energies

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The Interdependencies between Economic Growth, Energy Consumption and Pollution in Europe

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Abstract: The strong interdependency between economic growth and conventional energy consumption have led to significant environmental impact, especially with respect to greenhouse gas emissions. Conventional energy-intensive industries release increasing quantities every year, which has prompted global leaders to consider new approaches based on sustainable consumption. The main purpose of this research is to propose a new energy index that accounts for the complexity and interdependences between the research variables. The methodology is based on Principal Component Analysis (PCA) and combines the key components determined into a score that allows for both temporal and cross-country comparisons. All data analyses were performed using IBM SPSS Statistics 25™. The main findings show that most countries improved their economic performance since 2014, but the speed of the improvement varies a lot from one country to another. The final score determined reflects the complex changes taking place in each country and the efficiency of the governmental measures for sustainable economic growth based on low energy consumption and low environmental pollution.

Keywords: economic growth; energy efficiency; pollution; renewable energy

Citation: Androniceanu, A.-M.; Căplescu, R.D.; Tvaronavičienė, M.; Dobrin, C. The Interdependencies between Economic Growth, Energy Consumption and Pollution in Europe. *Energies* **2021**, *14*, 2577. https://doi.org/10.3390/en14092577

Academic Editor: Miguel-Angel Tarancon

Received: 29 March 2021
Accepted: 26 April 2021
Published: 30 April 2021

1. Introduction

Economic growth and modern life are inconceivable without electricity, and most of the last century's discoveries would not have been possible without electricity. The European Union (EU) aims to give up using coal entirely by 2050 but will need significant help from European banks, which still finance 26% of all coal-fired power plants in the world [1]. Many Western European countries (including Italy and Spain) target total coal abandonment by 2030, while Germany (where coal still supplies 40% of energy needs) plans to reach this target by 2038 [2]. However, there still is a long road to full transition, with only 38 of Europe's 287 active coal-fired power plants (EU-27, plus the Balkans and Turkey) being officially planned to shut down in the foreseeable future. This represents a capacity reduction of only 18,162 megawatts out of a total of 179,157 MW [3].

Eastern and Central European countries rely largely on coal in their electricity production and fear that an unconsolidated transition to other forms of energy production could have a negative impact on their economic growth. Visegrad countries have been experiencing challenging situations, as the economies of Czechia, Hungary, Poland and Slovakia are more dependent on coal than Western European economies [4,5]. Poland plans to build three new coal-fired power plants, representing an increase in capacity of about 5000 megawatts—by far the most significant increase in EU countries [6]. Hungary, Romania and Bulgaria are also looking into increasing coal-based energy output rather than reducing it, albeit to a lesser extent than the four countries previously mentioned [7]. The effects on the environment and population health are major [8]. Emissions from coal-fired power plants in Europe contribute significantly to the share of diseases caused by environmental pollution. The latest published data show that the impact in the European Union amounts to over 18 thousand premature deaths, approximately 8.6 thousand new cases of chronic bronchitis and over 4 million working days lost annually [9].

The economic costs of the impact of coal-fired power plants on energy in Europe are estimated at around €43.1 billion a year. According to The European Environmental Agency, in 2018, approximately 379 thousand premature deaths were attributable to air pollution in the 27 EU Member States and the United Kingdom [10]. These costs are mainly associated with respiratory and cardiovascular diseases, the most important groups of chronic diseases in Europe. Together, coal-fired power plants in Poland, Romania and Germany are responsible for more than half of the health effects. Other important effects are attributed to coal burning in Bulgaria, Czechia, France, Greece, Serbia, Turkey and the United Kingdom [11]. It is well known that the use of coal for energy production is one of the major obstacles to reducing emissions. Currently, energy consumption is constantly on the rise, and stagnation, let alone regression, is hardly likely in the foreseeable future. Sustainable development concepts should be integrated in targets for economic development, energy productivity and monitoring of energy consumption [12,13]. Increasing the wealth of a state that does not account for more efficient use of energy in order to protect and conserve natural resources and the environment is neither sustainable nor conceivable anymore. One of the fastest and most effective ways to boost organizational performance improvement with respect to social and environmental protection [14–17] is to act upon energy efficiency [18,19].

For a long time, it was considered that there is an intrinsic link between economic growth, energy production and consumption and pollution. The main opportunities for energy savings in the future will come from the optimal selection of production processes [20] and a reduction or even removal of wastes from the system [21]. That is, economic growth can only be achieved by assuming a higher consumption and production of energy and implicitly greater pollution of the planet. During the last decade, decoupling between energy production and consumption, pollution by greenhouse gas emissions and economic growth was observed globally and attributed to increases in energy productivity [22]. Very recent analyses conducted by the International Energy Agency (AIE) show that CO_2 emissions have stagnated globally for the second year in a row, while the global economy has grown by more than 3% [23]. Preliminary AIE data suggest that electricity generated from renewable energy played a crucial role, accounting for about 90% of total new energy generated in 2015–2019. This new decoupling trend is found in 21 states that have managed to reduce greenhouse gas emissions while increasing gross domestic product. Of those countries, 16 are EU Member States [24].

To achieve this independence between economic growth and negative environmental impact, various countries have several measures, ranging from carbon taxation to increased investment in renewable energy sources and technologies, and even shifts from emission-intensive industry to more environmentally friendly approaches [25]. In Europe, the transition to a low-carbon economy would require an additional investment of €270 billion or 1.5% of the EU's annual GDP over the next four decades [26]. A simultaneous analysis of GDP per capita, energy productivity, energy consumption and pollution reflects the decoupling between economic growth and energy consumption.

In this context, the present study aims at contributing to answering the question regarding the interdependences between economic growth, energy consumption and pollution in the EU countries by proposing a new index to measure progress towards more sustainable economic growth. To this aim, we chose a series of variables that focus on energy productivity, private and industrial energy consumption, the share of renewable energy in total energy consumption and population exposure to pollutants that pose health risks [27–30]. The results of this research are relevant both theoretically, because a new indicator that reflects the interdependencies between the selected variables was designed, and from a practical point of view, because it can contribute to the development of viable and sustainable economic development strategies in European countries.

2. Literature Review

Economic growth results from the interaction of production factors, namely the productive activities of private economic agents. Various models for economic growth, its determinants and its measures were identified in the literature [31]. As the expression of an economy's capacity to produce goods and services [32], economic growth is measured based on the increase in real Gross Domestic Product (GDP) [33] and is dependent on production dynamics, inflation and unemployment as main drivers of economic cycles [34]. These alternative periods are called booms and recessions, respectively. The 21st century sees a more rapid succession between periods of growth and recessions, the most notable being the global financial crisis [35], the debt crisis and, more recently, the COVID-19 crisis [36]. An economic cycle represents the fluctuation of a country's economic activity, characterized by an increase in aggregate economic indicators followed by a decrease [37].

As a continuous process, economic growth has greatly benefited from the last three industrial revolutions [38], which has led to further and more rapid growth, producing a virtuous economic circle [39]. Several studies have found that the quality of the business environment [40,41] and the services sector [42,43] play an important role in the economic growth of a state. Besides the focus on the productive capacity of an economy, the concept of economic growth encompasses citizens' quality of life, particularly for those actively contributing to it [44].

Recent research [45] has shown that the increase in energy demand is decoupling from economic growth, as a result of the reduction in energy intensity required for the same unit of GDP, with doubling of the economic indicator being accompanied by only a 14% increase in energy consumption by 2050 according to the Global Energy Perspective report published in 2019 [46]. The main driver of these trends is the decrease in energy intensity of the economic processes, which compensates for the increase in population consumption triggered by higher incomes. According to the same report, more efficiently used energy contributes to a slowdown in the growth of energy demand.

