energies

MDPI

Article

The Trend in Environmental Load in the European Union during the Period of 2012–2022

László Török

Department of Engineering Management and Enterprise, Industrial Process Management Institute, Faculty of Engineering, University of Debrecen, Ótemető u.2-4., 4028 Debrecen, Hungary; dr.torok.laszlo@eng.unideb.hu

Abstract: The environmental burden is a global problem affecting the European Union. A comprehensive analysis of the environmental burden is essential for creating strategies supporting sustainable economic development. This study attempts to answer the question of why, despite the continuously decreasing energy consumption of the EU, the environmental burden of this region is not substantially decreasing. This study provides novel insights into this research area by integrating EU economic dynamics and environmental efficiency indicators. In this study, we used the IPAT method. Before the main analysis, the researcher conducted cross-sectional dependence, slope heterogeneity, and Westerlund cointegration tests using the primary data. Based on the results, the EU member states were classified into clusters, and a linear trend model analysis was carried out. The results show that the total environmental load of the EU did not decrease significantly between 2012 and 2022. The fact that the environmental burden remained at the same level is explained by the fact that there were 16 member countries whose total environmental load increased but whose economic output was lower during this time period. This was offset by 11 member countries with high economic outputs, whose total environmental load decreased. This study proved that GDP growth was the main driving force maintaining the total environmental load at the same level. The EU should encourage member states to continue to implement environmental protection rules to limit and eliminate costly environmental burdens on their societies and economies. This study can be helpful to researchers, political decision-makers, and experts working on environmental public policies for the EU.

Keywords: environmental load; European Union; IPAT model; clusters; linear trend model

check for updates

Citation: Török, L. The Trend in Environmental Load in the European Union during the Period of 2012–2022. *Energies* **2024**, *17*, 3473. https://doi.org/10.3390/en17143473

Academic Editors: Hongyu Ren and Fanying Kong

Received: 25 June 2024
Revised: 5 July 2024
Accepted: 9 July 2024
Published: 15 July 2024

Copyright: © 2024 by the author. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

This study examined the effects of reducing the emissions of harmful substances through technological development on environmental sustainability in European Union member states between 2012 and 2022. The theoretical basis of this study is that current information technology and digital revolution "greens" the economy by radically reducing the specific raw material and energy demand of production. The consequence of this decrease is that a unit of GDP is produced with an ever-decreasing rate of harmful emissions.

Today, the relationship between humans and their environment is fundamentally changing because information technology and digital transformation are causing technological, social, and lifestyle changes. It is not just the specific input demand of production in various industries (energy, labor, etc.) that is constantly decreasing, but also the development that occurs in all segments of the economy, which strengthens each other's effect (accelerator effect). The changes in the relationship between humans and their environment go beyond the traditional approach of technology-optimistic researchers, who, by examining the effect mechanism of specific digital solutions from a technological point of view, have concluded that there will be positive changes in terms of environmental impact and sustainability [1–4].

Because of the advancements in the development of technologies, it is an increasingly widely accepted belief in society that, in addition to external factors, the introduction

and application of digital technologies can help reduce the environmental impact of GDP production. One of the drivers of today's technological development is digital transformation, which should be understood as the collective concept of new technological solutions that change value-added production. The essential technologies of this digital transformation include cyber–physical systems, artificial intelligence, technology for generating and analyzing large amounts of data, machine vision, 3D printing, and blockchain. These essential technologies contribute significantly to the increase in the efficiency of production and service processes, the rise in the level of satisfaction of needs, and the increase in the value-added production (GDP) of national economies [5–12].

From the point of view of this research, the relationship between economic growth, population, and the environmental burden of harmful emissions related to energy consumption is noteworthy. The relationship between these variables is an important research area of environmental economics [13–15].

The mitigation of the closeness of the relationship between the three independent variables of this study (GDP, population, technology), i.e., the improvement in the ratio of additional consumption of raw materials and energy required for a unit of growth (and the resulting harmful emissions), is ensured partly by technological development and partly by system-level innovations. Because of the correlation between these three variables, it is important to highlight some references examining these variables, as mentioned below [16–19].

The topic of this study and the results obtained from the collected and analyzed data are significant given that the EU has set robust targets for environmental impact reduction. There are five horizontal axes in the EU's future environmental impact reduction policy, which are interconnected and built upon each other. These axes are reducing greenhouse gas emissions by 55%; reducing methane gas emissions by 30%; increasing share of renewable energy by 40%; increasing energy efficiency by 32.5%; and achieving net-zero emissions in terms of environmental impact by the year 2050.

The present study contributes to the literature on the environmental burden of energy consumption in three ways. First, this is the first study to examine the impact of air pollutants and greenhouse gas (GHG) emissions on environmental degradation in EU member states and two other variables. Air pollutants and GHG emissions play a significant role in global warming. Few studies have been published that link GDP production, population size, and technology with environmental impact. Second, this study examined the emissions of harmful substances from resource use, including the emissions of N_2O, CH_4, HFC, PFC, SF_6, and NF_3 gases. Third, no analysis has yet been conducted on this topic for the period 2012–2022 investigated in this study. This is a particular period because it includes significantly restructured data due to the pandemic. The rest of this article is structured as follows: Section 2 provides a review of the literature related to the research topic. The data and method are presented in Section 3. The results are presented in Section 4. The discussion based on the results is presented in Section 5, and Section 6 formulates the conclusions and recommendations.

This study provides a comprehensive picture of the evolution of the EU's environmental burden for the period 2012–2022, aiming to assist decision-makers in promoting ecological sustainability and environmental protection. The data were collected through a meticulous and precise process and analyzed with a level of detail and accuracy exceeding that of previous research. This study provides unique insights for planning and implementing EU environmental impact reduction policies more effectively.

2. Literature Review

The IPAT equation is a formula that has become a milestone in measuring human environmental impacts when the population, consumption, and technological components are the leading causes [20]. The IPAT equation used in this study is a conceptual framework equation used to analyze the impact of human activities on the environment and show the relationship between three factors and environmental load: population size, affluence, and technological level. In this study, the technological level is defined in terms of the

emissions of air pollutants and greenhouse gases, as it is an appropriate indicator that contributes to the total environmental load. In the analysis, this study assumed that the emissions of air pollutants and greenhouse gases will continuously decrease due to technological development.

Technological development significantly impacts the emissions of air pollutants and GHGs into the atmosphere through, for example, improvements in energy efficiency, the increasing use of renewable energy sources, and the modernization of industrial processes. This close relationship between technological development and air pollution justifies the definition of the variable T in this way.

Another point is that there are many international and regional initiatives to measure and monitor the emissions of air pollutants and GHGs, such as the UN Framework Convention on Climate Change (UNFCCC) and the EU Emissions Trading System (ETS). The data from these initiatives are more reliable than other data sources, enabling robust analysis of the EU's total environmental burden.

