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Correlation of Greenhouse Gas Emissions with Economic Growth in the European Union (2010-2019)

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ABSTRACT

A prominent research area in energy economics is the study of the correlation between economic growth and CO_2 emissions. Using the combined application of correlation calculation and cluster analysis based on empirical data, the study typifies and arranges the EU member states into homogeneous groups based on the pattern of the two variables moving together based on data from the period 2010-2019. This methodology allows to a test of the "decoupling" theory that can be used to describe the interaction between environmental pressures and economic development. The results can be used to infer the status of clustered Member States in the decoupling process. The results are ambivalent across member countries. For several EU Member States, different degrees of decoupling can be observed, i.e. GDP growth has been accompanied by a reduction of the ecological footprint in those countries. However, there are also member countries where the decoupling did not work, because the reduction of CO_2 emissions was accompanied by a decrease in GDP.

Keywords: CO_2 Emissions, European Union, Energy Economics, Energy-Growth Relationship, Decoupling, Correlation, Cluster Analysis
JEL Classifications: F43, Q43

1. INTRODUCTION

Reconciling the economic development of industrial societies with the need to protect the environment is one of the defining global challenges of our time. The problem arises from the need for economic growth in society, which creates opportunities for society's members to achieve an even better standard of living.

At the same time, it should be borne in mind that the development of industrial production is accompanied by the physical and geographical consequences of "conquest." This includes the increasing exploitation of natural resources, which industry uses as raw materials or fuels for production. As industrial production expands, other things being equal, pollutant emissions continue to rise. This hurts the environment because industry returns the waste products of the natural resources it uses back into the environment. Nature, on the other hand, can no longer cope with the industrial "residue" that is being generated. Excessive amounts of greenhouse gases in the atmosphere lead to ecological imbalances.

Mankind is faced with a strange contradiction: while society should be able to produce an ever-increasing trajectory of production, this leads, under unchanged conditions, to constant degradation of the environment. Environmental degradation, in turn, is a threat to humanity itself. In turn, putting the protection of the environment on the back burner can also lead to socio-economic problems, such as scarcer goods, poorer living standards, etc.

The problem for mankind is to reconcile the need to maintain ecological balance in industrial societies with the need for increased production. This can only be achieved if the expansion of industrial production takes into account the need to protect the environment for future generations. This is essentially the concept of "sustainable development." Development becomes sustainable if the concentration of pollutants (such as greenhouse gases) released into the environment can be minimized.

The theory of decoupling, which is used to describe the interaction between environmental pressures and economic development, states that the relative rates of change of an environmentally and economically important variable that are causally related to each other can be compared. At the level of EU Member States, the rate of growth of an environmental indicator (e.g. CO_2 emissions) can be compared with the rate of growth of GDP. The European Union experienced dynamic economic growth between 2010 and 2019, so it is fascinating to see how greenhouse gas emissions in CO_2 equivalents have been related to this growth.

The present study aims to analyze the relationship between GHG emissions and their closeness to economic growth in the EU Member States.

The implied hypotheses of the study are as follows:

- Hypothesis 1: If GDP increases in the EU member states, then CO_2 emissions will increase due to a strong correlation because more energy is needed to produce more new value
- Hypothesis 2: If CO_2 emissions decrease in EU countries, GDP will decrease due to a strong correlation because less energy is needed to produce less new value.

2. LITERATUR REVIEW

One of the most important areas for action on climate change is the regulation of greenhouse gas (GHG) emissions. The rational strategy is to enforce environmental carrying capacity as a limit to management. The UN Sustainable Development Goal (SDG) 13 aims to quantify and reduce greenhouse gas emissions (United Nations, 2022). Experts believe that carbon dioxide (CO_2) is the largest contributor to climate change and is one of the main greenhouse gas components (IPCC, 2014).

A large body of literature focuses on the relationship between pollution and gross income (GDP) generated, which results in an inverted U-shaped curve, the so-called Environmental Kuznets Curve (EKC). According to the EKC correlation, the environmental burden in each country first increases as income rises, then stabilizes, and, after reaching a peak, starts to decline (Selden and Song, 1994). Another study has investigated the relationship between oil consumption, economic growth, and carbon emissions. The authors of the study for the Philippines for the period 1965-2012 found a one-way causal relationship between carbon emissions and economic growth. This suggests that increasing carbon emissions are associated with higher economic growth, but at the same time, the Philippines' economic development is also significantly dependent on carbon emissions (Lim et al., 2014). Researchers have examined which activities produce the highest levels of greenhouse gases. They have found that CO_2, the most emitted greenhouse gas, is mainly from human activities. Around 75% is emitted by cities, and 40% of global carbon dioxide emissions are produced by the construction industry (Zarco-Periñán et al., 2022). Previous research has established how carbon dioxide affects global warming. It has been found that carbon dioxide absorbs heat from the atmosphere so higher levels of carbon dioxide emissions increase the average temperature of the Earth's atmosphere (Solomon et al., 2007; Stone et al., 2009).

