Exports (percentage of gross domestic product) |
| INV_GDP | FDI (percentage of gross domestic product) |
| GDP_GR | GDP growth (annual %) |
| GDP_GR_PC | Yearly growth rate in GDP per capita percentage |

We determined causality for cointegrated variables based on testing the overall significance of lagged variables using the F-test or Wald test for the VECM model (Winarno et al., 2021):

$$\Delta y_{it} = \sum_{k=1}^{p-1} \lambda_{ik}^{*} \Delta y_{i,t-k} + \sum_{k=0}^{q-1} \delta_{ik}' \Delta x_{i,t-k} + \phi\left(y_{i,t-1} + \beta_i' X_{it-1}\right) + w_i + \varepsilon_{it} \quad (5)$$

DOI: 10.55643/fcaptp.1.54.2024.4280

*where* $\varphi$ *- the coefficient of the cointegrating equation;* $y_{i,t-1} + \beta_i^{'} X_{it-1}$ *- cointegrating equation or error correction term (ECT).*

Causality in the short term is the statistical significance of the first difference of the variable in the vector error correction equation. Using the Wald test, we can determine Granger causality. In the long run, it is about the significance of error correction in this equation. Granger causality, therefore, applies more to the short run. If the variables are stationary I(0), this means that there is no long-run causality, but short-run causality may exist.

Taking this into account, we implemented an algorithm for the analysis of cause-and-effect relationships between indicators of energy efficiency and economic growth in the form of panel data based on the algorithm presented in Figure 1.

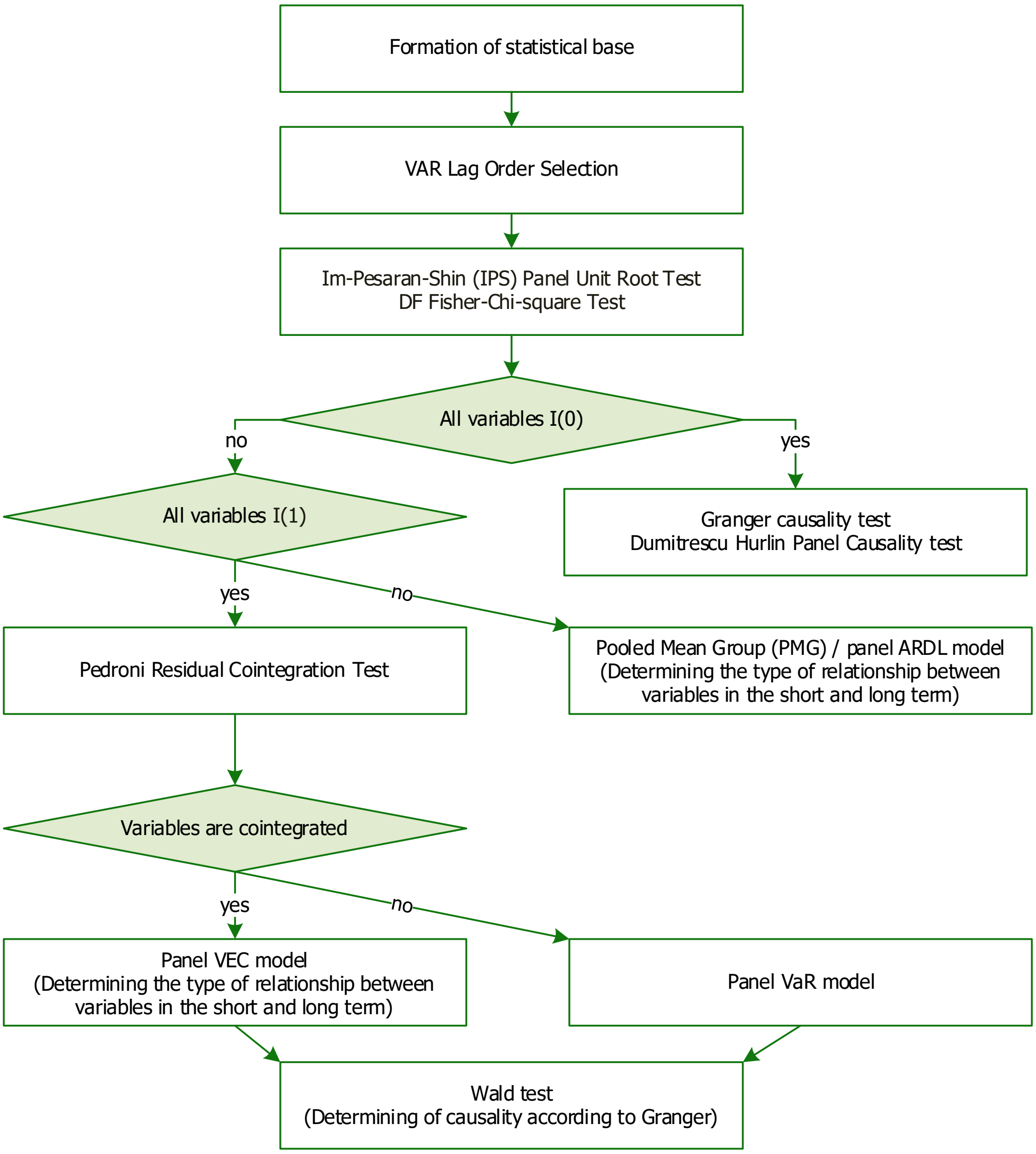


**Figure 1. An algorithm for the analysis of causal relationships in the case of panel data.**

## RESULTS

A time series is stationary if it does not exhibit any long-term trends or distinct seasonality. Time series stationarity was tested in Eviews using the unit root test, which is a cornerstone of modern time series analysis. Table 2 presents the results of the ADF - Fisher Chi-square test for the presence of unit roots.