The IPAT equation is widely known and provides an analytical framework with clear conclusions regarding ecological efficiency.

The classic equation used in the field of environmental economics is as follows:

$$I = P \times A \times T \quad (1)$$

where I (impact) is the total environmental burden (impact); P (population) is the number of inhabitants; A (affluence) denotes the well-being of the population, which is expressed as GDP per capita; and T (technology) is the environmentally friendly nature of technological development, in which is the greenhouse effect per capita can be represented as the emissions of greenhouse gases.

The variable T in the equation $I = P \times A \times T$ indicates how resource-intensive the production of GDP is. T also expresses the extent to which GDP has an environmental impact on the goods and services used and the creation, transportation, and disposal of such services. Improving efficiency can reduce resource intensity, lowering the T multiplier. Because technology can influence environmental impact in many ways, researchers often tailor the unit of T to the situation, to which the equation $I = P \times A \times T$ is applied. For example, in a situation where the effect of human activity on climate change is measured, an appropriate unit of measure for T might be greenhouse gas emissions per capita.

The $I = P \times A \times T$ formula, i.e., the IPAT equation, is excellent for analyzing the trend in the environmental impact in the EU and its member states because it provides a comprehensive picture of the effects of various factors. The equation breaks down the total environmental load into three main components: population (P), economic affluence (A), and technological efficiency (T). This approach allows us to examine the impact of population growth, per capita economic activity, and technological change on the environment. Due to its flexibility and applicability, the IPAT equation is widely recognized and used in environmental research.

In recent years, researchers have used the IPAT equation and its extended model to explore the impact of social development on environmental pressures [21–31].

3. Materials and Methods

Table 1 shows the values of the environmental load of the EU member states during the period of 2012–2022. The values were calculated based on Eurostat data [32–34].

As a simple conceptual framework equation, IPAT has the following three characteristics: First, it is simple and focuses on human factors such as population, economic affluence, and technology. Second, it systematically analyzes the relationship between these human factors and total environmental impact. Third, because of its reliability, the equation is widely used to investigate environmental effects such as carbon dioxide emissions [35,36].

The aggregated data in Table 1 show that the EU's total environmental load increased slightly until 2019 and then decreased over the period under review. However, this decline

was not linear, as, in 2020, a significant decline was experienced, likely due to the effects of the COVID-19 pandemic.

Table 1. Values of the total environmental load (I) of EU member states (2012–2022).

Year/ Country	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2022/2012 (%)
BE	4164	4128	3987	4200	4183	4206	4403	4401	3764	4169	4002	96
BG	280	260	269	304	289	312	291	300	247	314	393	140
CZ	1947	1813	1872	2002	2107	2245	2366	2432	2160	2268	2214	114
DK	2574	2636	2489	2391	2582	2501	2644	2444	2130	2303	2257	88
DE	30,751	31,364	30,678	31,012	31,570	31,833	31,333	29,581	25,908	27,842	27,855	91
EE	224	265	275	247	290	322	347	274	189	217	227	101
IE	2387	2423	2564	3367	3410	3822	4037	4073	4133	4867	5178	217
EL	1895	1735	1721	1621	1551	1644	1601	1505	1161	1312	1453	77
ES	7033	6443	6503	6967	6847	7375	7474	7152	5168	5954	6465	92
FR	14,262	14,122	13,261	13,616	13,978	14,717	14,065	14,343	11,533	12,981	12,868	90
HR	239	221	212	229	242	278	262	273	231	271	317	133
IT	12,450	10,698	10,273	10,709	10,655	11,326	10,656	10,735	8844	10,719	11,187	90
CY	208	181	188	176	199	237	243	250	211	241	252	121
LV	74	88	132	125	109	100	149	125	136	172	208	281
LT	114	117	125	145	161	179	195	205	201	221	194	170
LU	1009	974	945	923	939	966	1001	1038	837	939	810	80
HU	580	571	588	643	676	729	772	808	702	784	782	135
MT	58	55	59	49	45	52	56	62	48	55	64	110
NL	8059	8022	7908	8281	8458	8490	8472	8331	7047	7568	7323	91
AT	2782	2769	2578	2701	2723	3028	3288	3323	3025	2548	2572	92
PL	3546	3505	3596	3811	4001	4349	4655	4829	4718	5194	5533	156
PT	1086	1081	1300	1119	1195	1715	1236	1192	933	937	999	92
RO	625	553	503	515	502	594	643	650	553	645	666	107
SI	229	227	232	315	345	361	372	342	308	339	337	147
SK	478	467	477	510	528	547	594	558	462	554	561	117
FI	1422	1658	1454	1510	1783	1822	2224	1930	1561	1933	1940	136
SE	152	39	39	123	210	428	698	716	528	186	284	187
EU	98,633	96,415	94,228	97,611	99,578	104,178	104,077	101,872	86,738	95,533	96,941	98

Note: when calculating the value of I, population (P) is calculated in millions of people, GDP per capita (A) in thousands of euros, and air pollution and greenhouse gas emissions per capita (T) in tons. Source: own calculation.

3.1. Testing Data

Before performing the analyses, the following data tests were performed:

1. Pesaran CD (cross-sectional dependence) test:

$$\mathrm{CD} = \sqrt{2T/N(N-1)}\left(\sum_{i=0}^{N-1}\sum_{j=i+1}^{N-1} \times \mathrm{P}ij\right) \quad (2)$$

where P*ij* is the sample correlation coefficient of the residuals between cross-sections *i* and *j*, *N* is the number of cross-sections, and *T* is the time dimension.

2. Breusch–Pagan (slope heterogeneity) test:

$$\Delta = \sqrt{N} \times \left(\mathrm{H} - \mathrm{k}/\sqrt{2k}\right) \quad (3)$$

where $\mathrm{H} = 1/\mathrm{N} \sum_{i=1}^{N} x\ (e_i' x(I - X_i)\ (X_i')^{1} X_i') e_i/\delta^2$ *k* is the number of regressors, and *ei* are the residuals.

3. Westerlund cointegration test:

$$G_t = 1/N\sum_{i=1}^{N} r_i,\ G_\alpha = 1/N\sum_{i=1}^{N} \alpha_i \quad (4)$$

where r, r_i, and α, α_i are the individual test statistics for each cross-section.

Table 2 shows the results of the calculations after processing 297 data.

Table 2. Data testing methods and results.

Test Method	Number of Data Points	Test Result	Significance Level
Pesaran CD Test	297	0.2114	$p < 0.05$
Breusch–Pagan Test	297	0.2687	$p < 0.05$
Westerlund Cointegration Test	297	0.1223	$p < 0.05$

Source: own calculation.