Several authors have explored a causal link between economic growth and carbon emissions. Such a link was found in a study conducted in Bangladesh between 1972 and 2011. It showed that energy consumption is strongly related to economic growth, while carbon emissions growth is weakly related to economic growth (Ghosh et al., 2014). Other researchers have analyzed the impact of economic growth and carbon emissions on energy consumption. A study using panel data from 58 countries from 1990 to 2012 showed that economic growth, carbon emissions, and energy consumption are complementary (Saidi and Hammami, 2015). A recent study proposes the introduction of a new parameter to measure the efficiency of emissions. In this paper, the new parameter is CE2N. The parameter combines total emissions and emissions per capita and per GDP. With this parameter, the authors create a unified and universal indicator that takes into account emission efficiency, total emissions, and the time factor at the same time (Portillo et al., 2022).

Research has revealed that it is not possible to decouple economic growth and carbon emissions growth from the existing technological-economic structure. The biggest challenge is therefore to build new economic structures where investments in green technologies are more profitable. Overall, economic growth can already contribute to reducing carbon emissions beyond a certain level through the diffusion of green technologies (Andersson and Karpestam, 2013).

Another part of the relevant literature focuses on the links between income, energy production, and pollution. The majority of studies show that the level of individual income is closely related to energy consumption, and therefore higher economic development is associated with higher energy consumption. One study analyzed China's carbon emissions and energy consumption between 1953 and 2006. The study found that higher energy use, higher income, and more open trade typically lead to more carbon emissions (Ang, 2009). A multivariate study of China (Zhang and Cheng, 2009) found a one-way Granger causality in the long-run relationship between energy consumption and carbon emissions, with neither factor contributing to economic growth.

Other studies have analyzed the relationship between energy consumption and economic growth. One study examined the relationship between energy consumption and economic growth in OECD countries over the period 1980-2010. A panel data methodology was used to analyze the causal relationship between energy and growth. The research results showed that there is a significant relationship between energy consumption and economic growth in OECD countries over the period under study (Isik and Shahbaz, 2015). Another study examined the causal relationship between energy consumption and real GDP in fourteen MENA (Middle East and North Africa) countries over the period 1987-2019. The study used a bivariate vector autoregression model and a Granger causality approach. This study showed the existence of unidirectional, bidirectional, or no causal relationship between energy consumption and economic growth in different countries of the MENA region (Saqib, 2021). Evidence of the extensive nature of energy consumption was found in one study. The study investigates the dependence of economic growth on energy consumption levels in different countries of the world. Countries were grouped according to their level of economic development and geographical location (macro-regions). The authors show that the impact of energy consumption on GDP is more intense in non-OECD countries than in Organisation for Economic Co-operation and Development (OECD) countries (Komarova et al., 2022).

Hannesson (2009) argued in his study that there is a positive but not proportional relationship between GDP and energy use. There is a significant positive relationship between energy use growth and GDP growth for all countries combined and for all subgroups of countries, but the relationship is not proportional. There are indications that the growth of energy use decreases with GDP per capita for any given increase in GDP. One study examined energy consumption and economic growth in developing and developed countries. The study found that for developing countries, higher energy use leads to economic growth. For developed countries, researchers found less evidence of a dependence between energy consumption and economic growth (Waheed et al., 2019). Another study examined the relationship between CO_2 emissions and urbanization. The results show that for the V4 countries (Poland, Slovakia, Hungary, and the Czech Republic), changes in the rate of urbanization have an impact on CO_2 emissions. The phenomenon of urbanization was shown to influence the growth of energy consumption in the countries studied. These results suggest that the V4 countries should increase the use of renewable and ecological energy sources (Myszczyszyn and Supron, 2022). Hsiao (2022) examined greenhouse gas emission quotas. Empirical results showed that data from most countries in the world support the Kuznets curve hypothesis. Using the data collected from Our World in Data, the optimal allocation of greenhouse gas emission quotas can be solved by minimizing the risk of uncertainty under a predetermined global economic growth rate. One paper examines the short/long-term causal information flow between fossil fuel-related carbon dioxide (CO_2) emissions and economic growth (GDP) in the US economy between 1800 and 2014. The empirical results show that (i) the long-run causal information flow from GDP to CO_2 is positive, strong, uninterrupted, and concentrated until the 1990s; (ii) the reverse causality is positive but interrupted, short-run, and intensifies from the early 1990s (Torun et al., 2022).