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**Table 2. Results of the ADF test.** *(Source: compiled by the authors using Eviews on the basis of data from Eurostat, Enerdata and World Bank)*

| | The level of the series | | The first difference | | |
|---|---|---|---|---|---|
| | Statistic | Prob. | Statistic | Prob. | |
| **Energy efficiency indicators** | | | | | |
| CO_GDP | 126.202 | 0.000 | - | - | I(0) |
| EI | 36.204 | 0.999 | 502.36 | 0.000 | I(1) |
| C_ENER | 85.4466 | 0.170 | 635.337 | 0.000 | I(1) |
| S_PC | 94.4246 | 0.039 | 442.241 | 0.000 | I(1) |
| GAS_PC | 81.0088 | 0.074 | 453.789 | 0.000 | I(1) |
| C_ENER_ALL_PC | 59.6352 | 0.887 | 537.660 | 0.000 | I(1) |
| C_ENER_PC | 67.1084 | 0.701 | 526.085 | 0.000 | I(1) |
| EL_PC | 104.704 | 0.0109 | - | - | I(0) |
| ELS | 75.1151 | 0.4420 | 258.456 | 0.000 | I(1) |
| **Indicators of economic development** | | | | | |
| GDP_PC | 68.3379 | 0.663 | 351.026 | 0.000 | I(1) |
| GDP_GR_PC | 427.040 | 0.000 | - | - | I(0) |
| GDP_GR | 420.919 | 0.000 | - | - | I(0) |
| INV_GDP | 287.177 | 0.000 | - | - | I(0) |
| EMP | 129.176 | 0.000 | - | - | I(0) |
| EXP_GDP | 56.2670 | 0.937 | 431.589 | 0.000 | I(1) |

As a result, only two indicators of energy efficiency of European countries, namely the intensity of carbon dioxide emissions CO_GDP and gross electricity production per capita EL_PC turned out to be stationary time series I(0). Among the indicators of economic development, four-time series do not have unit roots: GDP_GR_PC, GDP_GR, INV_GDP, EMP. It is to these variables that the Granger causality test can be directly applied. For each pair of stationary variables, the optimal lag value for the corresponding VAR model was determined based on the Akaike information criterion (AIS).

In the following, we will use both causality tests implemented in Eviews: with common coefficients and the Dumitrescu Hurlin test. It should be noted that the latter test is more often used for the analysis of panel data, since it more correctly takes into account the peculiarities of panel data, namely, cross-sectional relationships (Küçüksakarya, 2021). Table 3 presents the results of Granger causality tests for all pairs of stationary variables representing energy efficiency and economic development of European countries.

**Table 3. Granger causality and Dumitrescu Hurlin Panel Causality tests between stationary time series.** *(Source: compiled by the authors using Eviews on the basis of data from Eurostat, Enerdata and World Bank)*

| Pairwise Granger Causality Tests | | | Pairwise Dumitrescu Hurlin Panel Causality Tests | | |
|---|---|---|---|---|---|
| Null Hypothesis: | F-Statistic | Prob. ability | | W-Stat. | Probability |
| GDP_GR_PC does not Cause CO_GDP | 15.69 | 2.E-14 | CO_GDP does not cause GDP_GR_PC | 1.97 | 0.441 |
| CO_GDP does not Cause GDP_GR_PC | 3.77 | 0.002 | GDP_GR_PC does not cause CO_GDP | 5.46 | 8.E-12 |
| CO_GDP does not Cause EMP | 3.19 | 0.007 | CO_GDP does not cause EMP | 2.54 | 0.641 |
| EMP does not Cause CO_GDP | 12.54 | 1.E-11 | EMP does not cause CO_GDP | 5.36 | 3.E-11 |
| CO_GDP does not Cause INV_GDP | 0.14 | 0.997 | CO_GDP does not cause INV_GDP | 2.82 | 0.296 |
| INV_GDP does not Cause CO_GDP | 1.50 | 0.153 | INV_GDP does not cause CO_GDP | 2.97 | 0.175 |
| GDP_GR does not Cause CO_GDP | 31.61 | 7.E-14 | GDP_GR does not cause CO_GDP | 5.49 | 5.E-12 |
| CO_GDP does not Cause GDP_GR | 6.23 | 0.002 | CO_GDP does not cause GDP_GR | 1.96 | 0.429 |
| GDP_GR does not Cause EL_PC | 2.99 | 0.050 | GDP_GR does not cause EL_PC | 1.77 | 0.357 |
| EL_PC does not Cause GDP_GR | 1.64 | 0.194 | EL_PC does not cause GDP_GR | 1.96 | 0.592 |
| GDP_GR_PC does not Cause EL_PC | 2.81 | 0.060 | GDP_GR_ PC does not cause EL_PC | 1.61 | 0.673 |
| EL_PC does not Cause GDP_GR_PC | 4.27 | 0.014 | EL_PC does not cause GDP_GR_PC | 2.57 | 0.478 |
| EMP does not Cause EL_PC | 0.07 | 0.927 | EMP does not cause EL_PC | 2.67 | 0.292 |
| EL_PC does not Cause EMP | 0.67 | 0.510 | EL_PC does not cause EMP | 2.54 | 0.238 |
| INV_GDP does not Cause EL_PC | 1.07 | 0.340 | INV_GDP does not cause EL_PC | 1.67 | 0.557 |
| EL_PC does not Cause INV_GDP | 2.12 | 0.120 | EL_PC does not cause INV_GDP | 1.57 | 0.669 |

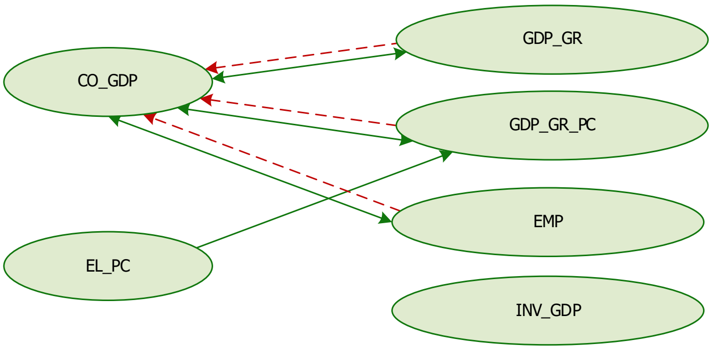


**Figure 2. Directions of causalities between stationary energy efficiency and economic development indicators according to common coefficients test (black colour) and DH test (red colour).**

Based on the Dumitrescu Hurlin Panel Causality test, it can be concluded that the forecasting of carbon dioxide emissions is significantly influenced by the economic growth indicators of European countries. Moreover, this dependence is one-sided. GDP growth, GDP per capita growth and Unemployment rate cause changes in the CO_GDP time series, precede changes in this time series and, in addition, make a significant contribution to the forecast of its values. The Granger causality test does not allow direct conclusions to be drawn about how one variable affects another in terms of "increase" or "decrease". It only indicates the presence of a cause-and-effect relationship in a time sequence. However, to understand exactly how variable x affects variable y (whether it's up, down, or something else), we need to examine the relationship in more detail. To do this, you can use regression analysis and other methods.