3.1.1. Pesaran CD Test Result

The *p*-value of the Pesaran CD test is 0.2114, which is higher than the significance level (0.05 for this study). This means there is not enough evidence to suggest the presence of cross-sectional dependence in the data of the 27 EU member states between 2012 and 2022 (I). The lack of cross-sectional dependence also means that the data of individual member states do not significantly influence each other's data. In other words, based on the data, the (I) values of the countries are independent of each other.

3.1.2. Breusch–Pagan Test Result

For the I values (the environmental burden), where I is defined as the product of the countries' population size (P), GDP per capita (A), and greenhouse gas emissions per capita (T), the result of the Breusch–Pagan test indicates the following: since heteroskedasticity is absent, the linear regression model that was applied to the I values can provide more reliable and accurate estimates. There is also no heteroscedasticity in this model, which confirms that the regression model results are reliable. It also follows from the model's reliability that the data used to examine the total environmental load of the EU member states correctly represent reality without significant differences in the variance.

3.1.3. Westerlund Cointegration Test Result

The *p*-value of this test (0.1223) indicates no solid statistical evidence for cointegration in the EU member states' (I) data at the usual 0.05 significance level. In other words, based on the data, we cannot say with certainty that there is a long-term equilibrium relationship between the examined time series (the I values indicating the environmental load of the EU member states). The test result also shows no solid statistical evidence that the total environmental load of the EU member states is in a long-term equilibrium relationship with each other. This means that each individual EU member state's total environmental load (I) follows a different long-term trend. From the result, it can be concluded that the individual member states follow different paths regarding their environmental load.

Using second-generation econometric techniques (cross-sectional dependency, slope heterogeneity, and Westerlund cointegration tests) to analyze the environmental burden of the EU and its member states increases the accuracy and reliability of the results. These procedures consider the interactions between the EU member states, country-by-country differences, and temporal co-movements, thereby enabling a more precise exploration of complex relationships and trends during the period of 2012–2022.

4. Results

4.1. Results of Changes in Total Environmental Load (I) between 2012 and 2022

The data in the last column of Table 1 show the extent to which the I values of the EU member states had changed by 2022 compared to the values in 2012. These are relevant data, as they represent the changes in the total environmental load of the EU member states compared to themselves in previous years and to other countries.

Data analysis was performed using the Shapiro–Wilk test. The results are as follows: sample size (n): 27, average (x): 1.241111, median:1.10, sample standard deviation (S): 0.466149, sum of squares: 5.649667, b:2.142237, skewness: 1.856885, and excess kurtosis: 4.025723.

Figure 1 illustrates that the data with respect to the changes in the values of the EU member states' total environmental load (I) follow a normal distribution. This normal distribution is a probability function that shows how the values of the evolution of the variable I are distributed. A normal distribution is an arrangement of data from a given population (in this case, I) where most values are concentrated in the middle of the range. The further an I value is from the center of the range, the fewer cases it has. The central part of the I distribution is located near the average, from which it follows that most of the values expressing the change in the total environmental load of the EU member states are grouped around the average.

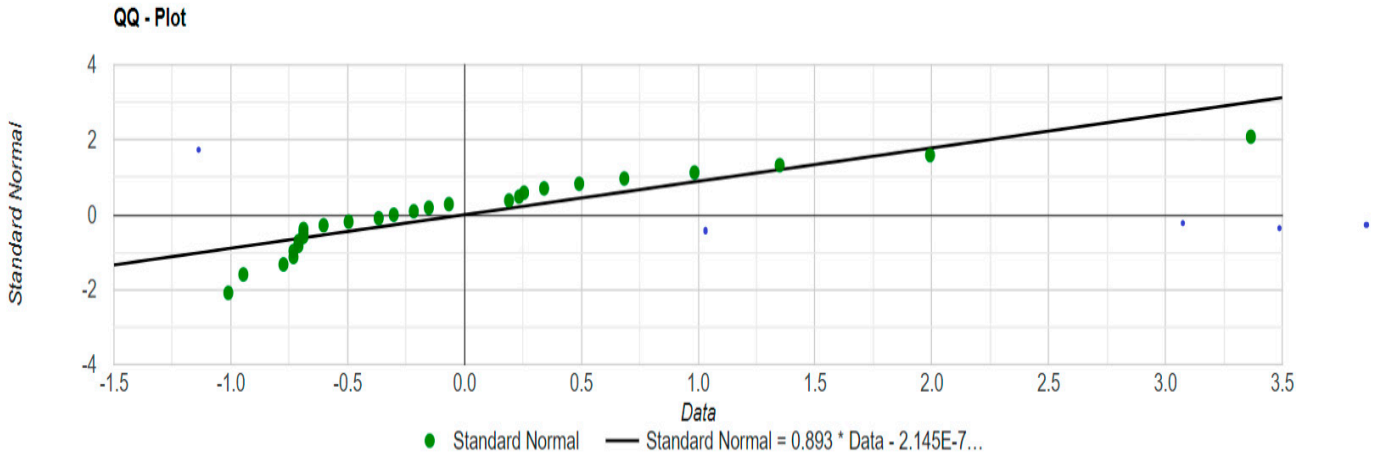

Figure 1. Distribution of changes in the I values of the EU member states. Source: own figure.

Figure 1 shows that the data is normally distributed.

4.2. Clusters of Changes in the Total Environmental Load (I) of EU Member States

The meaningful separation and grouping of data is an essential goal of many scientific fields. Cluster analysis is a frequently used method for data mining, pattern recognition, information retrieval, data compression, and computer graphics. Cluster analysis is not a specific procedure but a grouping method that divides the original data into meaningful or useful groups (clusters) depending on the desired end goal [37–42].

This subsection describes the analysis and interpretation of the arrangement of the EU member states into five clusters based on the I values of environmental load ($I = P \times A \times T$). During the analysis, this study took into account each country's population size (P), GDP per capita (A), and greenhouse gas emissions per capita (T). Based on the 2022/2012 ratio of the I values calculated with the three independent variables, the algorithm created the clusters shown in Figure 2. The results of the cluster analysis are as follows:

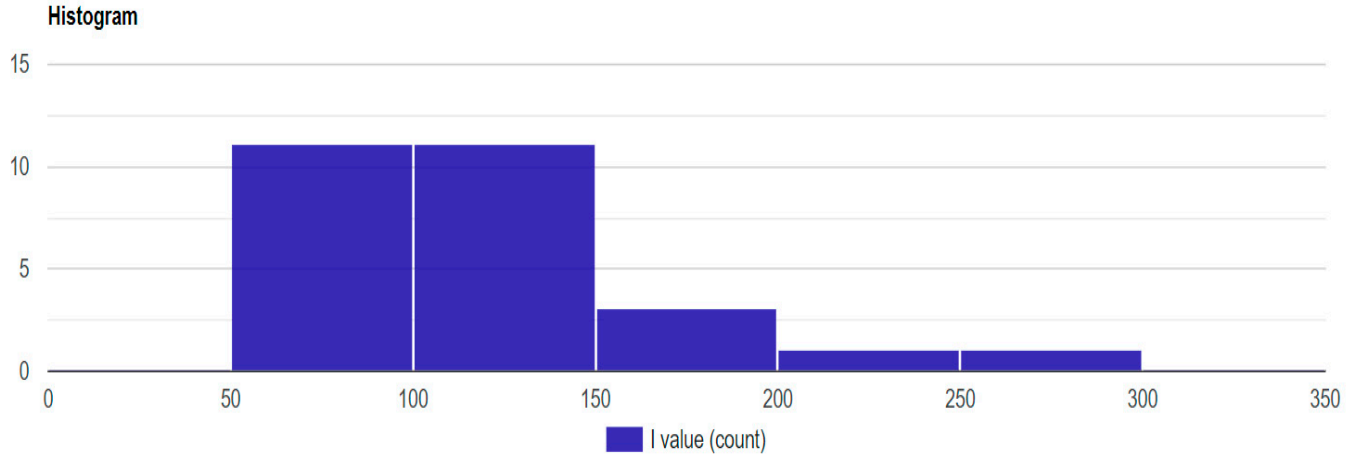

Figure 2. Clusters of the distribution of the I values of EU member states. Source: own figure.

Eleven EU member states were classified in the first cluster (with the change in the values of I showing a decrease between 50 and 100 percent): Belgium, Denmark, Germany, Greece, Spain, France, Italy, Luxembourg, the Netherlands, Portugal, and Austria.

These member states are characterized by the following independent variables in the trend of their total environmental load (I): high population, high GDP per capita, medium–high greenhouse gas emissions per capita, and high total environmental load (except for Luxembourg).

These EU member states have a large population size (except for Luxembourg) and a high economic output (GDP), which results in a significant environmental load (I). Their high industrial and financial activities result in high per capita greenhouse gas emissions.

The second cluster (with the change in the values of I showing an increase between 0 and 50 percent) comprises 11 EU member states: Bulgaria, the Czech Republic, Estonia, Croatia, Cyprus, Hungary, Malta, Romania, Slovenia, Slovakia, and Finland.

These member states are characterized by the following independent variables in the trend of the values of their total environmental load (I): medium population; low–medium GDP per capita; medium–high greenhouse gas emissions per capita; and high total environmental load (except for Cyprus and Malta). These EU member states are growing economies with a moderate environmental burden. Because of their economic development and industrialization, their environmental impacts are significant but not as high as in the case of the member states classified in Cluster 1.

The third cluster (with the change in the values of I showing an increase between 50 and 100 percent) includes three EU member states: Lithuania, Poland, and Sweden. These member states are characterized by the following independent variables in the trend of the values of their total environmental load (I): low–medium population; medium–high GDP per capita; medium greenhouse gas emissions per capita (except for Sweden, where the value of this variable is the lowest among the EU member states); and low total environmental load.

These EU member states have a smaller population, but their economic performance (except for Lithuania) is relatively high. Because of the smaller population, the environmental burden is lower overall; however, because of the intensity of economic activity, it is still significant in countries such as Poland.

The fourth cluster (with an increase of 200–250 percent in the change of the values of I) includes only Ireland. This member state is characterized by the following independent variables in the trend of the value of its total environmental load (I): low population; high GDP per capita (second highest among the EU member states after Luxembourg); very high greenhouse gas emissions per capita (highest among the EU member states); and high total environmental load. With Ireland's high economic performance and the highest

greenhouse gas emissions per capita in the EU, its total environmental burden is the sixth highest in the EU despite its low population.

Only Latvia was included in the fifth cluster (an increase of 250–300 percent in the change in the values of I). This member state is characterized by the following independent variables in the trend of its total environmental load (I): low population; low GDP per capita (fourth lowest among the EU member states); medium greenhouse gas emissions per capita (however, it has one of the highest growth rates in the EU, rising from 3.0 in 2012 to 8.0 by 2022); and low total environmental load.

Table 3 shows the clusters of EU member states.

Table 3. Characteristics of IPAT variables of clusters.

Cluster Serial Number	Cluster Countries	Population (P)	GDP per Capita (A)	Pollutants per Capita (T)	Total Environmental Load (I)
1.	BE, DK, DE, EL, ES, FR, IT, LU, NL, PT, AT	high	high	average–high	high (except for Luxembourg)
2.	BG, CZ, EE, HR, CY, HU, MT, RO, SI, SK, FI	average	low–average	average–high	high (except for Cyprus and Malta)
3.	LT, PL, SE	low–average	average–high	average (except for Sweden)	low
4.	IE	low	high	high	high
5.	LV	low	low	average	low

Source: own table.

4.3. Linear Trend Model Analysis

The linear trend model equation is as follows:

$$I_t = \alpha + \beta t + \epsilon_t \quad (5)$$

where I_t is the value of the environmental load (I) at a certain time point (year); α is the axis section (intercept) of the equation, which shows the value of I when $t = 0$ (initial value); β is the slope of the trend, which indicates how much the value of I changes every year; t is time (years); and ϵ_t is the error term, which includes effects not explained by the model.

The linear trend model examines the relationship between the total environmental load (I) and year for each EU member state. The model estimates each country's intercept and slope, indicating the initial value and the annual change.

Table 4 shows the results of the linear trend model test per EU member state.

Table 4. The trend of development of total environmental load (I) of each EU member state over time (2012–2022).

Country	Intercept (α)	Slope (β)	R-Squared	*p*-Value
BE	4164.45	−15.91	0.022	0.669
BG	267.09	8.73	0.420	0.079
CZ	1905.18	32.45	0.715	0.004
DK	2590.45	18.00	0.286	0.183
DE	30,876.82	−307.64	0.653	0.010
EE	242.09	−0.55	0.001	0.970
IE	2797.27	273.18	0.879	0.001
EL	1722.00	−47.64	0.641	0.011
ES	6805.36	−37.27	0.224	0.250

Table 4. *Cont.*

Country	Intercept (α)	Slope (β)	R-Squared	*p*-Value
FR	13,812.09	−78.18	0.498	0.045
HR	239.36	7.82	0.698	0.005
IT	11,122.64	21.27	0.017	0.717
CY	197.18	6.36	0.350	0.130
LV	102.45	7.45	0.572	0.024
LT	153.55	4.36	0.334	0.144
LU	978.18	−10.27	0.056	0.522
HU	597.82	18.64	0.780	0.001
MT	51.09	1.36	0.301	0.171
NL	8038.55	−13.64	0.047	0.556
AT	2782.00	−18.00	0.286	0.183
PL	3593.73	196.73	0.942	0.001
PT	1157.27	−20.36	0.134	0.412
RO	573.36	10.09	0.600	0.019
SI	280.64	5.36	0.322	0.156
SK	487.36	5.91	0.562	0.026
FI	1564.91	39.18	0.551	0.029
SE	257.55	5.91	0.102	0.469

Source: own table.