The study by Vo et al. examines the causal relationship between carbon dioxide (CO_2) emissions, energy consumption, renewable energy, population growth, and economic growth in the countries of the region. Using a variety of time-series econometric approaches, the analysis covers five ASEAN members over the period 1971-2014. Results show that there is no long-term relationship between the variables in the Philippines and Thailand, but there is in Indonesia, Myanmar, and Malaysia. The EKC hypothesis is observed in Myanmar but not in Indonesia and Malaysia (Vo et al., 2019).

A study has analyzed the relationship between greenhouse gas (GHG) emissions, employment, inflation, and gross domestic product (GDP) at constant prices by comparing two countries of the European Union (EU-27) and the European Free Trade Association (EFTA). The results of the study show that GDP at constant prices significantly influenced GHG emissions in the EU-27 countries. Meanwhile, the difference between inflation and employment had no significant effect. This finding shows that inflation was not a stable variable and had a strong autocorrelation. The variable of employment did not follow a normal distribution (Gricar et al., 2022). This paper empirically investigates the relationship between carbon emissions, economic growth, urbanization, and foreign trade in China from 1971 to 2020. The results show that when carbon emissions, economic growth, and urbanization are used as explanatory variables, there is a long-run cointegrating relationship with other variables. In the long run, urbanization has a significant positive effect on economic growth and carbon emissions. In the short-term relationship, economic growth, carbon emissions, and urbanization are all mutually reinforcing relationships (Jiang et al., 2022). The situation in Azerbaijan has been studied by Mukhtarov et al. (2023) The positive effect of GDP per capita on GHG emissions was of an economically acceptable magnitude. Indeed, an increase in real output (GDP per capita growth) can only be achieved by using more energy. Therefore, as GDP per capita rises, energy demand will increase. To meet the growing energy demand, the country has sought to use more affordable energy sources over the period under review. For Azerbaijan, oil and gas are more affordable than renewable energy sources. Therefore, the country favors the use of oil and gas reserves for energy production, hence the increase in CO_2 emissions (Mukhtarov et al., 2023). An institutional approach was used by the researchers in the study cited here. The empirical results suggest that achieving the SDGs requires the EU to increase innovation. At the same time, it is necessary to improve technology, restructure industry, create quality human capital, and improve the quality of public institutions (Bezic et al., 2022).

3. MATERIALS AND METHODS

This study is closely related to energy economics, with the central question being the relationship between greenhouse gas emissions and economic growth in EU member states. The correlation and causality between the two indicators is an important part of energy economics research and is the main research focus of this study.

3.1. Databases

Greenhouse gas emissions data are from the European Environment Agency (2021), GDP data from Eurostat (2022).

3.2. Methodology

The choice of time interval should be explained. The year 2010 was chosen as the starting point for the analysis because it was the year in which the subprime crisis in the European Union ended. By 2010, most of the EU Member States had already recovered from the worst shocks and economic growth had started. The years 2010-2019 are the right period to examine the correlation between CO_2 emissions and GDP trends. The two indicators analyzed are the CO_2 emissions and economic growth (change in GDP) of the

EU Member States. The former indicator is CO_2 emissions in thousand kilotonnes of CO_2 equivalent. The latter indicator shows GDP measured in Purchasing Power Standard (PPS).

The analysis is based on a combination of correlation analysis and hierarchical cluster analysis. Correlation refers to the mutual relationship between indicators. This relationship can theoretically be functional, stochastic, or completely independent. Before analyzing the relationship between the two indicators under study, it can be assumed that this relationship will be stochastic, since it is function-like, and complete independence can be excluded. A suitable procedure for the analysis of a stochastic relationship is correlation calculation. The calculation of the correlation coefficient will be based on the average data in Tables 1 and 2. However, this will be only the first procedure in the analysis of the relationship between the indicators. In the second procedure, hierarchical clustering will be performed using the calculated correlation coefficients. The clustering aims to identify and form relatively homogeneous subsets or groups of relatively heterogeneous objects (EU Member States) based on the characteristics of the objects. Correlation and clustering as research technique is often used by researchers for econometric analysis (Urbankova and Krizek, 2020; Török, 2022a; Török, 2022b; Chormungea and Jenab, 2018). The multivariate statistical method of cluster analysis will be used in this study to determine homogeneity across EU member states. Cluster analysis will be conducted to classify the EU Member States under study into clusters based on the extent to which the two indicators are closely related over the period under study.

