energies

MDPI

Article

Scenario Modeling of Energy Policies for Sustainable Development

Nadiia Artyukhova [1], Inna Tiutiunyk [2], Sylwester Bogacki [3], Tomasz Wołowiec [3], Oleksandr Dluhopolskyi [3,4,*] and Yevhen Kovalenko [5]

1 Department of Marketing, Sumy State University, 40007 Sumy, Ukraine
2 Department of Financial Technologies and Entrepreneurship, Sumy State University, 40007 Sumy, Ukraine
3 Faculty of Administration and Social Sciences, University of Economy and Innovation, 20-209 Lublin, Poland
4 Faculty of Economics and Management, West Ukrainian National University, 46027 Ternopil, Ukraine
5 Department of Economics, Entrepreneurship and Business Administration, Sumy State University, 40007 Sumy, Ukraine
* Correspondence: dlugopolsky77@gmail.com; Tel.: +380-682750430

Abstract: The article deals with the impacts of economic, ecological, and social development scenarios in ensuring sustainable energy development. EU countries were the statistical bases of the study; the assessment period was from 2000 to 2019. The information bases of the research were the World Bank, the Organization for Economic Cooperation and Development, and the European Commission data. Based on the generalized method of moments, the authors investigated the dependence of energy consumption on economic, environmental, and social development factors. The results confirm the positive relationship between renewable energy consumption and GDP per capita, foreign direct investment, and energy depletion. A negative relationship between the consumption of renewable energy, CO_2 emissions, and domestic gas emissions was proved. Based on intelligent data analysis methods (methods involving one-dimensional branching CART and agglomeration), countries were clustered depending on the nature of the energy development policy; portraits of these clusters were formalized. The study results can be useful to authorized bodies when determining the most effective mechanisms for forming and implementing sustainable energy development policies.

Keywords: energy consumption; sustainability; scenario modeling; economic growth; GMM; CO_2 emissions; energy efficiency; sustainable development

check for updates

Citation: Artyukhova, N.; Tiutiunyk, I.; Bogacki, S.; Wołowiec, T.; Dluhopolskyi, O.; Kovalenko, Y. Scenario Modeling of Energy Policies for Sustainable Development. *Energies* **2022**, *15*, 7711. https://doi.org/10.3390/en15207711

Received: 14 September 2022
Accepted: 15 October 2022
Published: 19 October 2022

1. Introduction

One of the most critical problems in the modern world is the environment, particularly involving the rapid growth of energy consumption. On the one hand, the world's fuel resources are characterized by significant amounts of reserves, the constant discovery of new fossil fuel deposits, and the growth of access to non-traditional sources of energy [1,2]. On the other hand, the need for energy resources grows every year (according to expert forecasts, energy consumption will grow almost 1.5 times by 2050), due to the possibility of rapid depletion of the most available deposits and the need to develop more complex and expensive energy sources [3–5]. This makes the use of most fuel resources unprofitable.

In [6–14], the authors confirmed that energy consumption negatively affects the environment. In terms of emissions, the impact of power plants on the environment is equal to the impact of metallurgical enterprises and exceeds all other industries (30% of all solid particles entering the atmosphere, 63% of sulfur dioxide, and more than 53% of ozone oxide entering the air from stationary source pollution is caused by energy). The largest consumers of energy resources during the entire period were the industrial sector and the field of transport [15–18]. In 2020, 26.1% of the total energy was consumed by industrial enterprises; 13.7%—services; 28.0%—households; and 28.4%—transport [19].

Significant volumes of energy consumption provoke adverse climate changes and increase the levels of environmental pollution and the energy dependence of consumer countries on donor countries [20–25]. Moreover, according to forecasts, maintaining the current levels of energy consumption and carbon dioxide emissions until 2025 will lead to an increase in the average temperature on Earth by 2 degrees.

Given the above, there is an urgent need to develop a road map for sustainable energy development by transforming the mechanisms of state environmental management and ensuring their integrated use and coordinated functioning. Under these conditions, carbon-free technologies based on the energy of the sun, wind, and water, as well as nuclear energy, which can provide humanity with energy for several millennia, take first place [26,27].

Ensuring sustainable energy development is a long-term process that leads to institutional, social, economic, and ecological transformations, as well as international adoption of treaties and conventions regulating energy consumption processes [28–30]. Therefore, the international community has adopted several acts that regulate these issues and determine individual vectors regarding the development of the energy market [31]. Thus, according to the "World Sustainable Development Goals 2016–2030", the main vector of global energy development should be the provision of general/free access to inexpensive, reliable, and sustainable energy, including by increasing the share of production and consumption of renewable energy sources.

The documents regulating the issues of sustainable development include the "Sustainable Development Agenda until 2030" and the 2015 UN General Assembly "Sustainable Development Goals" (SDG). According to Sustainable Development Goal 7, sustainable energy development consists of providing universal access to reliable and modern energy and significantly increasing the share of renewable energy in the energy balance.

One of the basic documents defining the vectors of reforming the global energy market is the "Energy Roadmap 2050" adopted by the European Commission in 2012. The mainstream development of EU countries has determined the creation of a new energy system model, which will make it safe, competitive, and sustainable in the long term due to an increase in the share of renewable energy sources (up to 66% of the total volume), and a reduction of greenhouse gas emissions by 80%, which will make it possible to reduce 85% of CO_2 emissions related to energy, leading to a decrease in energy demand of 41% by 2050.

Directive 2012/27/EU of the European Parliament and the council on energy efficiency defines a reduction in energy consumption by 20% and an increase in energy efficiency by 32.5% by 2030 as key targets for implementing the policy (of increasing energy efficiency) [32]. Thus, by 2030, the EU is planning to reduce final energy consumption to 956 Mtoe and/or primary energy consumption to 1273 Mtoe compared to 1787 Mtoe in 2021 [19], increasing the share of energy consumption from renewable sources to 32% [32]. The data in Figure 1 show that the average growth rate of the share of renewable energy consumption in the EU for 2000–2019 was 106.61 (p = 70.37%). These rates will not allow us to achieve the set goals by 2030. On the other hand, in individual EU countries, the growth rates of the share of consumption of renewable energy sources are 108.41 and 110.64 (p = 3.7%, respectively). This indicates the presence of effective tools for increasing the share of renewable energy consumption and the need for more detailed research and dissemination.

The realization that achieving these goals is possible only through the structural transformation of the energy market has led to the approval of national energy efficiency goals by most countries and the development of national strategies for their achievement. This contributed to a slight decrease in the volume of energy consumption throughout the world (Figure 2).