It is estimated that the importance of renewable energy resources will increase globally enough to cover more than half of the electricity generation capacity by 2035 [47] and by 2050, together with nuclear production, will account for 34% of energy produced. Based on these projections, the methodology we propose also includes the share of renewable energy in gross final energy consumption.

Although ambient air quality in Europe has improved in recent years, air pollution continues to pose a major threat to public health. The European Environment Agency [48] (EEA) estimates that 80–90% of Europe's urban population is currently exposed to higher concentrations of suspended dust and ozone than the values recommended by the World Health Organization [49]. The process of producing electricity begins inside the power plant, where the conversion of primary energy into electricity takes place by burning fossil fuels or renewable resources, coal, natural gas and hydroelectric or wind energy and generating a water vapor, used to operate a turbine connected to the generator, which drives the generator (alternating current).

Biomass energy (bioenergy) is stored chemical energy and includes any solid, liquid or gaseous fuel or any electricity or useful chemical, derived from organic matter, either directly from plants or indirectly from industrial waste derived from plants, commercial and urban waste or agricultural and forestry residues. During the conversion processes, such as burning, biomass releases energy, usually in the form of heat, and carbon is re-oxidized to CO_2 to replace that consumed while the plant has grown (using biomass for energy is a reverse process of photosynthesis).

Coal-based energy production further contributes to the already poor air quality in Europe caused by the transport sector, industrial processes, residential heating systems and agriculture. Coal power plants emit significant amounts of suspended dust, sulfur dioxide and nitrogen oxides—the latter indirectly contributing to ozone depletion [50]. Of these, the most worrying for health are particulate matter (PM2.5) and ozone. Since pollutants can travel long distances, including across borders, the entire European population is affected by air pollution caused by the use of coal. Following several decades of reduction in coal use for energy production, the trend is once again on the rise. Coal is still an important source of energy in Europe, covering about a quarter of electricity production. About 50 new coal-fired power plants are planned. However, the continued use of coal also has a price that decision-makers are very unaware of the unpaid health bill. This health bill is paid by citizens, national health insurance budgets and the economy in general, due to productivity losses.

There is a significant amount of evidence on how these air pollutants affect the lungs and heart; the literature on the topic traces their impact to chronic respiratory diseases, such as chronic bronchitis, emphysema and lung cancer, and cardiovascular diseases such as myocardial infarction, congestive heart failure, ischemic heart disease and cardiac arrhythmias. Acute effects include respiratory symptoms, such as chest pain and cough, as well as violent asthma attacks. Children, the elderly and other patients are more susceptible to these effects. Recent studies show that air pollution can lead to low birth weight and premature birth due to exposure during pregnancy. Of particular concern is the high emissions of mercury from coal-fired power plants, because mercury can affect children's cognitive development and cause irreversible damage to the vital organs of the child. Coal-fired power plants are the most important source of mercury pollution in Europe, and the EU is starting to focus on technical options to reduce these emissions under a new United Nations treaty [51].

Although coal-fired power plants are responsible for only a small part of the total ambient air pollution, they are the most important source of industrial air pollutants. A large coal-fired power plant emits several thousand tons of hazardous air pollutants annually and has an average lifespan of at least 40 years. The construction of new coal-fired power plants would mean that hazardous emissions and their effects on health would be maintained for many years. It would also cancel out the short-term reduction in air pollution in other sectors. In order to highlight the negative impact of pollution on population health, the following two specific variables were integrated into our dataset: pollution, grime or other environmental problems and exposure to air pollution by particulate matter.

Among fossil fuel sources, the only one that will increase by 2035 will be the share of natural gas, which will also cap after this time horizon. The additional natural gas-fired electricity generation capacity will amount to 675 GW by 2035, which three times the installed capacity of Organization for Economic Cooperation and Development (OECD) member countries in Europe. Demand for oil will peak at 108 million barrels per day by 2030, after which it will "drop substantially" [52].

The chemical industry will account for more than half of the increase in oil demand over the next 15 years, after which time the contribution of this sector will decrease as a result of the reduction in demand for plastics and growing recycling efforts. The strongest decline in oil demand will be in electricity generation and transportation. Electric vehicle sales will exceed the 100 million mark by 2035 and are expected to become a cheaper alternative in five to 10 years [53]. It is estimated that by 2022, the costs of autonomous energy generation and storage will be similar to the cost of purchasing energy from a supplier, according to a new study by Ernst and Young [54]. The study also shows that in all markets, by 2025, electric vehicles (EVs) will reach parity with traditional vehicles with internal combustion in terms of costs and performance.

The level of electricity consumption from conventional sources will be greatly impacted by changing consumer preferences for renewable energy. In turn, this preference would be facilitated by making this type of energy available at prices comparable to conventional energy and the development of infrastructure that makes consumption of energy from renewable sources convenient [55,56]. Based on current trends in research and development, as well as implementation of newly found technology in the renewable energy sector, it is estimated that in Europe and Oceania, renewable energy will account for about 50% of energy demand by 2050 [57].

Many European countries have already begun to change their energy-based business models [58] in response to legislative and regulatory pressures aiming at increased uptake of renewable resources and ambitious carbon footprint reduction targets. Forecasts show that in the next decade, the revenues of the traditional utility companies will decrease significantly [59–63]. This change is determined on the one hand by changes in business models [64] that integrate modern information technologies and opt for renewable energy production and on the other hand by private investments in household renewable energy production with the view to optimize energy costs for the family [65].

This research highlights the above changes in state economies and among the population during the period 2014–2019 and shows that, while the interdependencies between economic growth, energy production and consumption, and pollution in EU countries are quite strong, the economic development model [66] is seeing significant changes compared to the previous one [67,68]. Sustainable economic growth has become part of the agenda for most states worldwide and, while current data do not suggest this at scale, important shifts are expected in the not-so-distant future [69,70]. Based on the indicator we propose, the EU states are already transitioning towards a more sustainable and environmentally friendly economic model, so reaching that goal is mostly a matter of time and consistency from here onward [71,72].

3. Data and Methods

This section presents the data and pre-processing steps, together with the methodology for developing an energy index for Europe. All analysis was performed using IBM SPSS Statistics 25™(IBM SPSS Statistics for Windows, Version 25.0. IBM Corp; Armonk, NY, USA).

3.1. Data Source

All data were extracted from Eurostat database and refer to years 2014, 2018 and 2019 for 27 European countries, namely EU-28 (before 2020) without Malta. The rationale behind the choice of countries was based on data availability, and Malta was eliminated because it had missing information for most variables of interest. Given that the purpose of the present study is to propose a new index together with the methodology for computing it, we only chose three years for which we computed the new index and analyzed the results. The choice of the three years was made based on the following criteria:

- 2014 was chosen in relation to the 2030 Agenda for Sustainable Development adopted by the UN General Assembly in 2015, assuming these data were the most recent available at the time of preparation of the document; therefore, it seemed reasonable to use it as starting point;
- Data for 2019 comprise the most recent available information for all variables of interest;
- The year 2018 was selected for validation purposes. While 2014 data may also serve as validation data, five years is a long period in the current fluctuating context so the proposed methodology was also tested on the closest year to the development sample for which data were available.

As there were no major disruptions during any of the chosen years, they were considered stable enough for a comparative analysis and validation of the proposed methodology.

The list of variables chosen, together with their descriptions and sources, is presented in Table 1 in Appendix A.

3.2. Data Pre-Processing

The raw data was mostly clean, though there were some missing values to be dealt with for 2014 and 2019. For the latter year, missing information about energy taxes for Cyprus and Latvia and the percentage of households exposed to pollution, grime and other environmental problems were replaced by the values in the previous year (2018).