For clustering, the Between Groups method will be used. Before clustering, however, it is necessary to check whether the values of the indicators are normally distributed. For this purpose, a Shapiro-Wilk test will be performed on GDP, CO_2 emissions, and correlation coefficients. Finally, the study will use the so-called partitioning methodology to determine which cluster an EU Member State belongs to. The clustering will depend on the strength of the relationship between CO_2 emissions and GDP over the period under study. The evolution of the two indicators is illustrated in the graph below:

Figure 1 illustrates the decoupling of economic growth and CO2 emissions in the EU during the period under review.

4. RESULTS

Results are presented in three subsections in the following order. First the results of the analysis of GDP change, then the results of the analysis of the CO_2 emissions time series data are presented. In the third subsection, the results of the closeness of the relationship between the two indicators are presented.

4.1. Time Series Analysis of GDP Change

The European Union economy grew by an average of 2.45% per year in absolute terms, by €3,033 billion in 2019 compared to 2010.

According to the data in Table 2, Greece is the only country to have experienced a decline in GDP compared to the 2010 base period. The decline is explained by the fact that Greece has suffered the

Table 1: Total greenhouse gas emissions in European Union member states, (thousand kilo tons CO_2 equivalent), 2010-2019

Country	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2019/10
AU	82	80	78	79	76	78	80	81	80	80	97.6
BE	138	127	124	123	118	123	121	121	122	121	87.7
BG	48	56	52	49	51	54	51	54	51	50	104.2
CY	10	10	9	8	9	9	10	10	10	10	100.0
DK	69	63	58	59	56	52	56	53	55	50	72.5
HR	21	22	21	19	19	19	20	21	20	20	95.2
CZ	134	133	129	124	122	123	125	128	132	133	99.3
EE	16	16	17	20	20	16	18	20	19	15	93.4
FI	56	48	40	46	40	38	42	41	51	42	75.0
FR	485	462	460	458	433	441	451	463	448	441	90.9
DE	946	919	916	936	897	902	906	893	861	815	86.2
EL	118	115	112	104	102	95	91	96	92	87	73.7
HU	62	61	57	55	54	56	58	60	61	61	98.4
IE	72	69	67	67	67	70	72	73	73	70	97.2
IT	485	481	470	420	398	408	409	425	406	390	80.4
LT	10	9	8	9	12	11	9	8	11	9	90.0
LV	10	11	11	11	12	13	13	14	14	15	150.0
LU	13	13	13	12	12	11	11	12	12	12	92.3
MT	3	3	3	3	3	2	2	2	3	3	100.0
NL	227	213	209	209	201	209	210	207	202	196	86.3
PL	379	372	365	358	353	360	364	378	377	373	98.4
PT	63	60	60	60	57	62	65	85	65	60	95.2
RO	95	102	97	85	82	83	79	85	88	86	90.5
SK	39	38	34	33	33	34	34	35	36	33	84.6
SI	13	13	12	13	17	18	19	19	19	12	92.3
ES	334	335	329	304	304	314	304	318	314	296	88.6
SE	24	20	16	17	15	18	17	21	20	17	70.8
EU 27	3952	3851	3767	3681	3563	3619	3637	3723	3642	3497	88.5

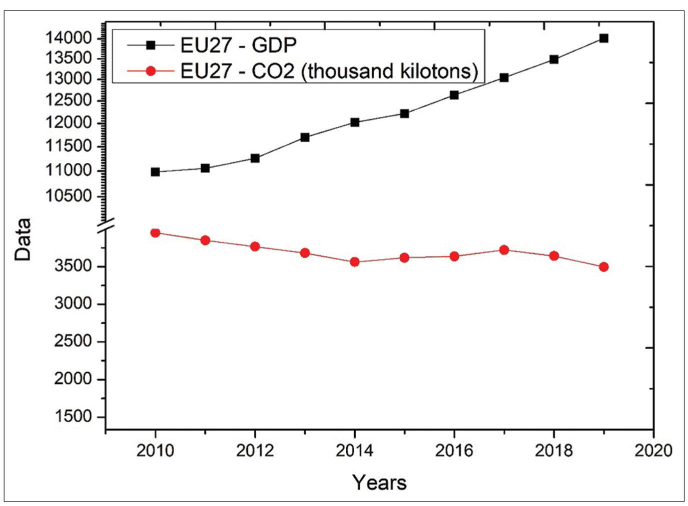
EU: European Union

Table 2: Gross domestic product in the member states of the European Union, (billion purchasing power standard Euros), 2010-2019