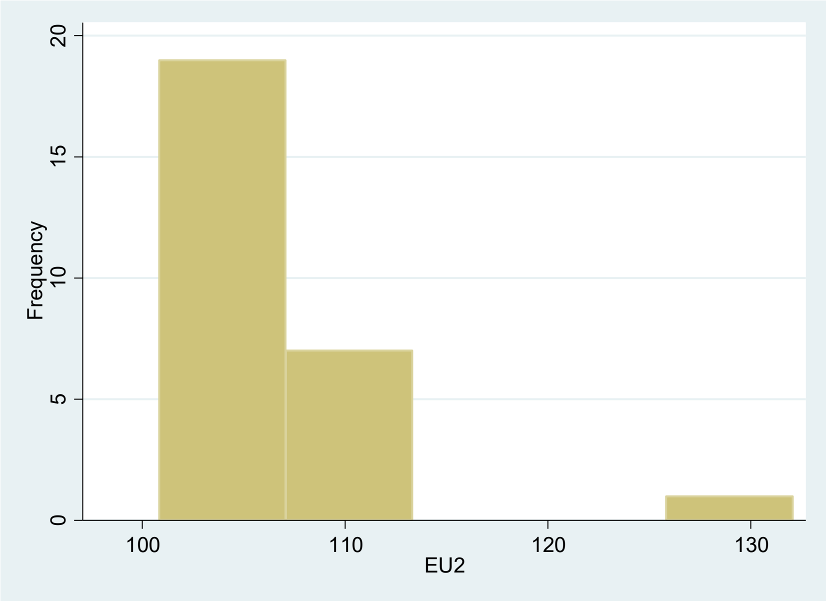

Figure 1. Frequency of the average growth rate of the share of renewable energy consumption in the EU, 2000–2019.

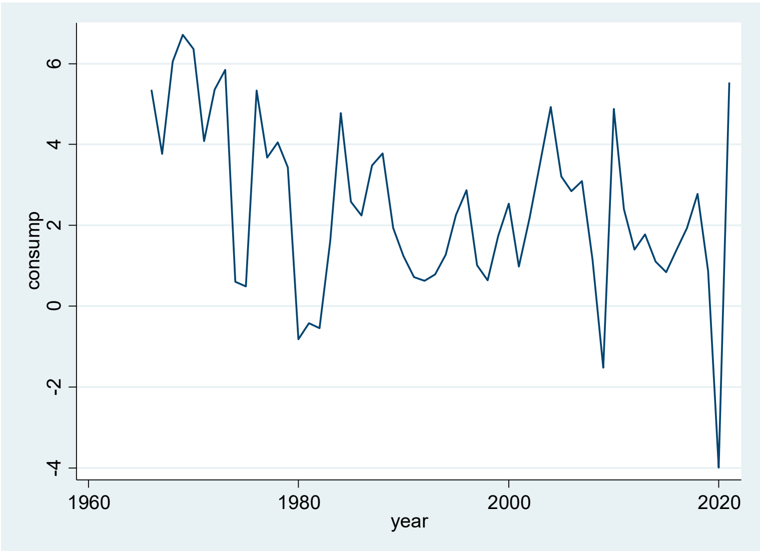

Figure 2. Annual change in primary energy consumption in EU countries. Source: [33].

Despite the fact that the COVID-19 pandemic led [34] to a 4.28% decrease in global energy consumption in 2020 (for the first time in the last 11 years), in 2021, its volume increased again by 5%; in value terms, it exceeded the 2019 level. A gradual increase in energy consumption has been observed in most countries (China—+5.2%; India—+4.7%; USA—+4.7%; EU—+4.5%), and the largest share of world energy consumption (almost 25%) continues to be occupied by China [33]. The spatial distribution results shown in Figure 3 demonstrate the absence of positive dynamics in reducing global energy consumption during 2005–2020.

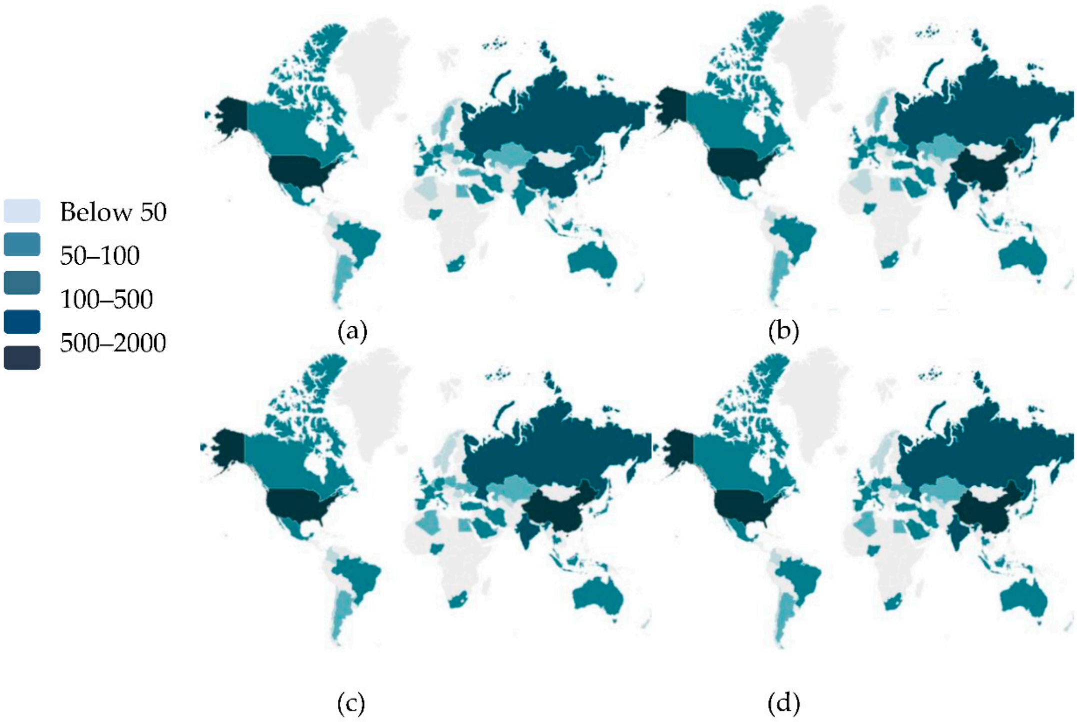

Figure 3. Spatial distribution of total energy consumption in the world: (**a**–**d**) represent the total energy consumption in 2005, 2010, 2015, and 2020.