Based on the linear trend model, this study examined the trends in the I values of each country over time. The intercept (α) shows the initial I value of a given country, while the slope (β) indicates the rate of change over time. High R-squared values (for example, for Ireland, Germany, and Poland) suggest that the time trends explain the variation in I values well. Low *p*-values (e.g., for Ireland, Germany, and Poland) indicate a significant relationship between time and I values. However, the time trends do not show a significant relationship for several countries (e.g., Belgium, Estonia, and Luxembourg).

Based on the analysis of the linear trend model, the following conclusions can be made:

The negative slope (β) values indicate that the total environmental load decreased during the examined period in the most developed EU member states (Belgium, Denmark, Germany, Greece, Spain, France, Italy, Luxembourg, the Netherlands, Portugal, and Austria). For other member states, the value of I significantly increases with β and the *p*-values with a variable intensity.

4.4. Analysis of the EU-Level Total Environmental Load (I) and Its Independent Variables

This subsection presents an analysis of the consolidated data of total environmental load for all EU member states as a whole (Table 5), thereby enabling the identification of larger-scale trends and correlations that are not necessarily visible at the level of individual member states.

The following should be noted from the data shown in Figure 3. The population (P) of the EU member states as a whole grew very slightly during this period, practically stagnating. The GDP per capita (A) steadily increased. In 2012, the index value was 100.00, which rose to 115.00 by 2022, showing an increase of 15%. In terms of environmental impact (T), the environmental impact indicator decreased during the period. In 2012, the index value was 100.00; by 2022, it had reduced to 86.00, representing a 14% decrease. The total environmental load (I) decreased minimally during the period. In 2012, the index value was 100.00; by 2022, it had reduced to 98.00, showing a decrease of 2%.

Table 5. Values of the EU's total environmental load (I) and its independent variables (P, A, and T) (2012–2022).

Variables	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
P *	441	441	443	444	445	446	446	447	448	447	447
A **	25,140	25,060	25,420	25,950	26,400	27,100	27,610	28,050	26,440	28,040	28,920
T ***	8.5	8.3	8.0	8.1	8.1	8.3	8.1	7.8	6.9	7.4	7.3
I ****	98,633	96,415	94,228	97,611	99,578	104,178	104,077	101,872	86,738	95,533	96,941

* million people; ** GDP per capita, thousand euros/capita/year; *** air pollutants and greenhouse gases per person, thousand tons/person/year; **** calculated theoretical value. Source: own calculation.

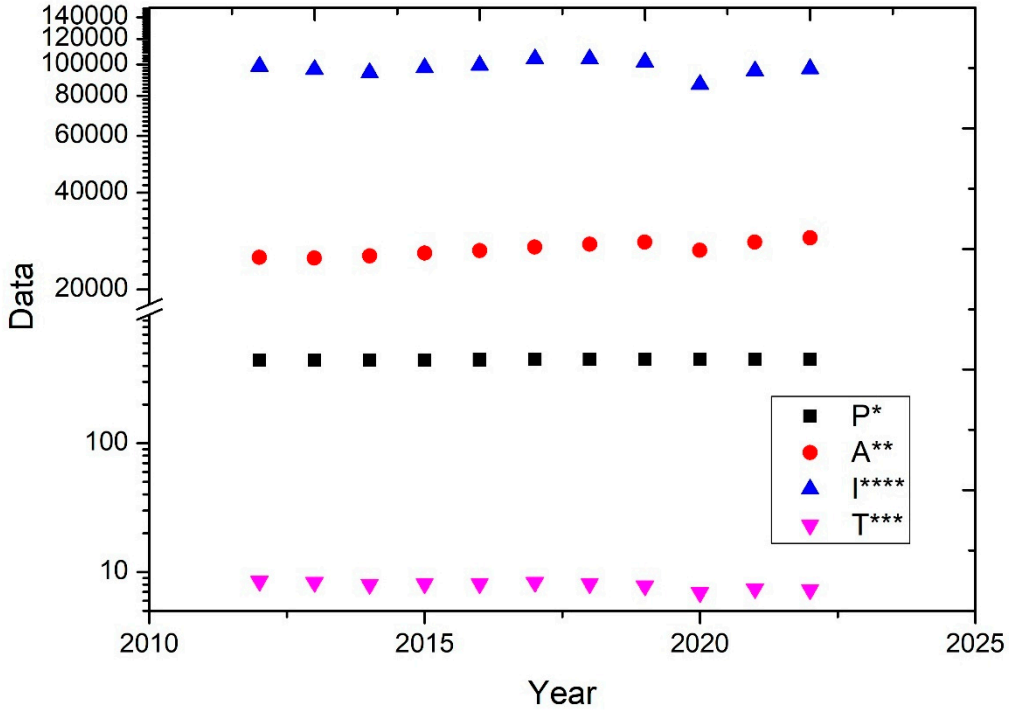

Figure 3. Values of the dependent (I) and independent (P, A, T) variables of the EU's total environmental load (2012–2022). Source: own figure. * million people; ** GDP per capita, thousand euros/capita/year; *** air pollutants and greenhouse gases per person, thousand tons/person/year; **** calculated theoretical value.

Figure 3 shows the values of one dependent and three independent variables of the IPAT model.

5. Discussion

Based on the analyses, this study identified several significant results. The first finding is with respect to the clustering separated the EU member states according to the degree and direction (decrease or increase) of total environmental load during the period under review. The results show that only the EU member states with high economic output and environmental load decreased their total environmental load between 2012 and 2022.

Using the linear trend model analysis, this study examined the trends of each EU member state's total environmental load values over time. Based on this analysis, the EU member states' environmental load (I) decreased slightly between 2012 and 2022. According to the results, the values of I decreased by an average of 0.2 percent per year, indicating that the EU member states, in general, successfully reduced their environmental load during this period. However, this decrease was only minimal.

This study's most significant result and conclusion is that the EU member states' aggregated total environmental burden (I) decreased minimally, by only two percent, during the period under review (see Table 1). Based on this result, it can be concluded that the environmental load of the EU remained at the same level in 2022 compared to 2012. As presented in Section 4.2, this study showed that the member states played significantly different roles in their contribution to the fact that the EU's environmental load did not change significantly during the period under review. The total environmental load decreased in 11 of the 27 member states and increased in 16 (see Figure 2). The value of I remained at the same level, explained by the fact that there were 16 member countries whose total environmental load increased but whose economic output was lower. This was offset by 11 member states with high economic output, whose total environmental load decreased.

Among the three independent variables (population, greenhouse gas emissions per capita, and GDP per capita), the population did not significantly influence the total environmental load, as the population size practically did not change in the EU during the examined period (2012 = 441 and 2022 = 447 million people).