Time series that deviate from their mean value over time are called non-stationary. Thus, disregarding the stationarity of variables in most cases leads to spurious regression. To overcome this problem of non-stationarity, the econometric analysis of time series is increasingly shifting towards the problem of cointegration. The reason is that cointegration is a powerful way to detect stable equilibria between variables. Taking cointegration into account today has become a major requirement for any economic model that uses non-stationary time series (Emeka et al., 2016).

Most time series that describe economic processes are non-stationary, and MLS-based regression involving non-stationary time series can lead to erroneous results. One of the solutions to this problem is to conduct a cointegration test. The purpose of cointegration is to find out whether there is a linear combination of non-stationary variables that results in a stationary time series. If there is cointegration between two variables that have similar non-stationary properties, then the regression can be obtained without false results. In practice, the Vector Error Correction (VECM) model is used to determine the type of long-term behaviour of variables with their short-term responses.

Stationarity is an important property for time series modelling. The problem is that in practice quite a few processes are actually stationary in their original form. Cointegration forms a stationary series from a linear combination of two or more non-stationary series. Regarding cointegration and causation, it should be noted that these are two different concepts. The existence of cointegration between two-time series does not automatically imply the presence of Granger causality between them (Xiangyun et al., 2018). If two-time series are cointegrated, this may be an indicator of a possible long-term relationship between them. Confirmation of the presence of cointegration between time series means that the relationship between the relevant variables is not spurious. In other words, there is a theoretical connection between them and the time series will be in equilibrium in the long run.

It should be noted that cointegration makes it possible to assess the presence of a long-term relationship between variables, while the Granger causality test is short-term. The Granger causality test determines the level of correlation between the past value of one variable and the current value of a second variable. In the long run, it is about the significance of the error correction in the VECM vector error correction model. Causality in the short term is the statistical significance of the first difference of the variable in the vector error correction equation. Using the Wald test, you can determine Granger causality. Thus, Granger causality applies more to the short run. If the variables are stationary I(0), this means that there is no long-run causality, but short-run causality may exist. The fact is that if all the series are stationary I(0) (have no trend), then it makes no sense to talk about cointegration in this case.

To identify short-term causal relationships, the presence of cointegration between the analyzed pairs of I(1) variables was checked and the presence of Granger causality was analyzed for non-cointegrated pairs. A check for the presence of cointegration was made based on the Pedroni Residual Cointegration Test in Eviews (Table 4).


DOI: 10.55643/fcaptp.1.54.2024.4280

**Table 4. Cointegration between non-stationary indicators of economic development and energy efficiency. Note: *K- cointegration exists, N- no cointegration.**

| | GDP_PC | EXP_GDP |
|---|---|---|
| EI | K | K |
| C_ENER | N | K |
| S_PC | N | K |
| GAS_PC | N | K |
| C_ENER_ALL_PC | N | N |
| C_ENER_PC | N | K |
| ELS | N | N |

A cause-and-effect relationship between non-cointegrated pairs of non-stationary time series is found at least only for the first differences of these series. Since causal relationships can only be determined for stationary time series, all non-stationary variables were transformed into stationary ones using first differences, which significantly changes the interpretation of the results of the Granger test. The results of the implementation of the Granger test for the first differences of non-cointegrated pairs of time series with the first level of integration are presented in Table 6 and Figure 3.

**Table 5. Granger causality and Dumitrescu Hurlin Panel Causality tests between non-cointegrated time series.** Note: D added before the variable means the first difference. *(Source: compiled by the authors using Eviews on the basis of data from Eurostat, Enerdata and World Bank)*

| Pairwise Granger Causality Tests | | | Pairwise Dumitrescu Hurlin Panel Causality Tests | | |
|---|---|---|---|---|---|
| **Null Hypothesis:** | **F-Stat.** | **Prob.** | **Null Hypothesis:** | **W-Stat.** | **Prob.** |
| DEXP_GDP does not Cause DC_ENER_ALL_PC | 12 .97 | 3.E-06 | DEXP_GDP does not cause DC_ENER_ALL_PC | 2.97 | 0.132 |
| DC_ENER_ALL_PC does not Cause DEXP_GDP | 0 .25 | 0.776 | DC_ENER_ALL_PC does not cause DEXP_GDP | 2.74 | 0.386 |
| DGDP_PC does not Cause DS_PC | 1 .44 | 0.237 | DS does not cause DEXP_GDP | 2.87 | 0.192 |
| DS_PC does not Cause DGDP_PC | 2 .51 | 0.081 | DEXP_GDP does not cause DS | 1.56 | 0.889 |
| DGDP_PC does not Cause DGAS_PC | 17 .23 | 5.E-08 | DGAS_PC does not cause DGDP_PC | 1.64 | 0.819 |
| DGAS_PC does not Cause DGDP_PC | 7 .62 | 0.000 | DGDP_PC does not cause DGAS_PC | 5.16 | 4.E-11 |
| DC_ENER does not Cause DGDP_PC | 1 .48 | 0.227 | DC_ENER does not cause DGDP_PC | 1.87 | 0.345 |
| DGDP_PC does not Cause DC_ENER | 1 .58 | 0.204 | DGDP_PC does not cause DC_ENER | 1.94 | 0.582 |
| DGDP_PC does not Cause DC_ENER_ALL_PC | 0 .01 | 0.982 | DC_ENER_ALL_PC does not cause DGDP_PC | 1.64 | 0.683 |
| DC_ENER_ALL_PC does not Cause DGDP_PC | 6 .13 | 0.002 | DGDP_PC does not cause DC_ENER_ALL_PC | 6.51 | 1.E-11 |
| DC_ENER_PC does not Cause DGDP_PC | 8 .63 | 0.000 | DGDP_PC does not cause DC_ENER_PC | 4.23 | 0,020 |
| DGDP_PC does not Cause DC_ENER_PC | 0 .16 | 0.845 | DC_ENER_PC does not cause DGDP_PC | 2.47 | 0.455 |
| DGDP_PC does not Cause DELS | 0.17 | 0.835 | DGDP_PC does not cause DELS | 2.77 | 0.395 |
| DELS does not Cause DGDP_PC | 6.39 | 0.001 | DELS does not cause DGDP_PC | 2.44 | 0.256 |
| DEXP_GDP does not Cause DELS | 5.43 | 0.004 | DEXP_GDP does not cause DELS | 1.87 | 0.657 |
| DELS does not Cause DEXP_GDP | 2.18 | 0.113 | DELS does not cause DEXP_GDP | 1.77 | 0.699 |