Country	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2019/2010
BE	329	331	339	355	363	374	383	394	406	424	128.9
BG	84	86	89	89	92	95	99	104	108	116	138.1
CZ	221	214	217	233	244	257	268	279	292	311	140.7
DK	181	175	180	189	193	200	209	217	225	232	128.2
DE	2411	2521	2579	2678	2796	2796	2896	2994	3071	3146	130.5
EE	22	23	24	26	28	28	29	30	33	34	154.5
IE	149	148	151	162	170	233	245	257	280	293	196.6
EL	235	226	216	217	217	208	212	214	222	221	94.0
ES	1117	1121	1125	1130	1163	1165	1213	1260	1289	1337	119.7
FR	1767	1782	1815	1908	1938	1954	2001	2046	2116	2245	127.1
HR	65	65	67	67	68	70	73	75	78	84	129.2
IT	1577	1547	1861	1587	1602	1611	1670	1729	1760	1803	114.3
CY	21	20	20	19	19	19	21	22	24	25	119.0
LV	28	31	33	34	35	36	37	38	40	42	150.0
LT	47	51	55	58	60	60	63	65	68	73	155.3
LU	35	35	36	38	41	44	45	46	48	49	140.0
HU	165	168	169	176	184	190	194	198	210	223	135.2
MT	9	9	9	10	10	12	13	13	14	16	177.7
NL	566	542	545	595	606	612	630	648	675	696	123.0
AT	266	271	279	297	303	310	319	328	342	351	132.0
PL	607	630	660	688	715	734	759	783	822	873	143.8
PT	218	205	205	216	223	221	227	233	240	253	117.4
RO	260	260	272	289	302	308	337	365	388	420	161.5
SI	43	43	44	44	47	47	50	52	55	58	134.9
SK	103	102	105	110	114	117	116	115	121	119	115.5
FI	158	157	159	164	165	167	173	179	185	189	119.6
SE	300	292	297	319	327	346	354	362	372	382	127.3
EU27	10,982	11,055	11,264	11,698	12,024	12,215	12,636	13,047	13,484	14,015	127.6

EU: European Union

Figure 1: GDP and CO2 emissions data in the European Union by year (2010-2019)



worst loss of growth potential. In an unprecedented fall in GDP in the European Union, the fall in productivity has been the dominant factor in Greece's case. Italy, Slovakia, Portugal, Cyprus, and Spain are the countries where GDP growth was between plus 0 and 20%. In the Netherlands, France, Sweden, Denmark, Belgium, Croatia, Germany, Austria, Slovenia, Hungary, Bulgaria, and Luxembourg, GDP growth ranged from plus 20 to plus 40%. GDP growth in Poland, Lithuania, Estonia, and Lithuania was between plus 40 and 60%. Romania and Malta grew between plus 60 and 80%, and Ireland grew by 96.6%. These three countries have the most dynamic growth performance in the European Union between 2010 and 2019. Romania's domestic consumption and investment, Ireland's extremely high investment rate, and Malta's high investment rate were the main drivers of economic growth (Piątkowski, 2020).

4.2. Time Series Analysis of CO_2 Emissions Data

CO_2 emissions from the European Union economy decreased by an average of 1.22% per year in absolute terms by 455 thousand kilotonnes in 2019 compared to 2010 emissions, amounting to 3497 thousand kilotonnes in 2019.

The 2019 CO_2 emissions data in Table 1 show that, in order, Sweden, Denmark, Greece, Finland, Italy, Slovakia, Germany, the Netherlands, Belgium, Spain, and Latvia have reduced their CO_2 emissions by between 20 and 30%. Romania, France, Luxembourg, Slovenia, Estonia, Croatia, Portugal, Ireland, Poland, Hungary, Austria, and the Czech Republic have reduced their CO_2 emissions by between 0 and 10%. Malta and Cyprus remained stable, but Bulgaria and Lithuania increased their CO_2 emissions.

More relevant correlations emerge when comparing the GDP per CO_2 emissions of member countries in 2019. From the data in Tables 1 and 2, the GDP per 1,000 kilotonnes of CO_2 can be calculated. Based on this calculation, the study arrives in the following order. Sweden stands out from the efficiency ranking and is in the first cluster, with a GDP of 22.5 billion euros per 1,000 kilotonnes of CO_2 emissions, followed by Lithuania. There are thirteen Member States with efficient GDP per CO_2

Figure 2: Standard deviation of correlation coefficients between GDP and CO_2 emissions