Next, the roles of the two other independent variables were examined. First, I examined the role of air pollution and greenhouse gas (GHG) emissions per capita. One of the most critical areas of action regarding climate change is the regulation of GHG emissions. The EU has set the goal of achieving at least a 20 percent reduction in GHG emissions by 2020 and a 40 percent reduction by 2030 compared to the 1990 emission level, as well as carbon neutrality by 2050.

Several studies have examined the role and significance of GHG emissions in the total environmental load, with the most important findings of these studies being diverse [43–47].

GHG emissions have continuously decreased in the European Union due to the permanent decrease in specific energy consumption. Improving energy efficiency will reduce GHG emissions, help fight climate change, enhance air quality, and reduce the EU's dependence on fossil fuels [44,48–50].

Because of the decrease in specific energy consumption, air pollutants and greenhouse gas emissions per capita also decreased in the EU member states (by 14.12 percent [34]) during the examined period. Consequently, this variable contributed to the reduction in the value of total environmental load. Despite this, the total environmental load did not decrease significantly in the EU member states during the period under review.

In addition to the population size remaining at the same level and the reduction in GHG emissions, based on the IPAT's arithmetic calculation, the total environmental load could only stay at the same level if the GDP per capita increased robustly. The GDP per capita was 25,110 euros in 2012 and 28,920 euros in 2022; the growth rate was 15.17 percent [33]. This economic growth variable can be considered representative, reflecting the economy's ability to produce goods and services, which entails a significant environmental burden. In addition, energy consumption is closely related to GDP output and population growth, as both require energy. Theoretically, an increase in the value of these two variables entails an increase in the total environmental load.

The most important result of this study is that, in addition to the unchanged population size in the EU, as a result of the robust reduction in per capita air pollutant and greenhouse gas emissions and the significant growth of GDP, the total environmental load did not change significantly between 2012 and 2022. In summary, it can be concluded that the main driving force behind the total environmental load remaining at the same level was the growth of GDP in the EU during the examined period.

I will present some results from the literature, which have been investigated using the variables of the IPAT equation. According to the research results, in most countries in the ASEAN region, population growth and GDP growth were the main driving forces of the increase in environmental load (CO_2 emissions). Fossil fuels contributed significantly to the increase in the environmental load (CO_2 emissions). However, the increase in CO_2 emissions was offset by the improved energy efficiency and carbon dioxide intensity of fossil

energy [31]. A study combined the IPAT model and the ARDL model to analyze the impact of GDP per capita, renewable energy consumption, urbanization, and unemployment on greenhouse gas emissions. The results show that while GDP per capita and urbanization increase the environmental load, renewable energy significantly reduces it [51].

Another study also used an improved version of the basic IPAT model. Exploring the complex relationship between economic and energy indicators and environmental outcomes, that study applied the STIRPAT model to analyze the environmental impact of GDP, population dynamics, fossil fuels, renewable energy, and nuclear power in South Korea. The study confirmed the results of previous research, showing that increases in GDP and population growth in South Korea lead to higher CO_2 emissions (higher environmental load) and that the transition to renewable energy can reduce the ecological load of the country [52].

A previous study applied the classic IPAT (impact–population–affluence–technology) master equation to measure and compare trends in material-use efficiency in Taiwan with other Asia-Pacific countries. That study found that the environmental burden was decoupled from economic growth. Regarding the decomposition analysis of the IPAT equation and comparison with 38 other countries, Taiwan's material-use efficiency did not perform as well as GDP growth [53]. According to a 2020 study, energy-related variables such as energy price and energy efficiency are also essential factors impacting the environmental load. Furthermore, the IPAT model (a method of decomposing environmental impact (I) into socio-economic variables: population (P), affluence (A), and technology (T)) suggests that socio-demographic variables such as population and urbanization have an impact on the non-linear relationship between income and emissions. In addition, the researchers proved that an aging population reduces the emission level by 0.4 percent, whereas a younger population increases it [54].

As with all research studies, this study has its limitations. Although technological development (T) plays a role in reducing air pollutant and greenhouse gas emissions in the EU (and all member states), this study did not carry out a detailed analysis of exactly which technological changes (renewable energy sources, energy efficiency measures, etc.) contributed most to the to decrease. The second limitation of this study is that the analysis did not examine economic factors that could have influenced the changes in GDP per capita (A) and T values. Factors such as economic recessions (e.g., due to pandemics) or booms may have impacted the variables influencing the total environmental load (I). Another limitation is that this study did not examine changes in the population composition due to processes such as urbanization, demographic changes, or migration, which may also have affected the total environmental load of the member states. The present analysis did not examine regional differences either. Individual EU member states' industrial structures and environmental protection policies may have had different effects on the dependent variable (I) and the independent variables (A, P, and T). Lastly, this study did not address the export of GDP emissions. It may have happened that some EU member countries reduced their emissions by transferring their production and environmental load to other countries. The above-described limitations of this research may indicate new research directions.

6. Conclusions and Recommendations

This research aimed to provide a detailed and comprehensive analysis of changes in the environmental impact of the EU and its member states during the period 2012–2022, thus supporting the EU's political decisions, its evaluation of the region's technological development, and its implementation of sustainable development goals. A secondary aim of this study was to increase the knowledge of the scientific community and contribute to more effective management of the environmental load.

Both positive and negative statements can be drawn from the study's main results. The impact of technological development should be considered positive since the reduction in specific air pollutants and greenhouse gas emissions indicates that the environmental regulations and technological developments introduced in the EU are effective. This has the

beneficial effect of reducing the overall environmental load. The increase in GDP per capita also has a positive impact, as the results show that the EU's economic performance has improved, which has generally led to a better quality of life and economic stability (except in 2020). In addition to maintaining economic growth, it is possible to moderately reduce environmental emissions in the EU, which is one of the goals of sustainable development. The results suggest that EU environmental policies aimed at reducing environmental emissions have been successful.

However, the fact that the total environmental load (I) practically did not change despite the decrease in specific environmental emissions can be considered as negative. This suggests that the increase in the amounts of products and services generated by the growth of GDP offsets the reduction in pollution. This presents a challenge in achieving the EU's sustainability goals.

The study results show that the current economic growth model in the EU is not necessarily compatible with long-term environmental sustainability. New innovative approaches are needed for sustainable development if a decreasing environmental load does not accompany the EU's economic growth.

In the EU, the total environmental burden decreased marginally between 2012 and 2022; the correct term to characterize the state reached is stagnation. To make meaningful progress, the EU must prioritize technological development and innovation that promotes economic growth without increasing the environmental burden. Particular attention should be paid to the development of green technologies and the circular economy, which enable GDP growth without burdening the environment. The EU also needs to tighten current environmental regulations further, especially regulations concerning pollutant and carbon dioxide emissions. Investments in low-carbon technologies and measures to increase energy efficiency must be supported.