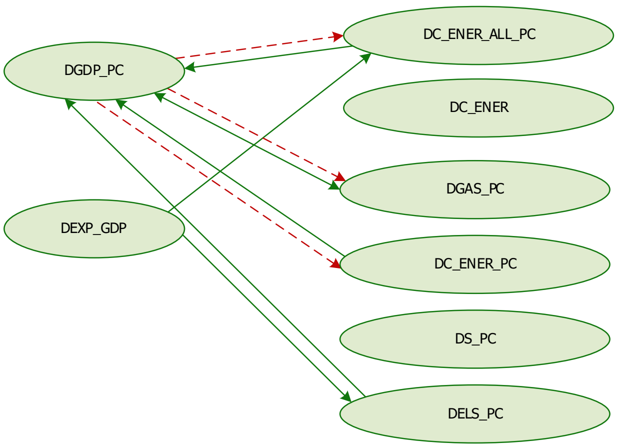


**Figure 3. Directions of causalities between non-cointegrated indicators of energy efficiency and economic development according to the common coefficients test (black colour) and the DH test (red colour).**

The results obtained from the DH test signal that economic development indicators cause energy efficiency indicators in all pairs in which a cause-and-effect relationship occurs. Interestingly, this trend also occurs for pairs of stationary time series (Figure 2). This shows that the level of energy efficiency of European economies depends significantly on the economic situation in these countries in previous years. However, when interpreting the results of the Granger test for time series in first differences, it is important to understand that in this case the relationship between changes in these series, but not between their absolute levels, is examined.

Thus, from the fact that DGDP_PC is the cause of DGAS_PC in the DH test, it can be concluded that changes in the growth of GDP per capita of European countries precede and are associated with subsequent changes in gas consumption. This suggests that when there are fluctuations in the economy (as indicated by changes in GDP growth), these changes have predictive power for fluctuations in gas consumption.

According to Granger, causality can be divided into long-term and short-term (Granger, 1969). For this, error correction models or VECMs are used, depending on the approach to determining causality. Long-term causality is determined by the error correction term, and if it is significant, it indicates the presence of a long-term causal relationship from the explanatory variable to the dependent variable.

In the following, we will assume that if the adjustment coefficient for the variable y is negative and statistically significant, this means that when the long-run equilibrium is disturbed (for example, due to changes in x), y will adapt to restore this equilibrium. In this context, the variable x can be considered to be the "cause" and the variable y to be the "effect" in the causal relationship. That is, when x changes, it causes changes in y to bring the system back to equilibrium. To determine the nature of causal relationships, we will build VECM models for all pairs of cointegrated time series. For EI and GDP_PC VECM models are presented in Table 6.

**Table 6**. **VECM model for time series EI and GDP_PC with Wald tests.** Note: Standard errors in ( ) & t-statistics in [ ], D(·) – first difference. *(Source: compiled by the authors using Eviews on the basis of data from Eurostat, Enerdata and World Bank)*

| | | | | | | |
|---|---|---|---|---|---|---|
| **Cointegrating equation** | EI(-1) | 1.000000 | | GDP_PC(-1) | 1.000000 | |
| | GDP_PC(-1) | -0.002491 | (7.2E-04)<br>[-3.46013] | EI(-1) | -4020.867 | (3305.81)<br>[-1.21630] |
| | C | 2.676117 | | C | -10760.31 | |
| **Error Correction:** | | **D(EI)** | **Probability** | | **D(GDP_PC)** | **Probability** |
| | CointEq1 | -0.038856 | 0.0100 | CointEq1 | 0.014175 | 0.0071 |
| | D(EI(-1)) | 0.117485 | 0.0015 | D(GDP_PC(-1)) | 0.190358 | 0.0000 |
| | D(EI(-2)) | 0.099618 | 0.0062 | D(GDP_PC(-2)) | -0.269492 | 0.0000 |
| | D(GDP_PC(-1)) | -5.68E-06 | 0.0440 | D(EI(-1)) | -458.5095 | 0.3806 |
| | D(GDP_PC(-2)) | 6.89E-06 | 0.0170 | D(EI(-2)) | -1611.888 | 0.0017 |
| | C | -0.069726 | 0.0000 | C | 965.1155 | 0.0000 |
| **Wald tests** | **Null Hypothesis: C(4)=C(5)=0** | | | **Null Hypothesis: C(4)=C(5)=0** | | |
| | **Test Statistic** | **Value** | **Probability** | **Test Statistic** | **Value** | **Probability** |
| | Chi-square | 8.400823 | 0.0150 | Chi-square | 11.44133 | 0.0033 |

The adjustment coefficient in VECM reflects the rate at which the system returns to equilibrium after being deflected by short-term shocks. This means that if energy intensity deviates from its long-term equilibrium level due to changes in GDP per capita, approximately 3.89% of this deviation will be corrected in the next period. The minus sign indicates that the correction occurs in the direction of reducing the deviation and attempts to return the system to equilibrium. That is, if energy intensity temporarily deviates from the level, it should have based on its long-term interaction with GDP per capita, then it will "adjust" back to that level at a rate of about 3.89% per period.

If the correction coefficient in the VECM model has a positive value, it indicates how the system reacts to deviations from the long-term equilibrium (Rahman & Vu, 2021). When the dependent variable GDP_PC deviates from its long-term equilibrium interaction with other variables (in this case with energy intensity EI), it will adjust in the direction of increasing this deviation at a rate of approximately 1.41% per period. In such a case, the existence of long-run causality from EI to GDP_PC cannot be asserted. The Wald test confirmed the statistical significance of the coefficients for lagged variables, and therefore, there is a short-term causal relationship in both directions between energy intensity EI and GDP per capita GDP_PC. Thus, between energy intensity and the size of GDP per capita of European countries, there is a one-way long-term causal relationship between GDP_PC to energy intensity EI and a two-way short-term one. The negative value of the

 DOI: 10.55643/fcaptp.1.54.2024.4280

adjustment coefficient and its statistical significance mean the existence of convergence from the short-term dynamics to the long-term equilibrium state in the long run.

In the case of a cointegrated pair of time series EI and EXP_GDP, the optimal lag for VAR models is 3. From Table 7, which presents the VECM models for this pair of variables, there is no reason to assert the existence of a long-term relationship between them. The fact is that in the case where EI is the dependent variable, the adjustment coefficient is not statistically significant, and in the case of the model with EXP_GDP as the dependent variable, it has a positive value. However, the Wald tests confirmed the statistical significance of the coefficients for lagged variables, and therefore, there is a two-way short-term causal relationship between the energy intensity of EI and the share of exports in GDP per capita.