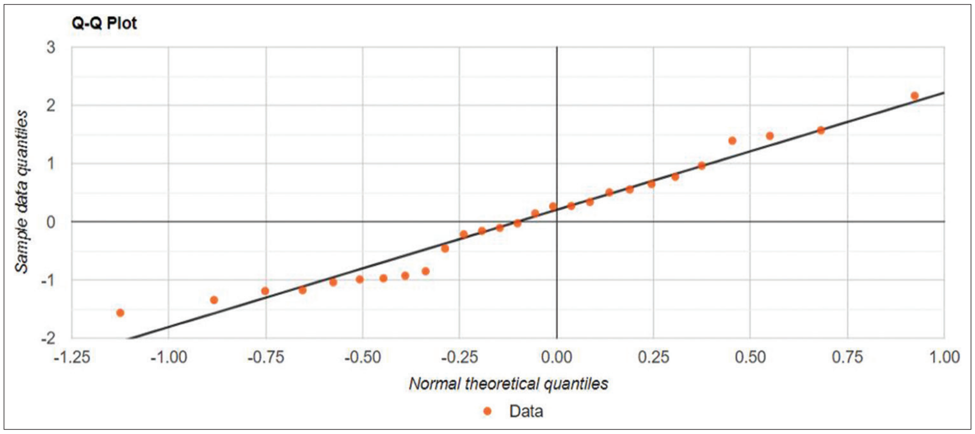
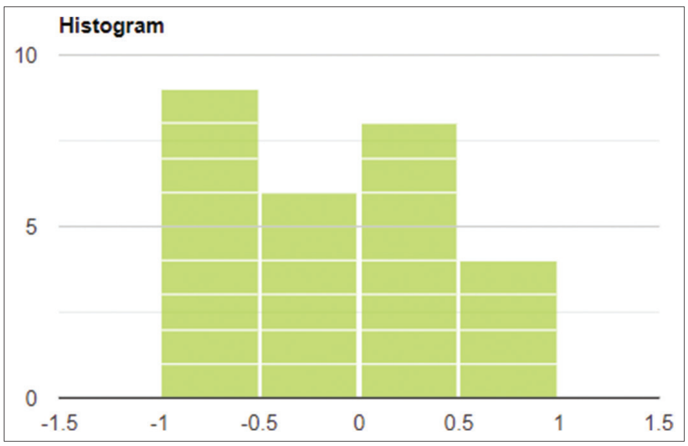


Figure 3: Clusters of European union member states (GDP and CO_2)



production. These Member States produce between €4.0 and €5.5 billion of GDP per 1,000 tonnes of CO_2 emissions. This cluster includes France, Malta, Romania, Slovenia, Denmark, Italy, Spain, Finland, Austria, Portugal, Croatia, Ireland, and Luxembourg. The previous cluster in terms of CO_2 emission efficiency is followed by countries that produce between €2.5 and €4.0 billion of GDP with 1,000 tonnes of CO_2 emissions. These countries are, in order, Germany, Slovakia, Hungary, the Netherlands, Belgium, Latvia, Greece, and Cyprus. The fourth cluster in terms of energy efficiency is made up of countries that produce less than €2.5 billion GDP with 1,000 tonnes of CO_2 emissions. These countries are order, Estonia, Bulgaria, the Czech Republic, and Poland.

The data in Tables 1 and 2 show that the EU produced an average of €2.555 billion of GDP per 1,000 kilotonnes of CO_2 emissions in 2010 and €4.001 billion in 2019. The efficiency of GDP production per 1,000 kilotonnes of CO_2 emissions has increased robustly, rising to 157% in 2019 compared to 2010.

4.3. Results of the Analysis of the Correlation between GDP and CO_2 Emissions

The correlation calculation between GDP values and CO_2 emission values for the years 2010-2019 resulted in the following correlation coefficients (r):Belgium: -0.6129, Bulgaria: -0.313, Czech Republic: 0.0654, Denmark: -0.7625, Germany: -0.8703, Estonia: 0.1714, Ireland: 0.6230, Greece: 0.5829, Spain: -0.5785, France: −0.5880, Croatia: −0.1790, Italy: −0.2076, Cyprus: 0.6708, Lithuania: 0.9616, Latvia: 0.0317, Luxembourg: -0.6866, Hungary: 0.2169, Malta: -0. Poland: 0.1466, Portugal: 0.2777, Romania: −0.5196, Slovenia: 0.3716, Slovakia: −0.5570, Finland: −0.1530, Sweden: −0.1144, Netherlands: −0.6793, Austria: 0.0281, Poland: 0.1466, Portugal: 0.2777, Romania: −0.5196, Slovenia: 0.3716, Slovakia: −0.5570, Finland: −0.1530, Sweden: −0.1144.

4.3.1. Testing data

Before performing the hierarchical cluster analysis, the correlation values should be tested. Performing this test answers the question: are the correlation values suitable for clustering? The results of the Shapiro-Wilk test are shown in the summary below:

P-value: 0.3798, W: 0.9605, Sample size (n): 27, Average ($\bar{x}$): −0.1007, Median: -0.1144, Sample Standard Deviation (S): 0.4913, Sum of Squares: 6.2755, b: 2.4551, Skewness: 0.3193.