Funding: This research received no external funding.

Data Availability Statement: Data are contained within the article.

Conflicts of Interest: The author declares no conflicts of interest.

Abbreviations

The European Union (EU) consists of 27 countries: Sweden (SE), Spain (ES), Slovenia (SI), Slovakia (SK), Romania (RO), Portugal (PT), Poland (PL), the Netherlands (NL), Malta (MT), Luxemburg (LU), Lithuania (LT), Latvia (LV), Italy (IT), Ireland (IE), Hungary (HU), Greece (EL), Germany (DE), France (FR), Finland (FI), Estonia (EE), Denmark (DK), the Czech Republic (CZ), Cyprus (CY), Croatia (HR), Bulgaria (BG), Belgium (BE), and Austria (AU).

References

1. Berman, B. 3-D printing: The new industrial revolution. *Bus. Horiz.* **2023**, *55*, 155–162. [CrossRef]
2. Duflou, J.R.; Sutherland, J.W.; Dornfeld, D.; Herrmann, C.; Jeswiet, J.; Kara, S.; Hauschild, M.Z.; Kellens, K. Towards energy and resource efficient manufacturing, A processes and systems approach. *CIRP Ann.-Manuf. Technol.* **2012**, *61*, 587–609. [CrossRef]
3. Kiel, D.; Müller, J.M.; Arnold, C.; Voigt, K.I. Sustainable Industrial Value Creation. Benefits and Challenges of Industry 4.0. *Int. J. Innov. Manag.* **2017**, *21*, 1740015. [CrossRef]
4. Stock, T.; Seliger, G. Opportunities of sustainable manufacturing in industry 4.0. *Procedia CIRP* **2016**, *40*, 536–541. [CrossRef]
5. Lastauskaite, A.; Krusinskas, R. The Impact of Production Digitalization Investments on European Companies' Financial Performance. *Economies* **2024**, *12*, 138. [CrossRef]
6. Török, L. The importance of digitalization and robotization in vehicle production in the European Union. *Int. Rev. Appl. Sci. Eng.* **2022**, *14*, 125–131. [CrossRef]
7. Li, P.; Liu, J.; Lu, X.; Xie, Y.; Wang, Z. Digitalization as a Factor of Production in China and the Impact on Total Factor Productivity (TFP). *Systems* **2024**, *12*, 164. [CrossRef]
8. Török, L. The relationship between digital development and economic growth in the European Union. *Int. Rev. Appl. Sci. Eng.* **2024**, 1–15. [CrossRef]
9. Trauer, J.; Pfingstl, S.; Finsterer, M.; Zimmermann, M. Improving Production Efficiency with a Digital Twin Based on Anomaly Detection. *Sustainability* **2021**, *13*, 10155. [CrossRef]

10. Bánhidi, Z.; Dobos, I. Measurement of digital development with partial orders, Tiered DEA, and cluster analysis for the European Union. *Int. Rev. Appl. Sci. Eng.* **2023**, *14*, 392–401. [CrossRef]
11. Galkovskaya, V.; Volos, M. Economic Efficiency of Implementing Digital Technologies in Energy Power. *Sustainability* **2022**, *14*, 15382. [CrossRef]
12. Jemai, H.; Badri, A.; Fredj, N.B. Towards a better understanding of the complex industrial systems: Case of production systems. *Int. Rev. Appl. Sci. Eng.* **2023**, *14*, 383–391. [CrossRef]
13. Setioningtyas, W.P.; Illés, C.B.; Dunay, A.; Hadi, A.; Wibowo, T.S. Environmental Economics, and the SDGs: A Review of Their Relationships and Barriers. *Sustainability* **2022**, *14*, 7513. [CrossRef]
14. Niu, M.; Zhang, S.; Zhang, N.; Wen, Z.; Xu, M.; Yang, Y. Progress in the Research of Environmental Macroeconomics. *Sustainability* **2022**, *14*, 1190. [CrossRef]
15. Blampied, N. Economic growth, environmental constraints, and convergence: The declining growth premium for developing economies. *Ecol. Econ.* **2021**, *181*, 106919. [CrossRef]
16. Kao, Y.-S.; Nawata, K.; Huang, C.-Y. Systemic Functions Evaluation based Technological Innovation System for the Sustainability of IoT in the Manufacturing Industry. *Sustainability* **2019**, *11*, 2342. [CrossRef]
17. Amitrano, C.C.; Tregua, M.; Russo Spena, T.; Bifulco, F. On Technology in Innovation Systems and Innovation-Ecosystem Perspectives: A Cross-Linking Analysis. *Sustainability* **2018**, *10*, 3744. [CrossRef]
18. Kjøde, S.G. Towards Systemic Innovation Programmes for Sustainability Transitions: A Comparative Study of Two Design-Led Cases. *Sustainability* **2023**, *15*, 10182. [CrossRef]
19. Todorovic, T.; Medic, N.; Delic, M.; Zivlak, N.; Gracanin, D. Performance Implications of Organizational and Technological Innovation: An Integrative Perspective. *Sustainability* **2022**, *14*, 2836. [CrossRef]
20. Ehrlich, P.R.; Holdren, J.P. Impact of population growth. *Science* **1971**, *171*, 1212–1217. [CrossRef]
21. MacKellar, F.L.; Lutz, W.; Prinz, C.; Goujon, A. Population, households, and CO_2 emissions. *Popul. Dev. Rev.* **1995**, *21*, 849–865. [CrossRef]
22. Wernick, I.K.; Waggoner, P.E.; Ausubel, J.H. Searching for leverage to conserve forests: The industrial ecology of wood products in the United States. *J. Ind. Ecol.* **1997**, *1*, 125–145. [CrossRef]
23. Waggoner, P.E.; Jesse, H.A. A Framework for Sustainability Science: A renovated IPAT Identity. *Proc. Natl. Acad. Sci. USA* **2002**, *99*, 7860–7865. [CrossRef]
24. Schulze, P.C. I=PBAT. *Ecol. Econ.* **2002**, *40*, 149–150. [CrossRef]
25. Xu, Z.; Cheng, G.; Qiu, G. ImpACTS equation for sustainability evaluation. *J. Geogr.* **2005**, *2*, 198–208.
26. Li, B.; Liu, X.; Li, Z. Using the STIRPAT model to explore the factors driving regional CO_2 emissions: A case of Tianjin, China. *Nat. Hazards* **2015**, *76*, 1667–1685. [CrossRef]
27. Dietz, T.; Rosa, E. Effects of Population and Affluence on CO_2 Emissions. *Proc. Natl. Acad. Sci. USA* **1997**, *94*, 175–179. [CrossRef]
28. Nosheen, M.; Iqbal, J.; Abbasi, M.A. Do technological innovations promote green growth in the European Union? *Environ. Sci. Pollut. Res.* **2021**, *28*, 21717–21729. [CrossRef]
29. Da Silva, B.A.; Constantino, M.; de Oliveira, O.S.; dos Santos, S.A.L.; Tabak, B.M.; da Costa, R.B. New indicator for measuring the environmental sustainability of publicly traded companies: An innovation for the IPAT approach. *J. Clean. Prod.* **2019**, *215*, 354–363. [CrossRef]
30. Szalay, Z.; Csoknyai, T. Life cycle costs and environmental impacts of a nearly zero-energy detached house. *Int. Rev. Appl. Sci. Eng.* **2013**, *4*, 163–169. [CrossRef]
31. Chontanawat, J. Driving Forces of Energy-Related CO_2 Emissions Based on Expanded IPAT Decomposition Analysis: Evidence from ASEAN and Four Selected Countries. *Energies* **2019**, *12*, 764. [CrossRef]
32. Eurostat, Population on 1 January. Available online: https://ec.europa.eu/eurostat/databrowser/view/tps00001/default/table?lang=en (accessed on 2 May 2024).
33. Eurostat, Real GDP per Capita. Available online: https://ec.europa.eu/eurostat/databrowser/view/sdg_08_10/default/table (accessed on 2 May 2024).
34. Eurostat, Net Greenhouse Gas Emissions. Available online: https://ec.europa.eu/eurostat/databrowser/view/sdg_13_10/default/table?lang=en&category=t_env.t_env_air (accessed on 3 May 2024).
35. Wang, K. Analysis of influencing factors of water use in Gansu Province based on IPAT equation China's Population. *Res. Environ.* **2011**, *21*, 148–152.
36. Wang, Y.G.; Wang, X.; Sun, C.H.; Lu, X.Y. Research progress in the application of IPAT and its extended model. *J. App. Ecol.* **2015**, *26*, 949–957.
37. Lim, Z.-Y.; Ong, L.-Y.; Leow, M.-C. A Review on Clustering Techniques: Creating Better User Experience for Online Roadshow. *Future Internet* **2021**, *13*, 233. [CrossRef]
38. Farahnakian, F.; Nicolas, F.; Farahnakian, F.; Nevalainen, P.; Sheikh, J.; Heikkonen, J.; Raduly-Baka, C. A Comprehensive Study of Clustering-Based Techniques for Detecting Abnormal Vessel Behavior. *Remote Sens.* **2023**, *15*, 1477. [CrossRef]
39. Mohamed Nafuri, A.F.; Sani, N.S.; Zainudin, N.F.A.; Rahman, A.H.A.; Aliff, M. Clustering Analysis for Classifying Student Academic Performance in Higher Education. *Appl. Sci.* **2022**, *12*, 9467. [CrossRef]
40. Pita, A.; Rodriguez, F.J.; Navarro, J.M. Analysis and Evaluation of Clustering Techniques Applied to Wireless Acoustics Sensor Network Data. *Appl. Sci.* **2022**, *12*, 8550. [CrossRef]