**Table 7. VECM model for time series EI and EXP_GDP with Wald tests.** Note: Standard errors in ( ) & t-statistics in [ ], D(·) – first difference. *(Source: compiled by the authors using Eviews on the basis of data from Eurostat, Enerdata and World Bank)*

| | | | | | | |
|---|---|---|---|---|---|---|
| **Cointegrating equation** | EI(-1) | 1.000000 | | EXP_GDP(-1) | 1.000000 | |
| | EXP_GDP (-1) | 0.163182 | (0.04460) [ 3.65897] | EI(-1) | 6.128142 | (4.33188) [ 1.41466] |
| | C | -13.15421 | | C | -80.61088 | |
| **Error Correction:** | | **D(EI)** | **Probability** | | **D(EXP_GDP)** | **Probability** |
| | CointEq1 | -0.001961 | 0.3076 | CointEq1 | 0.017136 | 0.0005 |
| | D(EI(-1)) | 0.126534 | 0.0011 | D(EXP_GDP(-1)) | -0.015404 | 0.7142 |
| | D(EI(-2)) | 0.111368 | 0.0036 | D(EXP_GDP(-2)) | -0.134781 | 0.0028 |
| | D(EI(-3)) | 0.032923 | 0.3838 | D(EXP_GDP(-3)) | -0.116381 | 0.0075 |
| | D(EXP_GDP(-1)) | -0.009269 | 0.0006 | D(EI(-1)) | 1.785096 | 0.0033 |
| | D(EXP_GDP(-2)) | 0.000447 | 0.8763 | D(EI(-2)) | 1.352703 | 0.0241 |
| | D(EXP_GDP(-3)) | -0.002173 | 0.4332 | D(EI(-3)) | -0.130986 | 0.8249 |
| | C | -0.058727 | 0.0000 | C | 1.727390 | 0.0000 |
| **Wald tests** | **Null Hypothesis: C(5)=C(6)=C(7)=0** | | | **Null Hypothesis: C(5)=C(6)=C(7)=0** | | |
| | **Test Statistic** | **Value** | **Probability** | **Test Statistic** | **Value** | **Probability** |
| | Chi-square | 12.16236 | 0.0068 | Chi-square | 15.94295 | 0.0012 |

There is a two-way long-term causal relationship between primary energy consumption C_ENER and the share of exports of goods and services in GDP EXP_GDP (Table 8). This means that if primary energy consumption deviates from its long-term equilibrium level due to changes in per capita exports, approximately 0.9% of this deviation will be corrected in the subsequent period. In other words, if primary energy consumption temporarily deviates from the equilibrium level with EXP_GDP, then it will return back to this level at a rate of about 0.9% per year. The deviation of EXP_GDP from the equilibrium state will be compensated at a rate of 0.08%. Short-run causality between these variables exists in only one direction: from EXP_GDP to C_ENER.

**Table 8. VECM model for time series C_ENER and EXP_GDP with Wald tests.** (Source: compiled by the authors using Eviews on the basis of data from Eurostat, Enerdata and World Bank)

| | | | | | | |
|---|---|---|---|---|---|---|
| **Cointegrating equation** | C_ENER(-1) | 1.000000 | | EXP_GDP(-1) | 1.000000 | |
| | EXP_GDP(-1) | 0.226602 | (0.41885) [ 0.54100] | C_ENER(-1) | 4.413020 | (0.82695) [5.33648] |
| | C | -62.40187 | | C | -275.3807 | |
| **Error Correction:** | **:** | **D(C_ENER)** | **Probability** | | **D(EXP_GDP)** | **Probability** |
| | CointEq1 | -0.009063 | 0.0000 | CointEq1 | -0.000868 | 0.0473 |
| | D(C_ENER(-1)) | -0.257071 | 0.0000 | D(EXP_GDP(-1)) | 0.147468 | 0.0365 |
| | D(C_ENER(-2)) | 0.231812 | 0.0000 | D(EXP_GDP(-2)) | -0.140645 | 0.0022 |
| | D(EXP_GDP(-1)) | -0.078386 | 0.0212 | D(C_ENER(-1)) | -0.094140 | 0.0717 |
| | D(EXP_GDP(-2)) | -0.015832 | 0.6483 | D(C_ENER(-2)) | 0.005820 | 0.9552 |
| | C | -0.138038 | 0.2841 | C | 0.994000 | 0.0000 |
| **Wald tests** | **Null Hypothesis: C(4)=C(5)=0** | | | **Null Hypothesis: C(4)=C(5)=0** | | |
| | **Test Statistic** | **Value** | **Probability** | **Test Statistic** | **Value** | **Probability** |
| | Chi-square | 6.217171 | 0.0447 | Chi-square | 3.394232 | 0.1832 |

In the case of deviation of domestic consumption of solid fossil fuel S_PC from the equilibrium state with EXP_GDP, 1.5% of this deviation is compensated each period, indicating the existence of one-way long-term causality in which EXP_GDP is the cause. The Wald test confirmed the existence of a short-term one-way cause-and-effect relationship between these variables, in which EXP_GDP also acts as a cause (Table 9).

**Table 9. VECM model for time series EXP_GDP and S_PC with Wald tests.** Note: Standard errors in ( ) & t-statistics in [ ], D(·) – first difference. *(Source: compiled by the authors using Eviews on the base of data form ESMS Indicator Profile (ESMS-IP), Enerdata 2022; World Bank, World Energy & Climate Statistics – Yearbook, 2022)*

| | | | | | | |
|---|---|---|---|---|---|---|
| **Cointegrating equation** | EXP_GDP(-1) | 1.000000 | | S_PC(-1) | 1.000000 | |
| | S_PC(-1) | 33194.42 | (8086.74)<br>[ 4.10479] | EXP_GDP(-1) | 3.01E-05 | (8086.74)<br>[ 4.10479] |
| | C | -105.1094 | | C | -0.003166 | |
| **Error Correction:** | | **D(EXP_GDP)** | **Probability** | | **D(S_PC)** | **Probability** |
| | CointEq1 | 0.005732 | 0.0336 | CointEq1 | -0.015263 | 0.0013 |
| | D(EXP_GDP(-1)) | 0.064447 | 0.1592 | D(S_PC(-1)) | -0.265233 | 0.0000 |
| | D(EXP_GDP(-2)) | -0.125588 | 0.0044 | D(S_PC(-2)) | -0.101230 | 0.0109 |
| | D(S_PC(-1)) | -435.9262 | 0.5429 | D(EXP_GDP(-1)) | 4.12E-06 | 0.0632 |
| | D(S_PC(-2)) | -1060.919 | 0.1593 | D(EXP_GDP(-2)) | -6.06E-06 | 0.0094 |
| | C | 1.103177 | 0.0000 | C | -3.77E-05 | 0.0000 |
| **Wald tests** | **Null Hypothesis: C(4)=C(5)=0** | | | **Null Hypothesis: C(4)=C(5)=0** | | |
| | **Test Statistic** | **Value** | **Probability** | **Test Statistic** | **Value** | **Probability** |
| | Chi-square | 2.082404 | 0.3530 | Chi-square | 8.894446 | 0.0117 |