The 2014 data had a single missing value, namely Exposure to air pollution for particulate matter less than 2.5 µm for Greece. After analyzing the year-to-year evolution of the available information both for Greece and for the other countries, the missing information was replaced with the mean of the values for 2013 and 2015.

Given the largely different countries both in terms of population size and economy, the following variables were created during the pre-processing stage in order to ensure cross-country comparability:

- GDP per capita and Energy taxes per capita (both expressed in million Euros) were derived by dividing GDP and energy taxes, respectively, by population size and multiplying the result by 1 million to convert it to Euros;
- Industry energy consumption and Services energy consumption (expressed in thousand tons of oil equivalent) were divided by GDP and multiplied by 1000 in order to express them as tons of oil equivalent consumed per Euro produced;
- Household energy consumption per capita (expressed in kg of oil equivalent per capita) was also transformed to ton consumed per Euro produced by dividing the original variable by 1000, multiplying it to the population and dividing the result by GDP, so that it became comparable with energy consumption from the economic sector.

Following these transformations, all initial variables were discarded and only resulting variables were used further.

3.3. Index Methodology

The proposed methodology is based on identifying underlying components using Principal Component Analysis (PCA) and combining them into a score that is then scaled so that it allows for both temporal and cross-country comparisons. Results were validated by applying the same methodology to two other years. The remainder of this section will be dedicated to describing in detail the methodology proposed.

The reason why we chose PCA instead of more widely used methods (like data envelopment analysis or decomposition analysis) is that it treats all variables as input and allows accounting for interdependencies between economic and environmental variables, as opposed to the frequently used methods that only account for the relationship between each input variable and the outcome.

The first step is to check for data normality, as PCA results are influenced by data distribution. For variables that were not normally distributed according to the Shapiro–Wilk test [73]. ln-transformations were applied to normalize them, followed by a new test.

The null hypothesis of the Shapiro–Wilk test is that a sample comes from a normally distributed population and the statistic is computed as:

$$W = \frac{\left(\sum_{i=1}^{n} a_i \cdot x_{(i)}\right)^2}{\sum_{i=1}^{n} (x_i - \overline{x})^2} \quad (1)$$

where:

- $x_{(i)}$—ith smallest number in the sample
- x_i—the ith element of the sample
- x_i—the sample mean
- a_i is given by $(a_1, \ldots, a_n) = \frac{m^T \cdot V^{-1}}{C}$, with:
  - $C = ||V^{-1} \cdot m||$

- ○ $m = (m_1, \ldots, m_n)^T$—expected values of the order statistics of independent and identically distributed random variables sampled from the standard normal distribution
- ○ V—covariance matrix of the normal order statistics

The second step was to check for and analyze the impact of outliers. Natural outliers explained by a country's population or economy size should have been eliminated during the pre-processing stage, and the impact of those causing data to be non-normally distributed was diminished by the transformation applied to normalize the variables. To ensure a balance between the need for data quality and processing complexity, the best approach for any remaining outliers was chosen by comparing the impact of no treatment with the elimination of the observation(s) with outliers and ln-transformation of the variable.

The third step was to standardize the variables to prevent the disproportionate contribution of a variable measured on a scale that is several orders of magnitude above others. This step was performed by using the *z-score* as presented below, and it effectively converted all variables to the same measurement unit, namely number of standard deviations from the mean:

$$z - score = \frac{x_i - \overline{x}}{\sigma} \quad (2)$$

where x_i is the ith element, $\overline{x}$ is the mean and σ is the standard deviation of the sample.

PCA [74] can be used as a dimensionality reduction technique by uncovering the underlying factors, called components. To be useful, PCA must be applied to data that contain clusters of correlated variables, so once the data were deemed of satisfactory quality, the next step was to compute the correlation matrix of the variables. Since data pre-processing ensured all variables were normally distributed, the Pearson correlation coefficient was computed for a sample as follows:

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \overline{x})^2 \cdot \sum_{i=1}^{n}(y_i - \overline{y})^2}} \quad (3)$$

where (x, y) is the pair of variables for which the correlation is computed. Each correlation is then tested for significance.

Given that Pearson's correlation coefficient is only useful for identifying linear correlations, a scatterplot matrix is also presented along with the results in order to detect potential non-linear relationships in the data.

The expectation is that PCA will confirm the results indicated by the correlation analysis and that the clusters of variables that were inter-correlated in the previous analysis will also be strongly correlated to the same component. Components generated by PCA are orthogonal (independent) and can be used further to compute the final score for each country as follows:

$$final\ score = \sum_{i=1}^{k} c_i \cdot f_i \quad (4)$$

where k is the number of components retained based on the PCA and correlation analysis results, f_i are the retained components and

$$c_i = \begin{cases} -1, & if\ higher\ factor\ scores\ lead\ to\ desired\ outcome \\ +1, & if\ lower\ factor\ scores\ lead\ to\ desired\ outcome \end{cases}$$

Since the final score is not easily interpretable as such, a rating scale was created using the following logic (the result is rounded to the nearest integer):

$$rating = \frac{best\ case\ scenario - score_i}{best\ case\ scenario - worst\ case\ scenario} \cdot 100 \quad (5)$$

The idea is to create best and worst scores for each component and combine them in a final score the same way as for the actual final scores. These scenarios were then used for scaling the scores so that the closer the score to 100, the closer the country is to the best-case scenario. Conversely, the closer the score is to zero, the closer the country is to the worst-case scenario. The resulting rating can then be used to compare countries or analyze a country's progress over time.

The validation of the results was done for two years, namely for 2014 and 2018. To test the new methodology, the data for each year were passed through the same transformation pipeline as the 2019 one, namely:

- Logarithmation of the same variables as for 2019;
- Identification and treatment of outliers;
- Standardization using the mean and standard deviation for 2019 to prevent data leakage;
- Determination of components using the 2019 coefficients;
- Calculation of the final score for each country.

In order to test the time consistency of the estimated scores, a correlation matrix was computed. The expectation was that the correlation would be high and monotonously decreasing, so that for years further apart, the relationship would be weaker than for closer years. Nevertheless, all correlation coefficients are expected to be significant and high (above 0.95).

For creating the best- and worst-case scenarios, the data for 2014 were chosen as they were likely the most recent available before the adoption of the 2030 Agenda for Sustainable Development, which includes Sustainable Development Goal 7, focused on energy. Other scenarios can be easily incorporated into the rating scale as well.

4. Research Results and Discussion

The main goal of the research is to design an energy index based on the correlation between economic growth, energy consumption and environmental pollution and to apply it for the states of the European Union.

The final variables resulted from the pre-processing stage, and their descriptive statistics for each year are presented in Table 1. For this research, variables were selected according to the criterion of relevance and importance for each of the three components analyzed: economic growth; energy consumption and pollution.

Table 1. Descriptive statistics of the final variables selected for analysis.