The null hypothesis assumes a normal distribution, we accept it with a P = 0.3798, so the correlation data can be considered as normally distributed.

Figure 2 illustrates the results of the Shapiro-Wilk test, according to which the correlation coefficients used in the analysis follow a normal distribution.

4.3.2. Clusters based on the correlation between GDP and CO_2 emissions

The meaning of correlation values in this case is the degree of correlation between the evolution of the two indicators (GDP and CO_2) over the period under study. The calculated correlation values are used to classify the EU Member States into four clusters.

The first cluster (interval: −1.0; −0.5) consists of nine Member States, in order Germany, Denmark, Luxembourg, the Netherlands, Belgium, France, Spain, Slovakia, and Romania. For the countries listed, there is a strong negative inverse relationship between GDP and CO_2 emissions. The negative inverse relationship between the indicators means that these Member States have experienced a significant increase in GDP while their CO_2 emissions have decreased significantly.

From the data in Tables 1 and 2 and the values of the correlation coefficients with negative signs, it is clear that the year-on-year improvement in CO_2 emissions of these nine Member States is negatively correlated with the specific values of GDP, which have increased dynamically over the same period.

The second cluster (interval: −0.5; 0) includes six Member States, order Malta, Italy, Croatia, Finland, Sweden, and Bulgaria. In the countries listed, there is a weak, negative, inverse relationship between GDP and CO_2 emissions. These Member States have experienced a smaller increase in GDP but also a smaller decrease in CO_2 emissions than the first cluster. This explains why, although a negative inverse relationship can be observed in this cluster, the relationship between GDP and CO_2 emissions is significantly weaker than in the first cluster.

The third cluster (interval: 0; 0.5) includes eight Member States, in order Austria, Lithuania, Czech Republic, Estonia, Hungary, Poland, Portugal, Slovenia, and Slovenia. For the EU Member States listed, the sign of the correlation changes, with a weak positive correlation of a linear proportion between GDP growth and CO_2 emissions of the Member States. The change in the direction of the correlation can be explained by the fact that these Member States have experienced moderate GDP growth, but their CO_2 emissions have remained on average stable.

The fourth cluster (interval: 0.5; 1) includes four Member States, order Greece, Ireland, Cyprus, and Latvia. For the listed Member States, there is a strong positive correlation between GDP growth and CO_2 emissions of the Member States. The strength of the relationship between the two indicators is that the average GDP growth of the four listed Member States is higher than that of the three previous clustered Member States (Latvia and Ireland have grown very robustly over the period!). This economic growth has been accompanied by an increase in the average CO_2 emissions of the country group, which is unique to this cluster. The combination of high GDP growth and CO_2 emission increases resulted in a strong positive correlation with a linear correlation for the four EU Member States in the cluster.

A relevant mathematical regularity is highlighted here. It is that CO_2 emissions decreased for Greece and Ireland, remained stable for Cyprus, but increased by 50% for Latvia. The average CO_2 emissions of the four EU countries are positive because of the high value for Latvia. This positivity has been properly addressed by the hierarchical cluster analysis methodology used. Clusters are illustrated in the histogram below:

Figure 3 shows how many member countries are similar to each other by cluster based on the correlation between the two variables.

5. DISCUSSION

A large and growing body of literature has examined environmental changes following economic growth. This study empirically investigated the causal relationship between GDP and CO_2 emissions for the 27 EU Member States from 2010 to 2019. When examining the correlation between GDP and CO_2 emissions in a theoretical approach, it is preliminarily assumed that these two indicators move together and in the same direction. A co-variation would imply that if the GDP of an economy increases, CO_2 emissions should also increase because increasing GDP requires increasing energy consumption. In such a case, the increase in GDP would be the causal factor (i.e. the independent variable) and the increase in CO_2 emissions would be the cause (i.e. the dependent variable).

However, the results of the present study do not support the theoretical causality described in the previous sentence. Indeed, the results of the paper show that there is no robust, strong positive correlation between GDP at PPS prices and CO_2 emissions in the European Union Member States. No, because GDP increased by 27.6% while CO_2 emissions decreased by 11.5% in 2019 compared to 2010.

In the continuation of this chapter, this paper presents literature that has also examined the relationship between the two macroeconomic variables. First, a reference to literature that shows the two indicators varying together and in one direction follows. And at the end of the chapter, the paper cites literature that provides evidence for the decoupling presented in the introductory section.