There is a one-way long- and short-term causal relationship between domestic natural gas consumption GAS_PC and export EXP_GDP, where EXP_GDP is the cause. The rate of adjustment of the imbalance in case of possible deviations from the long-term equilibrium will be 2.5% per year (Table 10).

**Table 10. VECM model for time series EXP_GDP and S_PC with Wald tests.** Note: Standard errors in ( ) & t-statistics in [ ], D(·) – first difference . (Source: compiled by the authors using Eviews on the basis of data from Eurostat, Enerdata and World Bank)

| | | | | | | |
|---|---|---|---|---|---|---|
| **Cointegrating equation** | GAS PC(-1) | 1.000000 | | EXP_GDP(-1) | 1.000000 | |
| | EXP_GDP(-1) | 6.81E-05 | (0.00013)<br>[ 0.53317] | GAS_PC(-1) | 14680.83 | (2536.47)<br>[ 5.78791] |
| | C | -0.032205 | | C | -472.7910 | |
| **Error Correction:** | | **D(GAS_PC)** | **Probability** | | **D(EXP_GDP)** | **Probability** |
| | CointEq1 | -0.025136 | 0.0000 | CointEq1 | 0.000784 | 0.0884 |
| | D(GAS_PC(-1)) | -0.069151 | 0.0761 | D(EXP_GDP(-1)) | 0.036878 | 0.3858 |
| | D(GAS_PC(-2)) | 0.119876 | 0.0004 | D(EXP_GDP(-2)) | -0.138630 | 0.0038 |
| | D(GAS_PC(-3)) | 0.049808 | 0.1238 | D(EXP_GDP(-3)) | -0.099051 | 0.0295 |
| | D(EXP_GDP(-1)) | -0.000204 | 0.0000 | D(GAS_PC(-1)) | -61.55517 | 0.2830 |
| | D(EXP_GDP(-2)) | 8.06E-05 | 0.0135 | D(GAS_PC(-2)) | 35.44951 | 0.4767 |
| | D(EXP_GDP(-3)) | -0.000115 | 0.0002 | D(GAS_PC(-3)) | -12.72514 | 0.7973 |
| | C | 2.96E-05 | 0.7999 | C | 1.383629 | 0.0000 |
| **Wald tests** | **Null Hypothesis: C(5)=C(6)=C(7)=0** | | | **Null Hypothesis: C(5)=C(6)=C(7)=0** | | |
| | **Test Statistic** | **Value** | **Probability** | **Test Statistic** | **Value** | **Probability** |
| | Chi-square | 55.88454 | 0.0000 | Chi-square | 2.096156 | 0.5527 |

Based on the obtained VECM models for the variables C_ENER_PC and EXP_GDP, we can only assert the existence of one-way causality from EXP_GDP to C_ENER_PC (Table 11).


DOI: 10.55643/fcaptp.1.54.2024.4280

**Table 11. VECM model for time series EXP_GDP and C_ENER_PC with Wald tests.** Note: Standard errors in ( ) & t-statistics in [ ], D(·) – first difference. (Source: compiled by the authors using Eviews on the basis of data from Eurostat, Enerdata and World Bank)

| | | | | | | |
|---|---|---|---|---|---|---|
| **Cointegrating equation** | EXP_GDP(-1) | 1.000000 | | C_ENER_PC(-1) | 1.000000 | |
| | C_ENER_PC(-1) | -0.007349 | (0.00343) [-2.14557] | EXP_GDP(-1) | -136.0718 | (39.4090) [-3.45281] |
| | C | -26.91905 | | C | 3662.924 | |
| **Error Correction:** | | **D(EXP_GDP)** | **Probability** | | **D(EXP_GDP)** | **Probability** |
| | CointEq1 | 0.013566 | 0.0048 | CointEq1 | 0.002936 | 0.2388 |
| | D(EXP_GDP(-1)) | 0.062527 | 0.1396 | D(C_ENER_PC(-1)) | 0.103901 | 0.0110 |
| | D(EXP_GDP(-2)) | -0.145906 | 0.0010 | D(C_ENER_PC(-2)) | 0.007143 | 0.8628 |
| | D(C_ENER_PC(-1)) | -0.000232 | 0.6888 | D(EXP_GDP(-1)) | -12.81739 | 0.0000 |
| | D(C_ENER_PC(-2)) | 0.000638 | 0.2752 | D(EXP_GDP(-2)) | 2.963593 | 0.3435 |
| | C | 1.169028 | 0.0000 | C | 18.49664 | 0.8566 |
| **Wald tests** | **Null Hypothesis: C(4)=C(5)=0** | | | **Null Hypothesis: C(4)=C(5)=0** | | |
| | **Test Statistic** | **Value** | **Probability** | **Test Statistic** | **Value** | **Probability** |
| | Chi-square | 1.263067 | 0.5318 | Chi-square | 8.894446 | 0.0001 |

Figure 4 schematically presents the types of causal relationships between co-integrated pairs of energy efficiency and economic development indicators based on VECM models.