Variables	Min	Max	Mean	Std. Dev.	Skewness	Kurtosis
			2014			
Energy productivity	2.23	14.00	6.97	3.01	0.72	0.17
Renewable energy	4.47	51.82	19.91	11.66	0.93	0.65
Exposure to particulates <2.5 µm	7.40	26.10	14.89	4.84	0.71	0.34
Exposure to particulates <10 µm	13.50	41.20	23.11	6.52	0.85	1.08
Pollution, grime, other	4.50	23.20	13.16	4.78	0.27	−0.13
GDP per capita	5919	90,643	26,569	18,215	1.71	4.55
Energy taxes per capita	146.01	1645.56	518.60	324.94	1.73	4.52
Industry final energy consumption	7.98	61.03	26.20	13.12	0.80	0.42
Services final energy consumption	6.72	25.78	13.02	5.47	0.87	−0.25
Household final energy consumption	9.31	52.63	27.74	14.91	0.66	−1.28
			2018			
Energy productivity	2.41	18.58	7.54	3.63	1.35	2.34
Renewable energy	7.34	54.65	21.59	11.71	1.11	0.93

Table 1. *Cont.*

Variables	Min	Max	Mean	Std. Dev.	Skewness	Kurtosis
Exposure to particulates <2.5 µm	6.20	24.30	13.80	4.77	0.25	−0.55
Exposure to particulates <10 µm	11.50	33.80	22.27	6.30	0.21	−0.56
Pollution, grime, other	6.30	24.80	12.79	4.53	0.66	0.43
GDP per capita	7959	99,755	30,894	20,375	1.69	3.84
Energy taxes per capita	191.62	1562.81	571.66	293.16	1.48	3.77
Industry final energy consumption	7.00	48.66	22.87	11.50	0.70	−0.07
Services final energy consumption	5.27	21.94	11.90	4.30	0.69	−0.11
Household final energy consumption	8.24	44.41	23.95	11.55	0.54	−1.21
2019						
Energy productivity	2.52	19.64	7.80	3.76	1.54	2.96
Renewable energy	7.05	56.39	22.52	11.94	1.12	1.06
Exposure to particulates <2.5 µm	4.80	19.60	12.06	3.74	0.00	0.04
Exposure to particulates <10 µm	10.20	30.90	20.23	5.59	0.11	−0.51
Pollution, grime, other	5.90	25.20	12.82	4.40	0.73	1.10
GDP per capita	8748	103,465	32,115	21,077	1.74	4.00
Energy taxes per capita	227.10	1654.18	587.46	295.82	1.77	5.41
Industry final energy consumption	6.44	45.34	21.39	10.53	0.64	−0.10
Services final energy consumption	4.95	20.71	11.19	3.88	0.68	0.05
Household final energy consumption	7.19	41.34	22.63	10.35	0.39	−1.20

Energy productivity—Eur/kg of oil equivalent; Renewable energy—% gross final energy consumption; Exposure to particulates <2.5 µm—µg/m^3; Exposure to particulates <10 µm—µg/m^3; Pollution, grime, other—% of households exposed; GDP per capita—Eur; Energy taxes per capita—Eur; Industry final energy consumption—ton/Eur; Services final energy consumption—ton/Eur; Household final energy consumption—ton/Eur. Source: authors' computation.

The variables in Table 1 were selected on the basis of studies in the literature and their importance and relevance in the current economic and social context. Over the last decade, major changes have taken place in energy, economic and environmental policies at the EU and Member State level. Thus, the EU states aim to have economic growth in the future, both in industry and in services, but with low consumption of traditional energy, more renewable energy and less pollution. From this perspective, the variables were selected. They are important for achieving the research objective, namely, the elaboration of an energy index. This index reflects the interdependencies between the selected variables and facilitates the comparison of the EU countries that have different energy, economic and environmental policies during the analyzed period. Through the proposed variables and the new index, the EU states are compared and several particularities were discovered. The main research variables and their relevance for this research are explained below.

Energy productivity was selected for measuring the economic benefit received from each unit of energy used both for economic growth and householders. Renewable energy has been integrated into research for two reasons: first, because it is a priority for the EU countries in their business model based on green energy as a main source of energy consumers, both from the industry and services and for households, and second, because renewable energy significantly reduces environmental pollution.

Industry final energy consumption, services final energy consumption and household final energy consumption were selected because they are the main energy consumers with a direct impact on economic growth and pollution in Europe. This issue is analyzed with the following three variables: Exposure to particulates <2.5 µm, Exposure to particulates <10 µm and Pollution, grime, other. Through these selected variables, a comparative analysis of the level of pollution in each country was developed. These reflect the degree of pollution generated by the main energy consumers in the EU countries during the analyzed period.

The novelty in this research consists in its focus on the interdependencies between these selected variables, which are compared and analyzed using the PCA and the new energy index, created to measure the influences of selected variables in different EU countries during the analyzed period.

The Shapiro–Wilk normality test (Table 2) indicated that five variables were not normally distributed, so a ln-transformation was applied, and the result has been re-tested. The second test confirmed the normality of the distribution.

Table 2. Results of the Shapiro–Wilk test.

Initial Variables	Statistic	df	Sig.
Energy productivity	**0.872**	**27**	**0.003**
Renewable energy	**0.912**	**27**	**0.025**
Exposure to particulates<2.5 µm	0.969	27	0.587
Exposure to particulates<10 µm	0.971	27	0.64
Pollution, grime, other	0.958	27	0.338
GDP per capita	**0.838**	**27**	**0.001**
Energy taxes per capita	**0.853**	**27**	**0.001**
Industry final energy consumption	0.948	27	0.196
Services final energy consumption	0.956	27	0.302
Household final energy consumption	**0.919**	**27**	**0.037**
Transformed variables			
Energy productivity (ln)	0.978	27	0.809
Renewable energy (ln)	0.989	27	0.987
GDP per capita (ln)	0.977	27	0.793
Energy taxes per capita (ln)	0.967	27	0.516
Household final energy consumption (ln)	0.944	27	0.152

Variables in bold are not normally distributed (Sig. < 0.05). Source: authors' computation.

As expected, outliers are not present in most of the normally distributed variables. Since the methodology is developed on 2019 data, unusual values were checked only for that year's data.

The variable regarding the percentage of households exposed to pollution, grime and other environmental problems registered an outlier for Germany. The following three approaches were chosen for testing and for dealing with the presence of this extreme value, namely:

- Removing Germany from the sample: despite having a reduced number of observations in the sample, elimination of Germany because of the outlier might be a valid choice if the resulting reduction in variability compensates for the smaller sample;
- Applying ln-transformation on the variable: this approach results in less variability in the data as the very large values are reduced more than the small ones, but being the most complex of the three, assessing its impact and contribution in is recommended subsequent analysis;
- Not changing anything: this approach is appropriate in a small sample if the treatment of the outlier proves to be too resource-expensive compared to the benefit obtained or if it causes results to worsen due to diminishing the sample.

Subsequent analysis will be performed with all three versions of the variable until the impact can be assessed and the best approach chosen.

All normally distributed variables were standardized using the means and standard deviations for 2019 (Table 3), to prevent information leakage from the other years. Performing this step is the best practice for any analysis and compulsory for datasets where variables are measured on very different scales.

Table 3. Standardization values: means and standard deviations for transformed variables, 2019.

Variables	Mean	Std. Deviation
Energy productivity (ln)	1.96	0.44
Renewable energy (ln)	2.99	0.52
GDP per capita (ln)	10.20	0.60
Energy taxes per capita (ln)	6.27	0.47
Household final energy consumption (ln)	3.01	0.49
Pollution, grime, other (ln)	2.49	0.35
Pollution, grime, other	12.82	4.40
Pollution, grime, other (w/mis)	12.34	3.70
Exposure to particulates <2.5 µm	12.06	3.74
Exposure to particulates <10 µm	20.23	5.59
Industry final energy consumption	21.39	10.53
Services final energy consumption	11.19	3.88

Source: authors' computation.

Following the standardization step, all variables are normally distributed and measured on the same scale, namely in standard deviations around their respective means. Next, the Pearson correlation matrix was computed and tested (Table 4).

Table 4. Correlation matrix—Pearson coefficient.