Reforming the energy system through equipment investments, the development of energy-efficient products and technologies [35,36] requires, on the one hand, a significant amount of financial resources [37] (according to the European Commission, the number of capital investments in 2050 will be less than 14.6% of Europe's GDP, and the total investment costs in the energy system will range from EUR 1.5 to 2.2 trillion between 2011 and 2050), and on the other hand, the implementation of international and national initiatives aimed at changing the existing mechanisms of the energy market [38,39].

The tools and strategies for implementing the road map for sustainable energy development have not been fully explored. Currently, there are several problematic issues that require more detailed research, in particular, identifying the mechanisms for ensuring sustainable energy development, which are more sensitive to changes in the economic, environmental, and social components of state policies, and evaluating their effectiveness compared to other sustainable development tools.

Thus, this study is devoted to the modeling of scenarios for ensuring sustainable energy development based on the analysis of data from EU countries. The purpose of this study was to formalize an objective and a consistent set of tools to ensure sustainable energy development by state administration bodies, taking into account the global triggers of the impacts of social and economic development on energy consumption indicators of EU countries. In addition, we used data-mining methods for modeling energy policy reform scenarios, clustering countries depending on them, and assessing the impacts of socioeconomic development indicators on energy consumption volume. The contributions of this study are as follows: firstly, when assessing the influence of a country's social and economic development indicators on the volume of energy consumption, a much larger (compared to previous research) group of indicators was taken into account. Secondly, this study modeled four scenarios regarding state energy policy reform, depending on the country's cluster affiliation, which (in contrast to one scenario) allowed taking into account the different natures of the dependencies of energy consumption volume on a country's development trends, and predicting energy consumption indicators within an existing (or new) cluster, and in case of a transition, depending on the social and economic development indicators.

The paper is structured as follows: Section 2 presents the literature review of mechanisms for ensuring sustainable energy development, the definitions of its main determinants, and a formulation of the hypothesis; Section 3 provides the methods applied in the study; Section 4 analyzes the scenario modeling results, including the formalization of scenarios for reforming the country's state energy policy, depending on its cluster affiliation and the nature of the dependencies between its social and economic development indicators, and the energy consumption volume; Section 5 concludes the paper and presents relevant policy recommendations based on the analysis and discussion from the previous sections.

2. Literature Review

2.1. Theoretical Framework

Despite the relevance of energy issues in the world, the scientific literature shows a lack of a unified understanding of the determinants affecting the sustainable energy development provision. A significant number of scientists consider the transition to renewable energy sources as a driving force for overcoming the energy crisis and improving the environmental situation throughout the world [40–43].

In scientific papers, energy consumption has been investigated in relation to economic progress. Precht [44] divided all barriers (pertaining to the implementation of low-carbon transition energy technologies in Commonwealth countries) into four groups: technological, financial, institutional, and social. Moreover, in countries with low levels of development, the most important are financial costs—the costs of technology adoption for the energy transition. The author referred to measures that contributed to eliminating the influences of these factors on the speed and volume of the transition to energy-saving technologies, e.g., the formation of correct price signals, which included setting prices for carbon emissions from fossil fuels and canceling subsidized prices for fossil fuels. On the other hand, the failure to take into account environmental costs associated with carbon emissions when forming market prices leads to a distortion of market prices and a decrease in the efficiency of the energy market. A significant number of Commonwealth countries provide subsidies for the use of fossil fuels for the poor. According to experts [43], these subsidies are actually not effective in supporting the poor, as almost 93% of them go to the highest income groups and act as negative prices on carbon, encouraging its use.

Malik et al. [44] focused on the causal relationship between macroeconomic factors (population growth, urbanization, industrialization, exchange rate, price level, food production index, and livestock production index) and the share of renewable energy consumption in Pakistan for the period 1975–2012, and proved the existence of a positive influence of macroeconomic factors on the resulting indicator. Gozgor et al. [45] analyzed the relationship between renewable and non-renewable energy consumption and economic growth based on panel data for 29 countries of the Organization for Economic Cooperation and Development (OECD) for the period from 1990 to 2013. The findings of the autoregressive distributed lag (ARDL) and the panel quantile regression (PQR) models confirmed that higher rates of economic growth have statistically significant and positive influences on the consumption of both non-renewable and renewable energies.

A similar opinion was held by Zhao et al. [46], who focused on fully modified ordinary least squares (FMOLS) in China, and proved that financial development and per capita income have significant impacts on the growth of the share of renewable energy sources. The authors emphasized that trade openness and internationalization provoked an increase in the share of non-renewable energy consumption while reducing the amount of renewable energy sources. A similar opinion was held by Li et al. [47], who, based on the results of a panel regression analysis of data from 102 countries, substantiated the importance of international trade openness in the development of renewable energy. According to the authors, the protection of intellectual property rights is an inhibitor of renewable energy development, especially in countries with low levels of scientific and technical progress.

Sineviciene et al. [48] focused on long-term dynamic relationships (using stochastic marginal function and comparative analysis) for a data panel of 11 post-communist countries in Eastern Europe during 1996–2013, and determined that GDP growth is a key factor in increasing both the energy efficiency and energy consumption of a country. Moreover, their results showed that CO_2 emissions per capita and fixed capital, and the share of industry in the economy are important factors in ensuring sustainable energy development. Thus, the authors emphasized that policies aimed at increasing energy efficiencies in communist countries in Eastern Europe should ensure further economic growth due to the strengthening of positive influences of other factors and the implementation of energy-efficient projects.

In most studies, the construction of a road map for a country's sustainable energy development consists of determining the main anthropogenic sources of CO_2 emissions and, accordingly, the main measures aimed at reducing these emissions. Thollander et al. [49] considered CO_2 emissions as by-products of the main sources of non-renewable energy consumption, such as fossil fuels.

Thus, Solarin [50], based on an analysis of data from 20 countries in the period from 1982 to 2013, concluded that the volume of energy consumption per capita, urbanization, real foreign direct investment per capita, and real gross domestic product per capita, are the main factors that determine the CO_2 emission volumes.

Balsalobre-Lorente et al. [51], using the dynamic ordinary least square (DOLS) estimator, determined that economic complexities and CO_2 emissions have inverted-U and N-shaped relationships with Portugal, Italy, Ireland, Greece, and Spain. The authors concluded that there is a need to introduce comprehensive energy and economic policies at the state level, which focus on the use of renewable energy sources as drivers of CO_2 emission reductions.

Acheampong et al. [52] used the GMM-PVAR method to investigate the relationship between renewable energy development, CO2 emissions, and economic growth. Based on the analysis of data from 45 African countries from 1960 to 2017, the authors substantiated the existence of a bidirectional causal relationship between economic growth and the use of renewable energy sources.