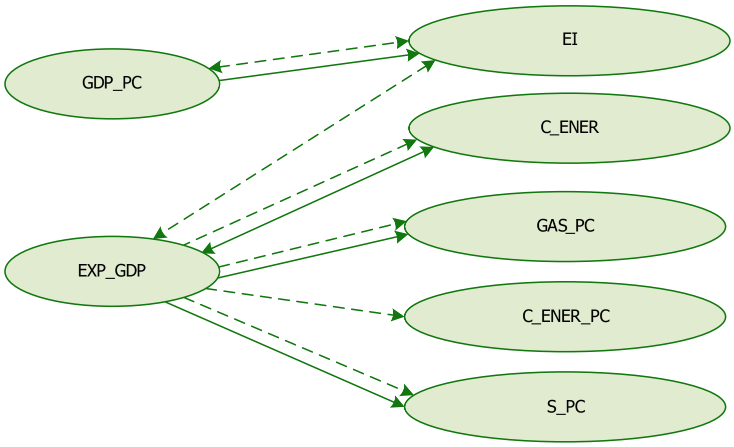


**Figure 4. Directions of causalities between co-integrated pairs of indicators of energy efficiency and economic development according to VECM models. Long-term relationship - solid line, short-term relationship - dotted line.**

## DISCUSSION

In this article we confirmed that the level of energy efficiency of European economies depends significantly on the economic situation in these countries in previous years, which is consistent to a certain extent with the results obtained by many rescuers, for example, Hussain et al. (2021), Gholizadeh et al. (2020). A similar result was obtained by Rajaguru et al. (2021), where they presented evidence of both long-term and short-term causal relationships between variables, representing economic growth and energy intensity. The existence of a close causal relationship between indicators of energy efficiency and economic development was confirmed in many articles. In addition, results obtained in our paper indicate that economic development indicators cause energy efficiency indicators in all pairs in which there is a causal relationship, regardless of whether it is a short-term or long-term relationship, stationary or cointegrated pairs.

In order to analyze causality between time series representing different levels of integration, Autoregressive Distributed Lag (ARDL) models should be used. Kyshakevych et al. (2023) analyzed the causal relationships between electricity consumption and economic growth for time series with different levels of integration using ARDL models.

## CONCLUSIONS

The article analyzed the cointegration and causal relationships between indicators of economic development and energy efficiency of 38 European countries for the period from 1995 to 2021 based on the use of panel data. To determine the direction of causal relationships for stationary time series, the Dumitrescu Hurlin test was used, which more correctly takes into account the features of panel data, namely, cross-sectional relationships. CO2 emission intensity was found to be a cause for annual GDP growth rate, annual GDP per capita growth rate and unemployment rate. Causality between non-cointegrated pairs of non-stationary time series was found based on the Dumitrescu Hurlin Panel Causality test for the first differences of these series. It should be taken into account that when interpreting the results of the Granger test for time series, the first differences examine the relationship between changes in these series, and not between their absolute levels.

In the case where there is cointegration between two-time series, we used the error correction model (VECM) to determine the type of long-term behaviour of variables with their short-term feedback. GDP per capita was found to be the driver of the level of primary energy intensity of European countries in the long term. One-way long-term causality was also found from the export of goods and services to domestic consumption of natural gas and solid fossil fuels. There is a two-way long-term cause-and-effect relationship between primary energy consumption and exports. The stationary time series of gross electricity production per capita and foreign direct investment were not represented in any of the causal pairs. We also determined the speed of return to the long-term equilibrium of a co-integrated pair of indicators in case of its violation due to possible crisis events in the economy of European countries.

Future research could include analyses aimed at developing and evaluating tools that improve energy efficiency without compromising economic growth. This may include analysis of tax incentives, subsidies, regulations, etc. Another promising direction for continuing research on this issue is the construction of econometric models for forecasting future trends in energy efficiency and their impact on economic development. This includes analyzing the relationships between energy consumption, CO2 emissions, GDP per capita and other economic indicators.

## ADDITIONAL INFORMATION

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### FUNDING

*The Authors received no funding for this research.*

### CONFLICT OF INTEREST

*The Authors declare that there is no conflict of interest.*

## REFERENCES

1. Abbas, C., Waqar, A., Fayyaz A., & Munir, A. (2020). Dynamic relationship among agriculture-energy-forestry and carbon dioxide (CO2) emissions: empirical evidence from China. *Environmental Science and Pollution Research*, 27, 34078–34089. https://doi.org/10.1007/s11356-020-09560-z

2. Alam, M., & Wahid M. (2020). The impacts of economic growth, trade openness and technological progress on renewable energy use in organization for economic co-operation and development countries. *Renewable Energy*, 145, 382-390. https://doi.org/10.1016/j.renene.2019.06.05

3. Almozaini, M. S. (2019). The Causality Relationship between Economic Growth and Energy Consumption in The World's top Energy Consumers. *International Journal of Energy Economics and Policy*, *9*(4), 40–53. https://www.econjournals.com/index.php/ijeep/article/view/7657

4. Andrei, J., Mieila, M., & Panait, M. (2017). The impact and determinants of the energy paradigm on economic growth in European Union. *PLoS One*, *12*(3), e0173282. https://doi.org/10.1371/journal.pone.0173282

5. Bao-Linh, T., Chi-Chung, C., & Wei-Chun, T. (2022). Causality between energy consumption and economic growth in the presence of GDP threshold effect: Evidence from OECD countries. *Energy*, 251, 123902. https://doi.org/10.1016/j.energy.2022.123902

6. Bayar, Y., & Dan Gavriletea, M. (2019). Energy efficiency, renewable energy, economic growth: evidence from emerging market economies. *Quality & Quantity: International Journal of Methodology*, *53*(4), 2221-2234. https://doi.org/10.1007/s11135-019-00867-9

7. Cevik, S., & Gao, K. (2023). Reaching (Beyond) the Frontier: Energy Efficiency in Europe. *IMF Working Paper*, WP/23/198, 19. https://doi.org/10.5089/9798400255540.001

8. Emeka, N., & Aham, K. (2016). Autoregressive Distributed Lag (ARDL) cointegration technique: application and interpretation. *Journal of Statistical and Econometric Methods*, *5*(4), 63-91. https://ideas.repec.org/a/spt/stecon/v5y2016i4f5_4_3.html

9. Enerdata (2022). Energy and Climate Databases Retrieved from https://www.enerdata.net/expertise/data-science.html

10. Eurostat (2022). Environment and energy statistics. Retrieved from: https://ec.europa.eu/eurostat/databrowser/explore/all/envir?lang=en&subtheme=nrg.nrg_quant&display=list&sort=category

11. Gao, X., Huang, S., Sun, X., Hao, X., & An, F. (2018). Modelling cointegration and Granger causality network to detect long-term equilibrium and diffusion paths in the financial system. *Soc. open sci, 5*, 172092. http://dx.doi.org/10.1098/rsos.172092

12. Gholizadeh, Y. (2020). Causality relationship between energy consumption and economic growth in the European Union countries. *EERI Research Paper Series*, *12*, 25. http://hdl.handle.net/10419/251104