	EP	RE	GDP	ET	HH	PLN	P	PM *	2.5	10	IND	SRV
EP												
RE	−0.167	1	−0.223	−0.174	0.356	−0.276	−0.231	−0.245	−0.282	−0.238	0.291	
GDP	**0.818**	−0.223	1	0.883	−0.86	−0.129	−0.092	−0.212	−0.647	−0.666	−0.581	
ET	**0.643**	−0.174	**0.883**	1	−0.709	−0.013	0.005	−0.035	−0.571	−0.531	−0.529	
HH	**−0.838**	0.356	**−0.86**	**−0.709**	1	0.075	0.056	0.122	0.462	0.445	0.668	
PLN	−0.195	−0.276	−0.129	−0.013	0.075	1	0.975	0.985	0.199	0.146	0.031	
P	−0.131	−0.231	−0.092	0.005	0.056	**0.975**	1	1	0.163	0.126	-0.022	
PM *	−0.258	−0.245	−0.212	−0.035	0.122	**0.985**	**1**	1	0.239	0.256	0.041	
2.5	**−0.427**	−0.282	**−0.647**	**−0.571**	**0.462**	0.199	0.163	0.239	1	0.896	0.313	
10	**−0.445**	−0.238	**−0.666**	**−0.531**	**0.445**	0.146	0.126	0.256	**0.896**	1	0.211	
IND	**−0.784**	0.291	**−0.581**	**−0.529**	**0.668**	0.031	−0.022	0.041	0.313	0.211	1	
SRV	**−0.875**	0.204	**−0.752**	**−0.534**	**0.783**	0.065	0.029	0.154	0.371	**0.457**	**0.622**	

* computed based on data for 26 countries; bold—significant at 0.05 level. EP—Energy productivity; RE—Renewable energy; GDP—GDP per capita; ET—Energy taxes per capita; HH—Household final energy consumption; PLN—Pollution, grime, other (ln); P—Pollution, grime, other; PM—Pollution, grime, other (with missing); 2.5—Exposure to particulates <2.5 µm; 10—Exposure to particulates <10 µm; IND—Industry final energy consumption; SRV—Services final energy consumption. Source: authors' computation.

For ease of interpretation, the coef ficients were color-coded such that an intense color indicates a strong correlation, blue color shows direct correlations and red color highlights inverse relationships between variables. The matrix shows that there are clusters of inter-correlated variables, which means the dataset is suitable for PCA.

Since Pearson's correlation coefficient only shows linear correlations, a scatterplot matrix was plotted to assess the linearity of the variable pairs. The closer the shape of the dots in each square is to a line, the stronger the linear the relationship is. The resulting plot confirms that where the correlation coefficient is high, the shape formed by the dots resembles a line, thus validating the conclusion based on the correlation matrix. Figure 1 contains bivariate analysis that involves measuring the degree of association of the variables considered in terms of direction, intensity and statistical significance. This figure shows how the researched variables are associated in terms of direction, intensity and statistical significance. The bivariate correlation presented refers to the analysis of the correlations between the twelve variables considered, designated as X and Y, mainly for determining the empirical relationship they have.

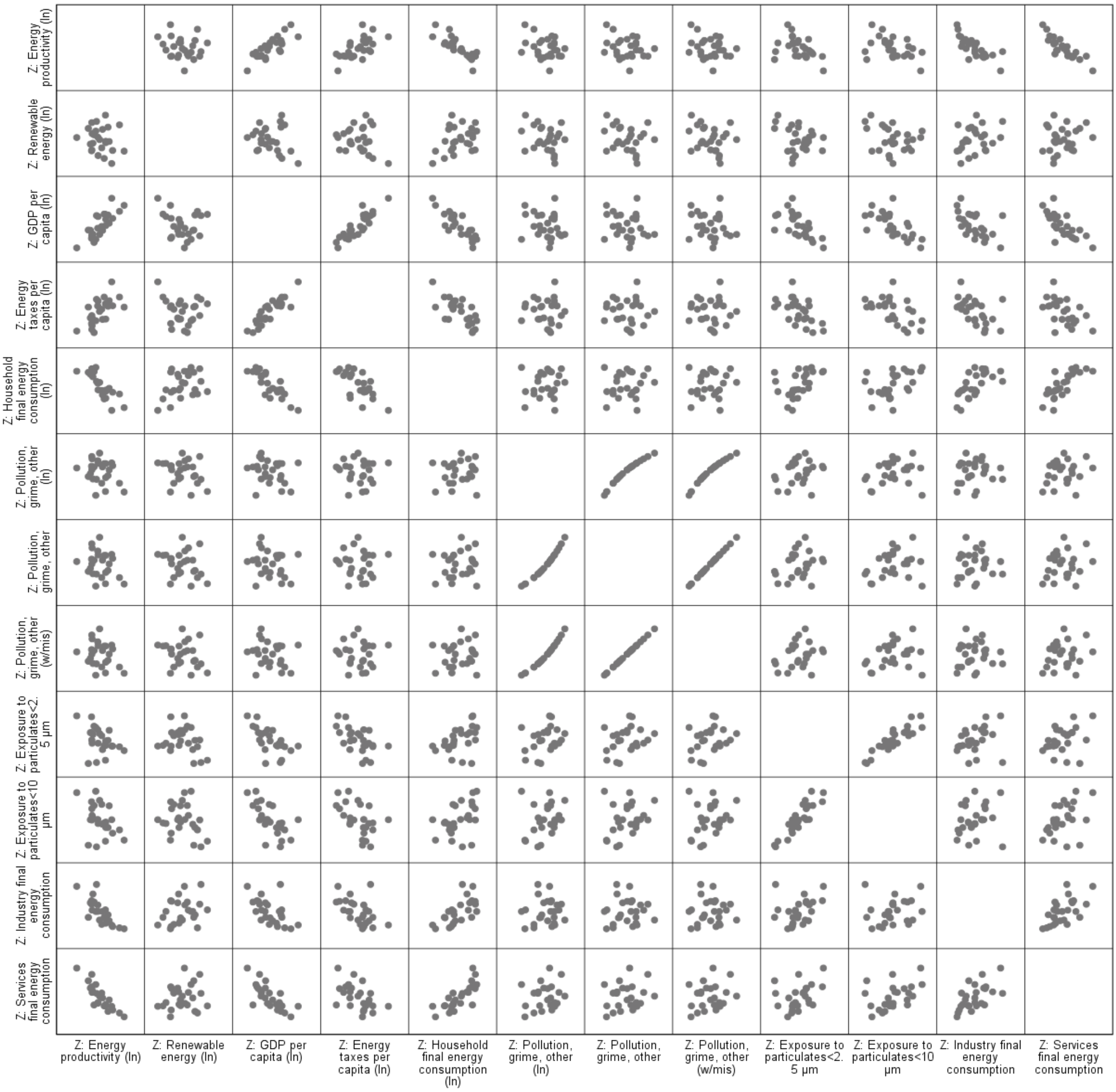

Figure 1. Bivariate relationship between variables in the dataset. Source: authors' computation.

Through bivariate correlation, the association and causality between them were tested. This analysis was used to see if the variables were related to each other and to measure how the investigated variables change together at the same time. The purpose of the bivariate analysis was to examine several relationships between several variables simultaneously. The bivariate correlation helped to understand the correlations between the researched variables.

Outlier impact was assessed during the PCA transformation stage. To this end, seven approaches were tested, and their were results evaluated based on sample adequacy, percentage of variance explained and number of components. The differences between the various approaches are given by the type of outlier treatment and variables included in the input data (Table 5).

Table 5. Approaches tested for PCA transformation.