In a study by Koengkan et al. [53], the relationship between financial openness, renewable and nonrenewable energy consumption, CO_2 emissions, and economic growth was evaluated. The authors examined data from 12 Latin American countries for the period 1980–2014; they found a high correlation between fossil fuel consumption and environmental degradation, a positive effect of economic growth and CO_2 emissions, and a negative effect of fossil fuel consumption and financial openness on the consumption of renewable energy.

Soytas and Sari [54], based on the analysis of time series data from 16 countries, investigated the causal relationship between GDP and energy consumption. Based on VEC modeling, they considered a stationary linear cointegrating relationship between variables for seven countries, bidirectional causality in Argentina, a positive impact of GDP on energy consumption in Italy and Korea, and the impact of energy consumption on GDP in Turkey, France, Germany, and Japan.

Islam et al. [55] analyzed the drivers of changes in renewable and non-renewable energy consumption. Thus, according to the ARDL (DARDL) modeling results, the authors claimed that income growth has positive and negative effects on renewable and non-renewable energy consumption, respectively. Urbanization and physical infrastructure have a negative impact on renewable energy consumption and a positive impact on non-renewable energy consumption. Foreign direct investment and institutional quality have positive effects on renewable energy consumption, while domestic investment has positive effects on both renewable and non-renewable energy consumption.

The impact of green growth on CO_2 emissions (regarding G7 countries) was investigated by Hao et al. [56]. The authors, using the distributive self-regressive-augmented transversal lag model (CSARDL), proved that short-term and long-term GDP growth affects the quality of the environment. Thus, the authors emphasized that changes in CO_2 emission volume, GDP, green growth, environmental taxes, consumption of renewable energy, and human capital in one of the G7 countries, will affect the indicators of other G7 countries that are interconnected with that country.

Li and Lung [57] investigated the relationship between weighted indices of coal and natural gas prices in electricity generation, real GDP, and renewable energy consumption. Based on the analysis of panel data of 7 European countries over a 34-year period (1985–2018), using the data envelopment analysis (DEA), the authors proved the key role of economic growth and non-renewable energy prices in increasing the consumption of renewable energy in developed economies (G7 countries).

Individual scientists are investigating institutional mechanisms for ensuring sustainable energy development. Marra and Colantoni [58], based on the panel vector autoregressive (PVAR) model, tested the hypothesis about the influence of institutional and socio-technical factors (policy stringency, public awareness, lobbying, education, controlling for income and energy imports) on the speed of the country's transition to renewable energy. Based on the analysis of data from 18 member states of the European Union for the period 1990–2015, the authors concluded that the strictness of the environmental policy does not affect renewable energy production, while income and education negatively affect this indicator. Moreover, the analysis shows the existence of a significant gap in the speed of transition to renewable energy. Thus, in countries that are less active on the production side, increasing policy stringencies will lead to an increase in renewable energy production, while in countries that are less active on the production side, excessive data lobbying negatively affects the transition to renewable energy production; however, increasing public awareness will contribute to the growth increase. In such countries, the social component of reforming the energy market should be focused on, and politicians should aim to reduce the share of energy produced from oil, natural gas, coal, and nuclear fuel. On the contrary, according to the estimates from the European Bank for Reconstruction and Development [59], the management and restructuring of enterprises are not important factors in increasing energy efficiency and reducing energy consumption per capita in post-communist countries.

Leitão [60], utilized fully modified least squares (FMOLS), dynamic least squares (DOLS), and two-stage least squares (TSLS) estimator, and emphasized that corruption endangers the functioning of the economy and exacerbates climatic and environmental problems. Based on the analysis of data from Portugal, Spain, Italy, Ireland, and Greece, for the years 1995–2015, the researcher proved that the corruption index and economic growth have statistically significant unidirectional positive effects on carbon dioxide emissions, while renewable energy sources and international trade reduce climate change and improve environmental quality.

Bilan et al. [61] agreed that corruption and the shadow economy, due to the reduction of green investments, negatively affect the development of green energy and the improvement of energy efficiency.

Miśkiewicz [62] substantiated the relevance of reforming the energy market, taking into account the principles of increasing energy efficiency and increasing the share of alternative energy sources. Vasylyeva and Pryymenko [63], based on the analysis of mechanisms for reducing a country's energy dependence and increasing energy security, concluded that the spread of green energy should be the basis of these processes.

2.2. Study Area Selection

The analysis of the dynamics of publishing the activity on energy consumption, carried out with the Scopus toolkit, showed a constant increase in the number of publications (Figure 4). Since 2000, the number of publications has increased by more than 19 times (2602 publications in 2021 compared to 133 in 2000).

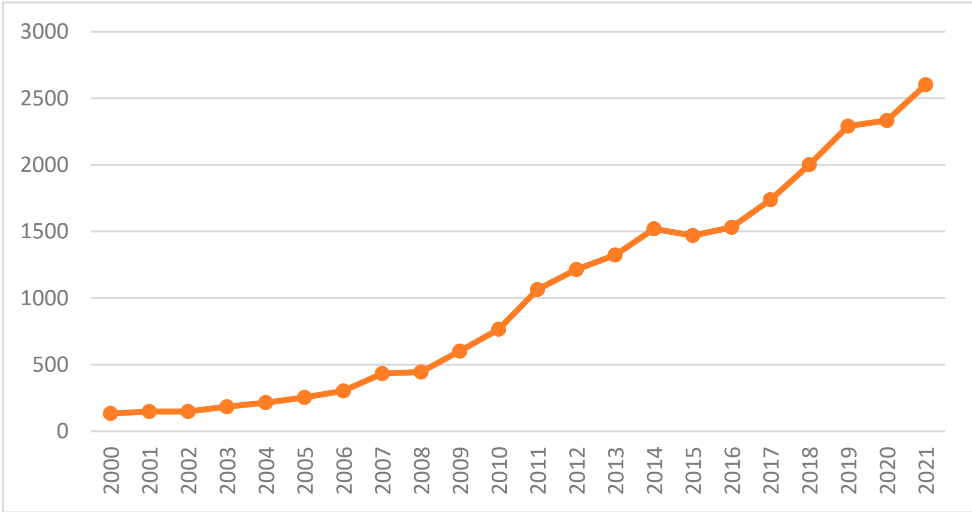

Figure 4. The dynamics of publication activity on energy consumption issues (based on Scopus data).