41. Kim, B.; Kim, J.; Yi, G. Analysis of Clustering Evaluation Considering Features of Item Response Data Using Data Mining Technique for Setting Cut-Off Scores. *Symmetry* **2017**, *9*, 62. [CrossRef]
42. Kronova, J.; Izarikova, G.; Trebuna, P.; Pekarcikova, M.; Filo, M. Application Cluster Analysis as a Support form Modelling and Digitalizing the Logistics Processes in Warehousing. *Appl. Sci.* **2024**, *14*, 4343. [CrossRef]
43. Balaras, C.A.; Dascalaki, E.G.; Patsioti, M.; Droutsa, K.G.; Kontoyiannidis, S.; Cholewa, T. Carbon and Greenhouse Gas Emissions from Electricity Consumption in European Union Buildings. *Buildings* **2024**, *14*, 71. [CrossRef]
44. Marotta, A.; Porras-Amores, C.; Rodríguez Sánchez, A.; Villoria Sáez, P.; Masera, G. Greenhouse Gas Emissions Forecasts in Countries of the European Union by Means of a Multifactor Algorithm. *Appl. Sci.* **2023**, *13*, 8520. [CrossRef]
45. Bluszcz, A.; Manowska, A.; Mansor, N.S. Assessment of the Potential of European Union Member States to Achieve Climate Neutrality. *Sustainability* **2024**, *16*, 1311. [CrossRef]
46. Hsieh, J.-C.; Lu, C.-C.; Li, Y.; Chiu, Y.-H.; Xu, Y.-S. Environmental Assessment of European Union Countries. *Energies* **2019**, *12*, 295. [CrossRef]
47. Dechezleprêtre, A.; Nachtigall, D.; Venmans, F. The joint impact of the European Union emissions trading system on carbon emissions and economic performance. *J. Environ. Econ. Manag.* **2023**, *118*, 102758. [CrossRef]
48. Bąk, I.; Tarczyńska-Łuniewska, M.; Barwińska-Małajowicz, A.; Hydzik, P.; Kusz, D. Is Energy Use in the EU Countries Moving toward Sustainable Development? *Energies* **2022**, *15*, 6009. [CrossRef]
49. Horobet, A.; Popovici, O.C.; Zlatea, E.; Belascu, L.; Dumitrescu, D.G.; Curea, S.C. Long-Run Dynamics of Gas Emissions, Economic Growth, and Low-Carbon Energy in the European Union: The Fostering Effect of FDI and Trade. *Energies* **2021**, *14*, 2858. [CrossRef]
50. Pata, U.K.; Erdogan, S.; Ozcan, B. Evaluating the role of the share and intensity of renewable energy for sustainable development in Germany. *J. Clean. Prod.* **2023**, *42*, 138482. [CrossRef]
51. Kinnunen, J.; Georgescu, I.; Nica, I. Evaluating the Environmental Phillips Curve Hypothesis in the STIRPAT Framework for Finland. *Sustainability* **2024**, *16*, 4381. [CrossRef]
52. Zimon, G.; Pattak, D.C.; Voumik, L.C.; Akter, S.; Kaya, F.; Walasek, R.; Kochański, K. The Impact of Fossil Fuels, Renewable Energy, and Nuclear Energy on South Korea's Environment Based on the STIRPAT Model: ARDL, FMOLS, and CCR Approaches. *Energies* **2023**, *16*, 6198. [CrossRef]
53. Wang, P.-C.; Lee, Y.-M.; Chen, C.-Y. Estimation of Resource Productivity and Efficiency: An Extended Evaluation of Sustainability Related to Material Flow. *Sustainability* **2014**, *6*, 6070–6087. [CrossRef]
54. Kim, J.; Lim, H.; Jo, H.-H. Do Aging and Low Fertility Reduce Carbon Emissions in Korea? Evidence from IPAT Augmented EKC Analysis. *Int. J. Environ. Res. Public Health* **2020**, *17*, 2972. [CrossRef]

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