Approach	Sample Adequacy	Variance Explained	Number of Components	Pollution, Grime, Other	Observations
1	0.733	72.506	2	original	
2	0.733	75.162	2	original	without Renewable energy
3	0.728	73.036	2	without outlier	
4	0.767	75.683	2	without outlier	without Renewable energy
5	0.729	82.793	3	ln-transformed	
6	0.764	75.178	2	ln-transformed	without Renewable energy
7	0.789	83.897	2	none	without Renewable energy

Source: authors' computation.

The fifth approach was selected as being the best one because it performed best among those including all variables of interest in the analysis, and the resulting components make economic sense (Table 6). The last approach was also considered, due to the high percentage of explained variance, but it was discarded in the end because the renewable energy variable was correlated with the resulting energy efficiency component ($r = 0.404$, $p = 0.037$), but not strongly enough to bring a significant contribution to it.

Table 6. Correlations between components and input variables based on PCA results.

Variables	Final Choice			Second Best Choice	
	Energy Efficiency	Pollution	Renewable Energy and Environmental Impact	Energy Efficiency	Pollution
Z: Energy productivity (ln)	−0.917	-	-	−0.922	-
Z: Household final energy consumption (ln)	0.892	-	-	0.861	-
Z: Services final energy consumption	0.841	-	-	0.852	-
Z: Industry final energy consumption	0.829	-	-	0.848	-
Z: GDP per capita (ln)	−0.799	-	-	−0.747	-
Z: Energy taxes per capita (ln)	−0.658	-	-	−0.627	-
Z: Exposure to particulates <10 µm	-	0.910	-	-	0.941
Z: Exposure to particulates <2.5 µm	-	0.905	-	-	0.931
Z: Pollution, grime, other (ln)	-	-	0.922	-	-
Z: Renewable energy (ln)	-	-	−0.537	-	-

Source: authors' computation.

It can be seen that including the two variables in the last component changes the correlation coefficients to some extent, but both the strength and the direction remain the same.

Three variables have inverse correlation with the energy efficiency component; thus, improvements in the respective areas will lead to lower values for the energy efficiency score. What is more, all three are the ln-transformed versions, which means increases in the original values, will lead to exponential decreases in the component score. Conversely, energy consumption by type of consumer is directly correlated to the component, thus lower consumption also leads to lower values on the factor, and exponentially so for household consumption. This suggests that:

- The smaller the value for this component, the better the performance of the respective country;
- The biggest impact can be achieved by increasing energy productivity and reducing household energy consumption;
- While the focus on energy consumption of industry and services may be beneficial due to the scale effect, the inertia is high in both cases, so measures taken in this direction, while having a non-negligible impact, are less effective than the for the first two components;
- The medium correlation between the component and energy taxes suggests that regulatory measures in this regard are bound to be less effective.

For the pollution component, the relationship it has with the variables defining it is straightforward, the less the population is exposed to fine particle matter, the lower the component value.

The last component shows that reducing pollution would have a great environmental impact, and increasing the share of renewable energy in gross final energy consumption can contribute to this. Both variables have exponential impact. Similar to the previous component, in the case of this component lower values are indicative of better performance [75]. The estimated coefficient matrix (Table 7) was used to compute the values for each country and year. Given that all components have the same relationship with the final score, the latter was obtained by adding the three components.

Table 7. Component Score Coefficient Matrix.

Variables	Energy Efficiency	Pollution	Renewable Energy and Environmental Impact
Z: Energy productivity (ln)	−0.246	0.098	−0.183
Z: Household final energy consumption (ln)	0.209	−0.029	−0.027
Z: Services final energy consumption	0.213	−0.062	0.074
Z: Industry final energy consumption	0.246	−0.16	0.074
Z: GDP per capita	−0.127	−0.135	0.069
Z: Energy taxes per capita	−0.074	−0.182	0.191
Z: Exposure to particulates <10 µm	−0.106	0.433	−0.074
Z: Exposure to particulates <2.5 µm	−0.099	0.42	−0.026
Z: Pollution, grime, other (ln)	0.116	−0.177	0.814
Z: Renewable energy (ln)	0.191	−0.249	−0.346

Source: authors' computation.

The best- and worst-case scenarios for 2014 were selected for creating the rating scale. These scenarios are based on the smallest and largest values for each component. According to the results presented so far, smaller values represent a better situation, so the minimum values for each component were added together to obtain the best-case scenario. Similarly, the maximum values were summed up to obtain the worst-case scenario. The results are presented in Table 8 below.

Table 8. Original values for countries contributing to the best- and worst-case scenarios of the rating scale.

Variables	Best Case		Worst Case		Component
	Value	Country	Value	Country	
Energy productivity	10.506	Luxembourg	2.226	Bulgaria	Energy efficiency
Household final energy consumption	9.31	Luxembourg	50.68	Bulgaria	
Services final energy consumption	7.24	Luxembourg	23.13	Bulgaria	
Industry final energy consumption	13.19	Luxembourg	61.03	Bulgaria	
GDP per capita	90,643	Luxembourg	5919	Bulgaria	
Energy taxes per capita	1645.56	Luxembourg	61.03	Bulgaria	
Exposure to particulates <10 μm	13.7	Finland	35.1	Poland	Pollution
Exposure to particulates <2.5 μm	8.4	Finland	26.1	Poland	
Pollution, grime, other	5.7	Croatia	15.4	Luxembourg	Renewable energy and environmental impact
Renewable energy	27.8	Croatia	4.5	Luxembourg	

Source: authors' computation.

The final scores were rescaled from 0 to 100 such that the worst case is 0 and the best case is 100. The closer the new values are to 100, the smaller the gap between them and the best-case scenario. The resulting rating can then be used to compare countries or analyze a country's progress over time.

For validating the results obtained for 2019 the analysis was replicated for 2018 and 2014 by taking the data through the same steps as for 2019, namely ln-transformation, standardization, estimation of components based on the Score Matrix (Table 7), and scaling using the same best- and worst-case scenarios. As expected, the correlations for each pair of years are high (above 0.95) and monotonously decreasing (the strongest correlation is between 2019 and 2018 and weakest between 2019 and 2014).

To further illustrate the use of the proposed index, a small analysis of the three years is presented. The final scores were computed for each country and year and ordered from largest to smallest based on 2019 values (Table 9). One thing to note is that the majority of the countries improved their performance since 2014. Furthermore, the rankings indicate much variation, with very few countries maintaining their relative position. This suggests that the improvement speed varies greatly from one country to another. While the proposed index cannot keep track of the individual evolutions for each variable, the resulting final score reflects the complex changes taking place and the variety of national legislations.

Interestingly, if compared either to the best-performing country for a particular year or to the best-case scenario (100 points), the results suggest a trend towards homogenization, particularly visible at the bottom of the ranking (large values in Figure 2). What this means is that while distances between best-performing countries remained relatively stable, countries that occupy the last positions in the ranking made significant progress towards the best-case scenario despite remaining in the last positions.

Figure 2 reflects the distance between the best-performing European country (left) and the best-case scenario (right). Thus, an interesting and useful comparison can be made by referring to the country with the best performance and the best-case scenario.

Going into more detail about improvements, the highest-achiever countries were mostly Eastern European, with top 10 being dominated by former communist states (Figure 3). Despite constantly being at the bottom of the ranking, Bulgaria made the biggest progress among considered countries. Starting from a score of 12, the closest any of the countries was to the worst-case scenario in any of the years, the country's performance went up to 29 points in 2019.

Table 9. Final scores and resulting country rankings, sorted by 2019 values.