A more detailed analysis of scientific works in publications indexed by the Scopus database allowed visualizing the interrelationship of keywords and carrying out their network clustering.

Figure 5 shows five clusters that represent 1000 relationships between keywords. An in-depth analysis of each of the specified clusters allows for determining the most common keywords that, according to scientists, are related and affect energy consumption.

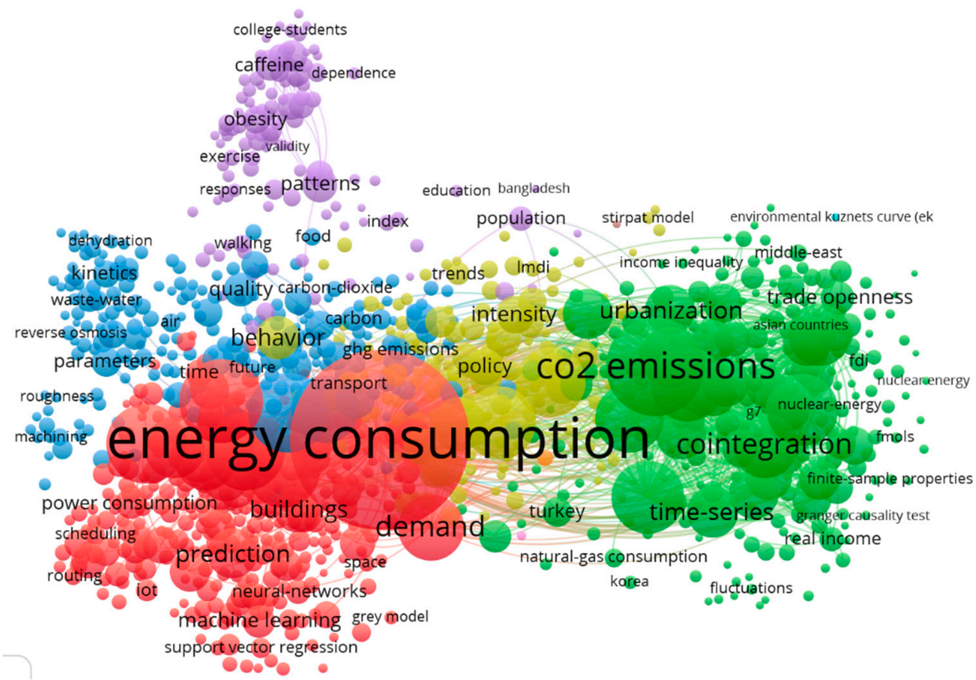

Figure 5. The network map of the bibliometric analysis concerning renewable energy consumption.

The first and largest (red) cluster examines the energy consumption (links—942, occurrences—4812, total link strength—20,253) via a connection with the cost of individual energy sources, production volumes, the state of the environment, smart technologies, solar energy, etc. The study of these connections was carried out using optimization methods, artificial intelligence tools, artificial neural networks, analysis of large datasets, and forecasting.

The second (green) cluster examines energy consumption (links—673, occurrences—1445, total link strength—13,407) through the connection with CO_2 emissions, corruption, the level of democracy, eco-innovations, economic growth, the cost of energy, exports, financial development, foreign direct investment, globalization, quality of the institutional environment, renewable energy sources, etc. The study of these relationships was carried out using the methods of causality, correlation analysis, co-interaction, panel analysis, and vector autoregressions.

The third (blue) cluster examines energy consumption (links—744, occurrences—943, total link strength—5160) along with such concepts as potential, efficiency, environmental performance, evolution, input–output, lifecycle, progress, quality, waste, etc. The most common methods of analysis include data envelopment analysis, economic analysis, life cycle analysis, and mathematical modeling.

The fourth (yellow) cluster links energy consumption (links—628, occurrences—479, total link strength—5499) with economic development, global warming, household consumption, inequality, etc. Scenario analysis methods serve as methodological tools for substantiating this relationship.

The smallest (purple) cluster links energy consumption (links—318, occurrences—185, total link strength—1113) with validity, mortality, association, awareness, consequences, awareness, etc.

Among the keywords found in the publications, the most significant were "CO_2 emission", "economic growth", "electricity consumption", "financial development", "cointegration", "impact", "renewable energy", "efficiency", "performance", "demand". Thus, it can be assumed that these keywords can be considered the main drivers of reducing energy consumption (Table 1).

Table 1. The TOP-10 co-occurrence keywords in the papers concerning energy consumption.

No.	Keyword	Total Link Strength
1	CO_2 emission	13,407
2	Economic growth	7727
3	Electricity consumption	7288
4	Financial development	6423
5	Cointegration	6223
6	Impact	6198
7	Renewable energy	6184
8	Efficiency	5160
9	Performance	5125
10	Demand	4500

In [64], the main factors that had the greatest impacts on energy consumption included the rural population, total population, gross domestic product, consumer price index, and carbon dioxide emissions. The findings of the study [65] showed the influences of the following groups of drivers: energy structure (the share of coal, oil, natural gas, biomass, hydro, and others), energy intensity (energy consumption per GDP), population growth, and GDP per capita. Based on the study results, the authors emphasized the importance of increasing energy efficiency and adjusting energy policies in the context of reducing energy consumption and achieving sustainable energy development in a country. The main measures of reforming the state energy policy should include accelerating the processes of energy transformation and modernization, coordinating the supply and demand for energy, focusing on technological progress, strengthening the adjustment of the economic structure in the future, and considering changes in energy consumption in the process of ensuring the uninterrupted operation of the economy.

Thus, the analysis of the results of previous research shows the presence of a significant number of approaches, and the use of various methodological research tools in the analysis of the problem regarding a significant amount of energy resource consumption. The advantage of these studies involves the use of a significant number of countries or spheres of activity. These studies have certain limitations. Most of the existing approaches and models use limited indicator systems (only economic, social, or environmental) to formalize the drivers of changes in energy consumption volume while ignoring the possibility of their complex influences on the resulting indicators. This leads to the fact that the tools and strategies for implementing the road map for sustainable energy development have not been fully explored. Thus, there is a gap in the availability of an approach that considers the complex impacts of indicators regarding a country's development in the scenario modeling of an energy policy for sustainable development, which determined the relevance and scientific significance of this study.

3. Materials and Methods

Annual data from the World Bank, the Organization for Economic Cooperation and Development, and the European Commission serve as the information base of the study. The period of the study was 2000–2019. EU countries were chosen as the objects of the study. Formalization, data preprocessing, and econometric analysis were performed using the Stata 14 software package.