One paper measures the energy-related CO_2 emissions and dynamic development pathways of 57 cities in the Yellow River Basin (YRB) between 2006 and 2019. The results show that between 2006 and 2019, economic growth and CO_2 emissions of cities along the YRB are dominated by weak correlation, with an average contribution of 53.2% (Kong et al., 2022). In their study, Nan et al. find that the incentive effect of economic growth on carbon emissions is offset by an increase in the rate of green innovation. It turns into an inhibitory effect; that is, green innovation changes the relationship between economic growth and carbon emissions and plays a significant role in reducing China's carbon emissions. Moreover, analysis of variation over time indicates that the positive effect of economic growth on carbon emissions gradually declines over time (Nan et al., 2022). According to a study, economic growth in China continues to drive CO_2 emissions, and the relationship between the two is still on the upward slope of the CKC (Carbon-dioxide Kuznets Curve). Economic growth has significant spatial spillover effects, with economic growth in other regions inhibiting the region's carbon emissions decline (Li and Li, 2023). The results of Mardani et al.'s paper show that the relationship between CO_2 emissions and economic growth justifies policy options that reduce CO_2 emissions by imposing constraints on economic growth. Given that there is a two-way causal relationship, if economic growth increases or decreases, additional CO_2 emissions are incentivized at higher or lower levels. From the previous finding, it follows that the potential reduction in emissions hurts economic growth (Mardani et al., 2019).

There are contradictory results in the research of Jardón et al. Assuming cross-independence, the existence of an EKC with a real turning point was confirmed for a group of countries, and they, therefore, rejected the existence of an EKC (Jardón et al.,2017). Wawrzyniak and Doryn (2020) provide empirical evidence that an inverted U-shaped relationship between economic growth and carbon emissions exists for the 93 emerging and developing countries they studied. The study by Abbas (2020) examined the relationship between energy consumption and GDP. The paper established that the contribution of energy consumption to GDP per capita is greater in developed countries than in developing countries. The study concluded that per capita energy consumption is crucial to developing countries' efforts to maintain their standard of living. Research similar to the topic of the present study was conducted by Islami et al. (2022). The results of the analysis included in the thesis show that the population has a positive and significant impact on carbon dioxide (CO_2) emissions in the G-20 member countries. Researchers have also shown that gross domestic product (GDP) has a small positive effect on carbon dioxide (CO_2) emissions in the G-20 member states.

6. CONCLUSION

This study has empirically investigated the relationship between GDP and CO_2 emissions for the 27 European Union member states from 2010 to 2019. The calculations performed using correlation and hierarchical cluster analysis did not confirm the first hypothesis (except for Greece). The first hypothesis was not confirmed because the GDP of the EU Member States increased by 27.6% between 2010 and 2019, while the CO_2 emissions of the EU Member States decreased by 11.5%.

The relative decoupling of the two indicators occurred during the period under study because the EU GDP growth rate is positive and the CO_2 emission rate is negative over the period 2010-2019. In absolute terms, the decoupling of GDP and CO_2 emissions occurs when environmental pressures are not increasing (unchanged) and only economic output is increasing. However, this absolute decoupling is not confirmed by the GDP and CO_2 emissions data of the EU Member States over the period under review but is instead a relative decoupling.

However, the second hypothesis has been proven in the case of Greece, where CO_2 emissions have fallen very significantly and GDP emissions have fallen in parallel. The former decreased by 26.3% and the latter by 6.0% in 2019 compared to 2010. A special fact about Greece is that the environmental Kuznets curve hypothesis was fulfilled for the country before 2010. Greece's GDP per capita had reached a level at which its CO_2 emissions had already fallen (López-Menéndez et al., 2014). Something happened to Greece because it is the only EU country where the theory of decoupling environmental pressures has not been implemented. This is because the theory says that CO_2 emissions should fall as GDP grows.

The significance of the study is that its results confirm the theory of environmental decoupling in the EU. This also means that the EU has made progress towards sustainable management over the period under review, as it is producing increasing GDP with decreasing CO_2 emissions.

As with other studies, this study has its limitations. The study was carried out on data from EU Member States, the scope could have been wider. Another limitation of the current research is that the empirical analysis focused on the relationship between economic growth and CO_2 emissions, but only for a narrow period. Moreover, during this period (2010-2019) the EU experienced dynamic economic growth and produced excellent GDP data.

The topic of this study can be explored in numerous directions in the future, some of which are mentioned by the author. A future research direction could be to investigate the decoupling theory of environmental pressures within the EU as a member state, or even on a broader, even global spectrum. An interesting research direction could also be the future need for fiscal and/or environmental regulations to reduce greenhouse gas emissions in CO_2 equivalent terms.

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