Countries	Final Score			Country Rank		
	2019	**2018**	**2014**	**2019**	**2018**	**2014**
Sweden	81	81	75	1.5	1	3
Ireland	81	79	78	1.5	2	1
Denmark	78	76	76	3	3	2
Finland	68	67	63	4	4	6
Austria	67	65	64	5	5	4.5
Spain	62	60	59	6	6	7
Estonia	61	58	46	7	9	13
United Kingdom	60	59	64	8	7.5	4.5
Luxembourg	58	59	53	9.5	7.5	10
Portugal	58	57	54	9.5	10	9
France	57	56	57	11.5	11	8
Cyprus	57	53	45	11.5	13	15
Croatia	56	50	52	13	14.5	11
Italy	55	54	46	14	12	13
Netherlands	54	50	46	15	14.5	13
Germany	50	47	44	17	17	16
Belgium	50	48	43	17	16	18
Slovakia	50	44	37	17	19	21.5
Slovenia	48	43	43	19	20	18
Czechia	47	40	32	20	22.5	23
Lithuania	45	46	43	21	18	18
Romania	44	39	37	22	24	21.5
Latvia	43	38	31	23	25	24
Greece	42	42	40	24	21	20
Hungary	41	40	29	25	22.5	25
Poland	35	27	27	26	26	26
Bulgaria	29	24	12	27	27	27
Number of countries that, compared to previous year *, scored/ranked:						
Higher	23	21	25	10	11	10
Lower	2	3	1	10	13	14
Same	2	3	1	7	3	3

* values in the 2014 columns reflect comparisons between 2019 and 2014. Source: authors' computation.

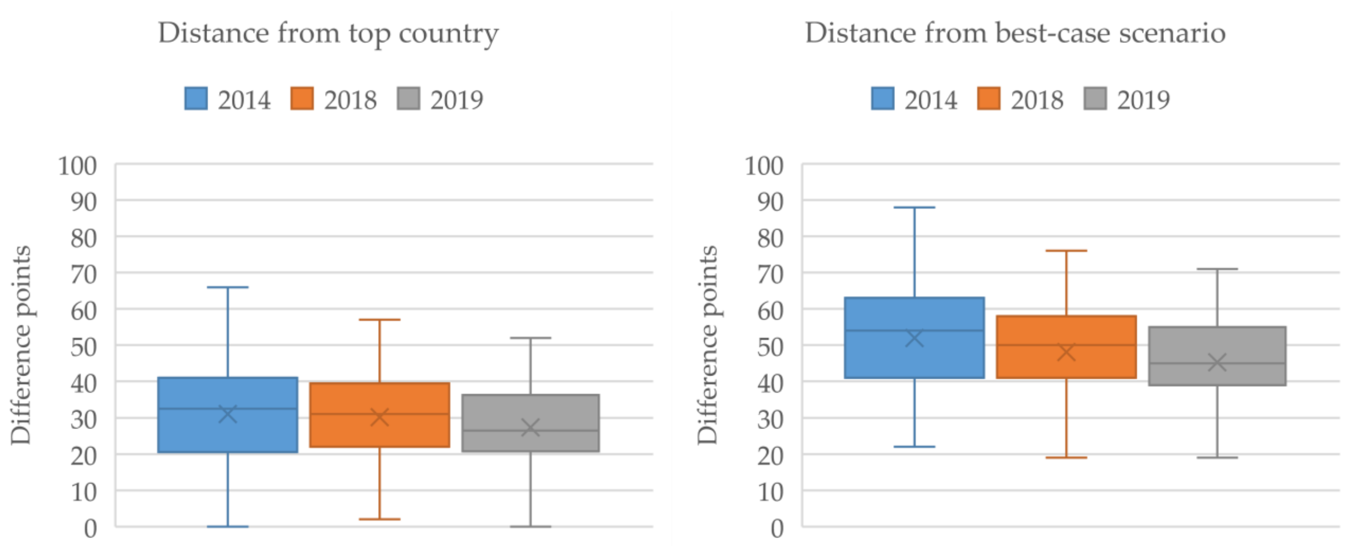

Figure 2. Distance from best-performing country of the year and best-case scenario. Source: authors' computation.

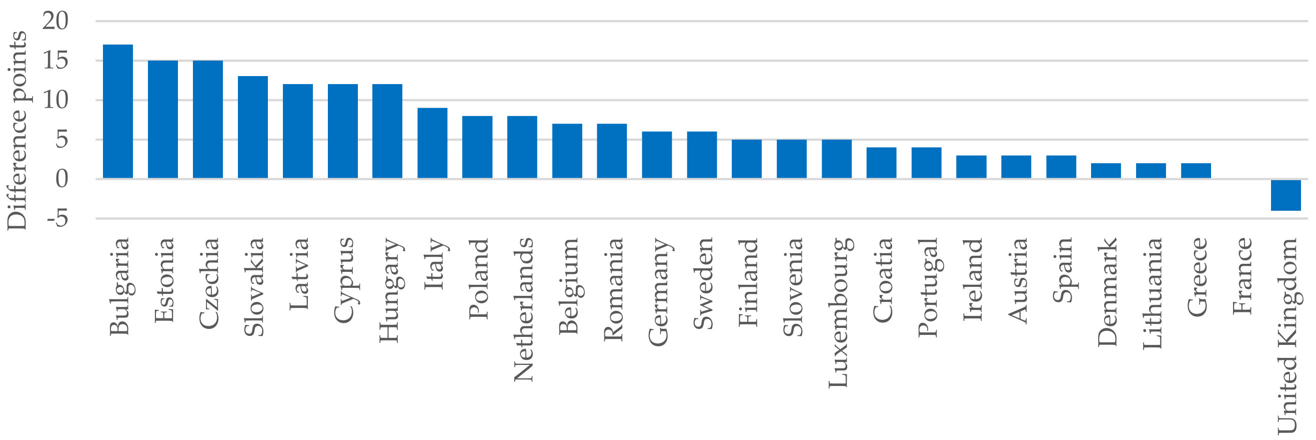

Figure 3. Overall changes in country scores in 2019 compared to 2014. Source: authors' computation.

What is more, it got closer to the second-last country in the sample, Poland, reducing the distance from 15 points to only 6. Another remarkable improvement is registered by Estonia, with a 15-point improvement that also translated into moving six positions ahead in the ranking, from 13th place (tied with Italy and Netherlands) in 2014 to the seventh country in the top. No less notable of an improvement was also made by Czechia, also 15 points, which started as fifth from the bottom and moved up three positions by 2019. At the other end of the spectrum, UK's context seems to have worsened, both in absolute and in relative terms, having dropped from fourth position (tied with Austria) to eighth, with a score decreasing by 4 points in 2019 compared to 2014.

Between the most recent two years analyzed, the top 10 seem to be populated mostly by the same countries, but in different positions (Figure 4). The biggest progress in terms of score was registered by Poland, but this did not translate into a higher ranking position. On the other hand, Czechia, Slovakia and Latvia went up two positions the list in 2018 compared to 2019. Estonia, Hungary and Italy exited the top 10 and were replaced by Croatia, Romania and Slovenia, all of which also moved up two positions in the ranking. Despite the medium-low change in score registered by Estonia, the country also moved up two positions, into seventh place.