Scenario modeling of sustainable energy development was carried out in two stages. In the first stage, a system of indicators that influenced the strategy choice for reforming the country's energy market (in terms of economic, environmental, and social components) was formalized. Thus, the following indicators served as the research information base:

Group 1—indicators of economic development: gross capital formation (current USD$); GDP per capita (current USD$); foreign direct investment, net inflows (BoP, cur. USD$); industry (including construction) value added (annual % growth); manufacturing, value added (% of GDP); imports of goods and services (% of GDP); exports of goods and services (% of GDP); research and development expenditure (% of GDP).

Group 2—indicators of ecological development: energy consumption in the industry (% total energy consumption); renewable energy consumption (% of total final energy consumption); CO2 emission; energy depletion (% of GNI); CO2 emissions from electricity and heat production, total (% of total fuel combustion).

Group 3—social development indicators that determine the ability to use energy-saving technologies at the household level. The Index of Social Development, which is based on the integration of 51 indicators, is an indicator that provides a holistic assessment of the social development level of the country (access to electricity; deaths attributed to outdoor air pollution; greenhouse gas emissions; corruption; access to justice; access to quality healthcare; access to quality education).

In the second stage of the study, the impacts of these factors on the scenario choices for reforming the country's energy market, and the tactical and strategic state management system of energy use processes, were evaluated.

The analyzed countries were clustered; sustainable energy development was carried out using agglomerative methods of minimum dispersion. According to this method, in the first step, each object was considered a separate cluster. The two closest objects were merged, and a new cluster was formed. The procedure continued until all objects were combined into one cluster.

One of the stages of clustering countries, depending on energy development scenarios, was the arrangement of a set of objects into relatively homogeneous groups using the k-means method, the use of which involved determining the average values for each cluster, Euclidean distances, and Euclidean distance squares between clusters. The centers of each of their clusters were determined using the distance sorting method and the selection of observations at constant intervals.

Determining the optimal number of clusters based on the value analyses of the inter-group (between SS) and intragroup (within SS) variances, a comparison of the variance analysis results for three, four, and five clusters were carried out, according to the following criteria:

- Maximization of the value of the Fisher criterion and approximation of the probability of rejecting the null hypothesis to the null value;

- Minimization of the intragroup variance and maximization of the intergroup variance.

Portraits of relevant country clusters were formalized using the one-dimensional CART branching method.

At the initial stage, the study of the main determinants affecting the energy consumption amount was carried out using the panel data regression model, which was characterized by several advantages compared to cross-section and time-series data [66].

Based on the analysis of articles on the drivers of renewable energy development [5,19], the model that determined the nature of the change of the dependent variable in relation to all independent variables had the following form:

$$EC = f(EDI_i,\ ECDI_i, SDI_1 \quad (1)$$

where EC is energy consumption; EDI_i—i-th indicator of economic development; $ECDI_i$—i-th indicator of ecological development; and SDI_1—i-th indicator of social development.

Today, the panel data regression model is a common tool used for analyzing the relationship between indicators and is one of the most popular. In [67], the authors noted that the main advantage of using panel data analysis tools is to minimize bias in the results. Thus, the use of this method will lead to reliable and competent estimates of the parameters α0 and β1...n.

The dependence of energy consumption on economic, environmental, and social development factors can be formalized using the generalized method of moments (GMM). According to Polcyn et al. [19], the use of this method can increase the reliability and validity of the results. In addition, the generalized method of moments allows one to neutralize the endogenous nature of the changes in the resulting indicator. The advantages of using this method in the analysis of economic and financial indicators are that it allows one to take into account the weight of each component of the model, and, unlike the classical method, allows one to take into account a much larger number of restrictions than the number of parameters. Thanks to this, the use of this method is effective in terms of saving time and obtaining more accurate results.

$$U_n(\beta) = \frac{1}{n}\sum\nolimits_{i=1}^{n}\ u_i(\beta) \quad (2)$$

where $U_n(\beta)$ can be greater than the dimension of β:

$$Q_n(\beta) = U_n^T(\beta)\sum\nolimits_n^{-1}(\beta)U_n(\beta) \quad (3)$$

where $\sum_n(\beta)$ is the empirical version of the variance–covariance matrix:

$$\sum_n(\beta) = \frac{1}{n^2}\sum\nolimits_{i=1}^{n} u_i(\beta)u_i^T(\beta) - \frac{1}{n}U_n(\beta)U_n^T(\beta) \quad (4)$$

B can be determined using the following iterations:

- Using the initial value β_0 in the expression $\sum_n(\beta)$;
- At the k-th iteration, the quadratic target function β_k is minimized;
- Using the values of β_k in the formula $\sum_n(\beta_k)$ and returning to step 2;
- Repeating these iterations until predetermined criteria are met.

At the next stage of formalizing the scenarios, ensuring sustainable energy development of the country by using classification trees (the one-dimensional CART branching method), we conducted a more detailed analysis of country cluster portraits. The use of this method allows for predicting the country's membership in a cluster depending on the values of the model's input indicators.

4. Results

Table 2 shows the descriptive statistic results for the analyzed energy consumption drivers. The balance of the analyzed data panel is evidenced by the same number of observations for each one (*n* = 541). All analyzed variables are characterized by significant variability. Thus, the share of energy consumption in the industry ranges from 1 to 53.9% of total energy consumption. The CO_2 emission volumes are in the range of 2.93–25.6.

Table 2. Definitions of variables and descriptive statistics for all countries.

Variables	Mean	Std. Dev.	Min	Max
Energy consumption in industry, % total energy consumption	17.66115	11.60438	1	53.9
GDP per capita (current US $)	2.14×10^{10}	5.77×10^{10}	-3.45×10^{11}	7.34×10^{11}
Foreign direct investment, net inflows (BoP, cur. USD$)	28,971.23	21,277.81	1621.24	123678.7
Renewable energy consumption (% of total final energy consumption)	16.62307	11.5724	0	52.88
CO_2 emission	7.580756	3.528094	2.93	25.6
Population growth, %	2.293984	6.598446	−24.86	74.39
Industry (including construction), value added (annual % growth)	14.95812	4.9773	3.89	34.9
Manufacturing, value added (% of GDP)	0.224582	0.848165	−3.85	3.93
Access to electricity	99.55834	0.03856	99.1	100
Deaths attributed to outdoor air pollution	4.755423	2.014964	0.612447	9.909073
Greenhouse gas emissions	144,281	198,514.2	1880	976,270
Gross capital formation (% of GDP)	23.05694	4.575821	11.89228	54.6975
Imports of goods and services (% of GDP)	58.05659	28.49082	22.84665	174.6221
Exports of goods and services (% of GDP)	59.79897	33.66988	18.54458	205.4821
Research and development expenditures (% of GDP)	1.449661	0.882911	0.2269	3.8738
Energy depletion (% of GNI)	5.36×10^8	1.14×10^9	0	8.23×10^9
CO_2 emissions from electricity and heat production, total (% of total fuel combustion)	42.33723	16.31682	2.853598	86.02941

Source: author's calculations.