13. Granger, C. W. J. (1969). Investigating Causal Relations by Econometric Models and Cross-spectral Methods. *Econometrica*, *37*(3), 424–438. https://doi.org/10.2307/1912791.JSTOR 1912791

14. Hussain, S., & Chunjiao, Y. (2021). Causal Relationship of Energy Consumption and Economic Growth – A Case Study of Pakistan International *Journal of New Economics and Social Sciences*, *1*(13), 139–162. https://doi.org/10.5604/01.3001.0015.2290

15. Ifa, A., & Guetat, I. (2022). Analysing short-run and long-run causality relationship among public spending, renewable energy consumption, non-renewable energy consumption and economic growth: Evidence from eight of South Mediterranean Countries. *Energy Exploration & Exploitation*, *40*(2), 554-579. https://doi.org/10.1177/01445987211049304

16. Kirikkaleli, D., Sokri, A., Candemir, M., & Ertugrul, H. (2018). Panel Cointegration: Long-Run Relationship between Internet, Electricity Consumption and Economic Growth. Evidence from OECD Countries. *Investigación Económica, 77*(303), 161–76. https://doi.org/10.22201/fe.01851667p.2018.303.64158

17. Küçüksakarya, S. (2021). A panel causality analysis of the relationship between financial development and economic growth in OECD countries. *Bmij, 9*(2), 662-672. https://doi.org/10.15295/bmij.v9i2.1817

18. Kyshakevych, B., Maksyshko, N., Voronchak, I., & Nastoshyn, S. (2023). Ecological and economic determinants of energy efficiency in European countries. *Scientific Horizons, 26*(8), 140-155. https://doi.org/10.48077/scihor8.2023.140

19. Kyshakevych, B., Nastoshyn, S., & Andriychyk, M. (2023). Assessment of causal relationships between electricity consumption and economic growth in European countries, *Investytsiyi: praktyka ta dosvid, 15*. https://doi.org/10.32702/2306-6814.2023.15.23

20. Lopez, L., & Weber, S. (2017). Testing for Granger causality in panel data. *IRENE Working Papers, 17*(03). https://econpapers.repec.org/scripts/redir.pf?u=https%3A%2F%2Fwww5.unine.ch%2FRePEc%2Fftp%2Firn%2Fpdfs%2FWP17-03.pdf;h=repec:irn:wpaper:17-03

21. Rahman, M., & Vu, X.-B. (2021). Are Energy Consumption, Population Density and Exports Causing Environmental Damage in China? Autoregressive Distributed Lag and Vector Error Correction Model Approaches. *Sustainability, 13(7)*,3749. https://doi.org/10.3390/su13073749

22. Rajaguru, G., & Khan, S. (2021). Causality between Energy Consumption and Economic Growth in the Presence of Growth Volatility: Multi-Country Evidence. *Journal of Risk and Financial Management*, *14*(10), 471. https://doi.org/10.3390/jrfm14100471

23. Shaari, M. S., Abidin, N. Z., & Karim, Z. A. (2020). The Impact of Renewable Energy Consumption and Economic Growth on CO2 Emissions: New Evidence using Panel ARDL Study of Selected Countries. *International Journal of Energy Economics and Policy, 10*(6), 617–623. https://www.econjournals.com/index.php/ijeep/article/view/9878

24. Shahateet, M., Al-Majali, I., Khalid, A., & Al-Hahabashneh, F. (2014). Causality and Cointegration between Economic Growth and Energy Consumption: Econometric Evidence from Jordan. *International Journal of Economics and*

*Finance*, *6*(10), 270-279. https://doi.org/10.5539/ijef.v6n10p270

25. Winarno, S., Usman, M., Kurniasari, D., & Widiarti. (2021). Application of Vector Error Correction Model (VECM) and Impulse Response Function for Daily Stock Prices. *Journal of Physics: Conference Series*, 1751, 012016. https://doi.org/10.1088/1742-6596/1751/1/012016

26. World Bank. (2023). https://data.worldbank.org

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## АНАЛІЗ КОІНТЕГРАЦІЇ ТА ПРИЧИНОВО-НАСЛІДКОВИХ ЗВ'ЯЗКІВ МІЖ ПОКАЗНИКАМИ ЕКОНОМІЧНОГО ЗРОСТАННЯ ТА ЕНЕРГОЕФЕКТИВНОСТІ КРАЇН ЄВРОПИ

У сучасних умовах, коли європейські країни поставили перед собою надзвичайно амбітну мету – скорочення викидів парникових газів мінімум на 55% до 2030 року порівняно з рівнем 1990 року, важливо проаналізувати причиново-наслідкові зв’язки між ключовими показниками енергоефективності національних економік та економічного зростання, визначити характер їхнього впливу одне на одного. У статті проведено аналіз коінтеграції та причиново-наслідкових зв’язків між панельними даними, які визначають економічний розвиток і енергоефективність 38 країн Європи за період із 1995 по 2021 рік. Стаціонарні часові ряди аналізували на причиновість за допомогою тесту Dumitrescu Hurlin, який порівняно з класичним тестом Грейнджера точніше враховує структуру панельних даних, а саме крос-секційні взаємозв’язки. Річні темпи зростання ВВП виявилися причиною для зростання інтенсивності викидів CO2. Для пар часових рядів із першим рівнем інтеграції у випадку існування коінтеграції між ними автори використали модель корекції помилок (Vector Error Correction (VECM)) для визначення типу довгострокової поведінки змінних зі своїми короткостроковими відгуками. Експорт товарів і послуг виявився довгостроковою причиною для внутрішнього споживання природного газу й твердого викопного палива. Довгостроковий причиново-наслідковий зв'язок було виявлено лише між споживанням первинної енергії та експортом. Слід відзначити, що у виявленій у роботі короткостроковій та довгостроковій причиново-наслідковій залежності показники економічного розвитку виступають причиною для показників енергоефективності незалежно. Це сигналізує про те, що рівень енергоефективності європейської економіки визначається в значній мірі економічним розвитком країн Європи в попередні періоди. З метою аналізу причиново-наслідкових зв’язків між часовими рядами, які мають різні рівні інтеграції, можна скористатись ARDL-моделями.

**Ключові слова:** причиново-наслідкові зв’язки, VECM, причиновість за Грейджером, довгострокова рівновага, енергоємність економіки, економічний розвиток, коінтеграція, країни Європи

**JEL Класифікація:** F43, K32, C01, C32