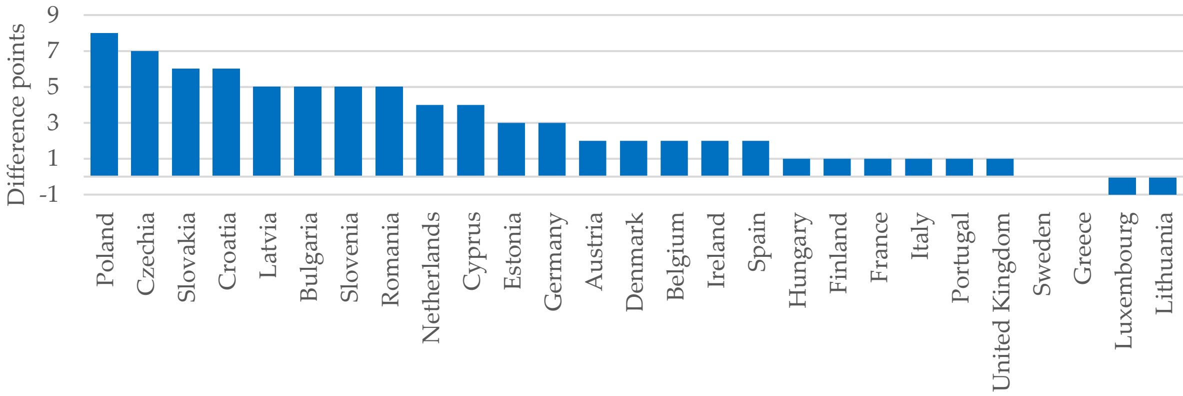

Figure 4. Changes in country score in 2019 compared to 2018. Source: authors' computation.

The two figures above suggest shifts in the evolutions of the countries considered. In the case of some countries, an important part of the progress registered over the entire period (Figure 3) happened during the last year (Figure 4), which is indicative of intensifying the efforts towards a cleaner and more environmentally friendly economy. Among countries at the bottom of the list in 2019 that show significant improvements are Poland, Romania, Latvia and Bulgaria. Notable progress was also made by some of the larger economies of the EU, for example, Germany, Netherlands and Spain. Given the initial status and size of economy, while the progress registered by the latter countries is smaller in absolute terms, the impact on the environment is large enough to matter.

Limitation and Future Research

The instrument proposed is useful and reliably shows interdependencies between economic perspective and environmental impact. To be able to show the usefulness of the index, the year 2014 was chosen as base for determining the best- and worst-case scenarios. The choice made was by highlighting that the information was most likely the latest available when UN's Sustainable Development Goal 7 was adopted together with the 2030 Agenda. This being said, different scaling scenarios can be applied, like, for example, using 2014 data to determine the worst-case scenario and target values for the indicators in the index as the best-case scenarios. This way, the instrument can be used for measuring countries' progress towards the set goals. The drawback to this approach is that the target values needed must be set to each of the 10 variables included in the index calculation methodology, which requires a relatively thorough analysis, especially at multi-state level.

A future study starting from current results would be to analyze COVID-19 and subsequent data to verify if the results still hold true [76,77]. As the period up to 2019 inclusively was relatively stable, data for 2020 are very likely impacted by worldwide lockdowns and economic activity disruption. For this reason, new analysis is recommended on newer data and comparisons with results presented in this research paper.

5. Conclusions

As efforts are made globally to reduce pollution, the proposed methodology can represent a valuable instrument for tracking country progress by taking into account the complexity and interconnections between the impacts economic and private activities have on the environment.

The main contribution of the present study is the energy index proposed for tracking countries' progress in time and in comparison with other countries. Its novelty consists in the fact that it accounts for complex interdependencies between variables rather than analyzing them in pairs of input–outcome variables. The three components identified, energy efficiency, pollution, and renewable energy and environmental impact, while independent from each other, capture the complex relationships between economic growth, energy productivity and consumption, pollution and efforts towards a more sustainable economic growth [78]. The index incorporates the three dimensions targeted by the EC, namely reducing greenhouse gas emissions, increasing share of renewable energy in consumption and improving energy efficiency and combines them into an instrument that is easy to use both for cross-country comparisons, and for time series analysis.

The research was performed in two main directions, namely on a correlative analysis of the variables considered within the three components and on a comparative analysis of them in the states included in the research. During the pre-processing stage, the following variables were created in order to ensure cross-country comparability: GDP per capita and energy taxes per capita, industry energy consumption and services energy consumption, and household energy consumption per capita. These were grouped into three components: energy efficiency, pollution and renewable energy and environmental impact. The components were combined into a score that was then scaled two allow for both temporal and cross-country comparisons. In order to prevent a disproportionate contribution of the states, the research variables were standardized by using the z-score. The Shapiro–Wilk normality test indicated that five variables were not normally distributed. Another result was related to the Pearson correlation matrix. The matrix shows that there are clusters of inter-correlated variables, which means the dataset is suitable. Bivariate relationship between variables in the dataset shows that all existing relationships in the data are linear.

A notable result is that the biggest impact in terms of energy efficiency can be obtained by increasing energy productivity, coupled with lower of more efficient consumption in households. Since industrial change is slower to achieve and legislative pressure does not seem to have significant impact, it follows that incentivizing more responsible household consumption could be the most lucrative direction to begin with. In parallel, investments in renewable energy production, both at the national and at the household level, would lead to faster decrease of pollution since they would allow for smaller demand of traditional energy production.

The results of the research can be used by the EU governments to adapt their economic, energy and environmental policies by developing a renewable energy business model that ensures sustainable economic growth and low environmental pollution in Europe [79].

Author Contributions: Conceptualization: A.-M.A., M.T. and C.D.; Methodology: R.D.C.; Validation: A.-M.A., M.T. and C.D.; Formal analysis: R.D.C.; Investigation: A.-M.A.; Resources: all authors; Data curation: R.D.C.; Writing—original draft preparation: A.-M.A., R.D.C., M.T. and C.D.; writing—review and editing: A.-M.A. and R.D.C.; Visualization: A.-M.A. and R.D.C.; Supervision: M.T. and C.D. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: We had the administrative and technical support of the International Centre for Public Management from the Bucharest University of Economic Studies and from Vilnius Gediminas Technical University.

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

Appendix A

Table 1. Data definitions and sources.

Indicator	Source
Energy productivity	Available online: https://ec.europa.eu/eurostat/databrowser/view/T2020_RD310/default/table (accessed on 15 March 2021)
Final energy consumption in households per capita	Available online: https://ec.europa.eu/eurostat/databrowser/view/SDG_07_20/default/table (accessed on 15 March 2021)
Final energy consumption in industry	Available online: https://ec.europa.eu/eurostat/databrowser/view/TEN00129/default/table (accessed on 15 March 2021)
Final energy consumption in services	Available online: https://ec.europa.eu/eurostat/databrowser/view/TEN00128/default/table (accessed on 15 March 2021)
Share of renewable energy in gross final energy consumption	Available online: https://ec.europa.eu/eurostat/databrowser/view/T2020_RD330/default/table (accessed on 15 March 2021)
GDP	Available online: https://ec.europa.eu/eurostat/databrowser/view/NAMA_10_GDP$DEFAULTVIEW/default/table (accessed on 15 March 2021)
Energy taxes	Available online: https://ec.europa.eu/eurostat/databrowser/product/view/ENV_AC_TAXIND2 (accessed on 15 March 2021)
Exposure to air pollution by particulate matter	Available online: https://ec.europa.eu/eurostat/databrowser/view/SDG_11_50/default/table (accessed on 15 March 2021)
Population on 1 January	Available online: https://ec.europa.eu/eurostat/databrowser/view/DEMO_PJAN$DEFAULTVIEW/default/table (accessed on 15 March 2021)
Pollution, grime or other environmental problems - EU-SILC survey	Available online: Available online: https://ec.europa.eu/eurostat/databrowser/product/page/ILC_MDDW02 (accessed on 15 March 2021)
Number of private households	Available online: https://ec.europa.eu/eurostat/databrowser/view/LFST_HHNHWHTC$DEFAULTVIEW/default/table (accessed on 15 March 2021)

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