Based on the panel regression parameter estimation results using GMM modeling, it can be concluded that there is a positive relationship between energy consumption and most of the analyzed indicators, e.g., access to electricity, deaths attributed to outdoor air pollution, greenhouse gas emissions, gross capital formation, GDP per capita, industry (including construction) value-added, manufacturing, exports of goods and services, CO_2 emission; energy depletion, and CO_2 emissions from electricity and heat production. For example, an increase in GDP per capita by 1% leads to an increase in the consumption of renewable energy by 0.87%. In addition, a positive relationship was established between the level of access to electricity and the volume of its consumption, as a consequence of the energy depletion of the country. The increase in the volume of energy consumption also directly depends on the volume of greenhouse gas and CO_2 emissions. This determines the presence of a positive relationship between energy consumption and mortality from outside air pollution. Conversely, the negative values of the correlation coefficient indicate that countries that are financed by funds for the development of renewable energy sources and the introduction of energy-saving technologies demonstrate significantly lower amounts of energy consumption. According to the calculation results, a negative relationship between the volume of energy consumption and foreign direct investment, imports of goods and services, research and development expenditures, and renewable energy consumption, was confirmed (Table 3).

Table 3. Panel generalized method of moments model.

Variables	Renewable Energy Consumption						
	Coefficient	**Std. Error**	**z**	**$p > \|z\|$**	**[95% Conf. Interval]**		**Relationship**
$ECDI_1$	−0.01732	0.01015	−1.71	0.037	−0.00254	0.03724	negative
$ECDI_2$	0.00534	0.00312	1.71	0.045	0.01147	0.00077	positive
$ECDI_3$	0.15586	0.05215	2.25	0.002	0.05387	0.25830	positive
$ECDI_4$	0.01633	0.00492	1.89	0.001	0.00671	0.02600	positive
EDI_1	0.01307	0.00765	1.29	0.006	0.00191	0.02809	positive
EDI_2	0.87380	0.00597	146.35	0.000	0.86341	0.88681	positive
EDI_3	−0.02872	0.00865	−3.32	0.001	−0.01180	0.04571	negative
EDI_4	0.02144	0.00815	2.64	0.008	0.00550	0.03743	positive
EDI_5	0.00046	0.00280	0.16	0.021	0.00594	0.00503	positive
EDI_6	−0.00402	0.00236	1.29	0.006	−0.00865	0.00058	negative
EDI_7	0.01617	0.00614	1.99	0.006	0.00415	0.02823	positive
EDI_8	−0.00021	0.00127	−0.07	0.003	−0.00270	0.00228	negative
SPI_1	0.20667	0.06916	2.99	0.003	0.07143	0.34252	positive
SPI_2	0.02166	0.00652	2.50	0.001	0.00890	0.03447	positive
SPI_3	0.48419	0.00331	81.10	0.001	0.47843	0.49140	positive

Note: SPI_1—access to electricity; SPI_2—deaths attributed to outdoor air pollution; SPI_3—greenhouse gas emissions; EDI_1—gross capital formation (% of GDP); EDI_2—GDP per capita (current USD$); EDI_3—foreign direct investment, net inflows (BoP, current USD$); EDI_4—industry (including construction) value added (annual % growth); EDI_5—manufacturing, value added (% of GDP); EDI_6—imports of goods and services (% of GDP); EDI_7—exports of goods and services (% of GDP); EDI_8—research and development expenditure (% of GDP); $ECDI_1$—renewable energy consumption (% of total final energy consumption); $ECDI_2$—CO_2 emission; $ECDI_3$—energy depletion (% of GNI); $ECDI_4$—CO_2 emissions from electricity and heat production, total (% of total fuel combustion).

The growth of financial resources can lead to an increase in the amount of funds directed to the development of new (or the introduction of already existing) energy-saving technologies or renewable energy sources.

Thus, the results confirm the hypothesis about the complex influences of the social, economic, and ecological development indicators on a country's volume of energy consumption. The established dependencies confirm the results of previous studies on GDP growth affecting the quality of the environment [56,57], the positive impact of growth on the adoption of technology costs for the energy transition (including the costs of development and implementation) [44], statistically significant and positive influences on the energy consumption of renewable energy [45], and trade openness [46].

The R-squared value of 0.845 indicates a sufficient level of reliability of the results. Thus, the analyzed factor characteristics can explain 84.5% of the change in the energy consumption volume. In addition, an F-statistic value ($p > |z|$) less than 5% indicates that the obtained parameters of the regression model are statistically significant (F < 0.05).

To verify the reliability of the results, we analyzed the relationship between the energy consumption amount and economic, ecological, and social development indicators (of the analyzed countries) using the fixed-effects and random-effects models (Table 4).

According to the panel regression parameter results for the fixed effects model, all analyzed variables explain approximately 95.4% of the variation in the energy consumption amount (R-squared = 0.954). This confirms the sufficient fit of the fixed effects model. The F-statistic value (Prob = 0.000) testifies to a high level of statistical significance of the overall panel regression (F < 0.05). Overall, the regression parameters of panel data with fixed effects confirm a positive relationship between the volume of energy consumption and access to electricity, deaths attributed to outdoor air pollution, greenhouse gas emissions, gross capital formation, GDP per capita, industry (including construction) value-added, manufacturing, exports of goods and services, CO_2 emissions, energy depletion, CO_2 emissions from electricity, and heat production. For example, an increase in GDP per capita by 1% leads to an increase in EC by 0.508%. In turn, an increase in energy depletion by 1% leads to an increase in EC by 0.149%. The results testify to the inverse influence of foreign direct investment, imports of goods and services, research and development expenditures, and renewable energy consumption on the volume of energy consumption.

Table 4. Panel regression results for the fixed-effects model.

Variable	Coefficient	Std. Error	t-Statistic	Prob.	Relationship
$ECDI_1$	−0.017 *	0.010	−1.635	0.000	negative
$ECDI_2$	0.005 **	0.003	1.576	0.000	positive
$ECDI_3$	0.149 *	0.047	2.151	0.000	positive
$ECDI_4$	0.015 *	0.005	1.686	0.001	positive
EDI_1	0.012 *	0.007	1.163	0.000	positive
EDI_2	0.508 *	0.006	3.246	0.001	positive
EDI_3	−0.026 *	0.008	−3.031	0.001	negative
EDI_4	0.021 *	0.008	2.524	0.000	positive
EDI_5	0.000 **	0.003	0.146	0.000	positive
EDI_6	−0.004 *	0.002	−1.189	0.000	negative
EDI_7	0.015 *	0.006	1.817	0.000	positive
EDI_8	−0.001 *	0.001	−0.063	0.000	negative
SPI_1	0.185 *	0.066	2.672	0.000	positive
SPI_2	0.020 *	0.006	2.304	0.001	positive
SPI_3	0.464 *	0.003	77.646	0.001	positive
R-Squared			0.954		
Prob (F-statistic)			0.000		

Note: * $p < 0.01$, ** $p < 0.05$.

The results from calculating the panel regression results for the random-effects model (Table 5) confirm the sufficient reliability and statistical significance of the results (R-square is 0.845, and Prob = 0.000).

Table 5. Panel regression results for the random-effects model.

Variable	Coefficient	Std. Error	t-Statistic	Prob.	Relationship
$ECDI_1$	−0.020 *	0.000	−2.108	0.000	negative
$ECDI_2$	0.005 *	0.000	1.581	0.000	positive
$ECDI_3$	0.157 *	0.008	2.369	0.000	positive
$ECDI_4$	0.034 *	0.000	4.395	0.000	positive
EDI_1	0.019 *	0.000	2.045	0.000	positive
EDI_2	0.690 *	0.004	25.244	0.000	positive
EDI_3	−0.044 *	0.000	−5.495	0.000	negative
EDI_4	0.032 *	0.000	4.079	0.000	positive
EDI_5	0.004 *	0.000	1.374	0.000	positive
EDI_6	0.012 *	0.000	4.199	0.000	positive
EDI_7	0.035 *	0.000	4.707	0.000	positive
EDI_8	−0.002 *	0.000	−0.668	0.000	negative
SPI_1	0.665 *	0.044	10.727	0.000	positive
SPI_2	0.185 *	0.001	23.136	0.000	positive
SPI_3	0.428 *	0.001	17.840	0.000	positive
R-Squared			0.876		
Prob (F-statistic)			0.000		

Note: * $p < 0.01$.

In a similar vein to the fixed-effect regression results, Table 6 shows a negative relationship between energy consumption and foreign direct investment, research and development expenditures, and renewable energy consumption. Thus, an increase in foreign direct investment, research and development expenditures, and renewable energy consumption by 1% leads to a decrease in energy consumption by 0.044, 0.002, and 0.02%, respectively. The rest of the indicators have positive effects on the energy consumption amount.

Table 6. The eigenvalue fragments in the correlation matrix and the selection of social development indicator priorities.

Component	Eigenvalue	Difference	Proportion	Cumulative
SPI_1	2.38746	1.02637	0.3411	0.3411
SPI_2	1.36109	0.378104	0.1944	0.5355
SPI_3	0.982983	0.153547	0.1404	0.6759
SPI_4	0.829436	0.12728	0.1185	0.7944
SPI_5	0.702156	0.179743	0.1003	0.8947

Note: SPI_1—access to electricity; SPI_2—deaths attributed to outdoor air pollution; SPI_3—greenhouse gas emissions; SPI_4—corruption; SPI_5—access to justice.

In the second stage of the research, in order to assess the influences of factors on the scenario choices for reforming the country's energy market, we evaluated the most relevant indicators that directly affected renewable energy consumption. Considering that within the framework of the third group of indicators, we analyzed 51 indicators characterizing social development, based on the main component method, we determined the expediency of including all indicators in the calculations. The eigenvalues of the priority correlation matrix of social development indicators shown in Table 6 prove that more than 89.47% of the variation of the integral index of social development was provided by its five components. Thus, when assessing the impact of indicators (i.e., on the social development of the country, regarding energy consumption), it is advisable to use only five factors.

In the next stage, we determined the priority of the country's social development indicators. For this purpose, we analyzed the contribution of each of the five indicators (based on the correlation coefficient) to the social development indicator using the weighted arithmetic mean method (Table 7).

Table 7. Social development indicator contributions by the main components.

Variable	Component 1	Component 2	Component 3	Component 4	Component 5
SPI_1	0.01631	0.00152	0.01826	0.00493	0.00015
SPI_2	0.01590	0.00094	0.01526	0.00692	0.00118
SPI_3	0.01542	0.00199	0.01962	0.00318	0.00005
SPI_4	0.01608	0.00102	0.01666	0.00494	0.00051
SPI_5	0.01643	0.00201	0.01751	0.00437	0.00009
SPI_6	0.01535	0.00596	0.00841	0.00283	0.00173
SPI_7	0.01602	0.00117	0.01463	0.00672	0.00104

Note: SPI_1—access to electricity; SPI_2—deaths attributed to outdoor air pollution; SPI_3—greenhouse gas emissions; SPI_4—corruption; SPI_5—access to justice; SPI_6—access to quality healthcare; SPI_7—access to quality education.

The results from prioritizing the indicators of social development allow determining the most relevant indicators, in particular, SPI_1—access to electricity; SPI_2—deaths attributed to outdoor air pollution; SPI_3—greenhouse gas emissions; SPI_4—corruption; SPI_5—access to justice; SPI_6—access to quality healthcare; SPI_7—access to quality education.

In the next stage of the research, based on agglomerative methods of minimum variance (iterative divisive k-means method and tree clustering), countries were clustered according to the most relevant scenarios of state energy policy reforms.

The basis of these calculations involved determining (using variance analysis tools) the number of groups into which the countries could be divided (Figure 6).

The analysis of the results (i.e., of the grouping of countries within three and five clusters) proved the low quality of the clustering process. Thus, indicators SPI_1—access to electricity, EDI_2—GDP per capita (current USD$); EDI_3—foreign direct investment, net inflows (BoP, current USD$); EDI_4—industry (including construction) value added (annual % growth); $EcDI_5$—CO_2 emissions from electricity and heat production, and total (% of total fuel combustion) obtained p-values that exceed the critical (0.05), while for indicators SPI_3—greenhouse gas emissions; EDI_6—imports of goods and services (% of GDP); EDI_7—exports of goods and services (% of GDP); $EcDI_3$—CO_2 emission—values were borderline to critical. Moreover, Fisher's test was not statistically significant, and the values of group variance and intra-group variance indicated the inexpediency of dividing countries into three clusters.

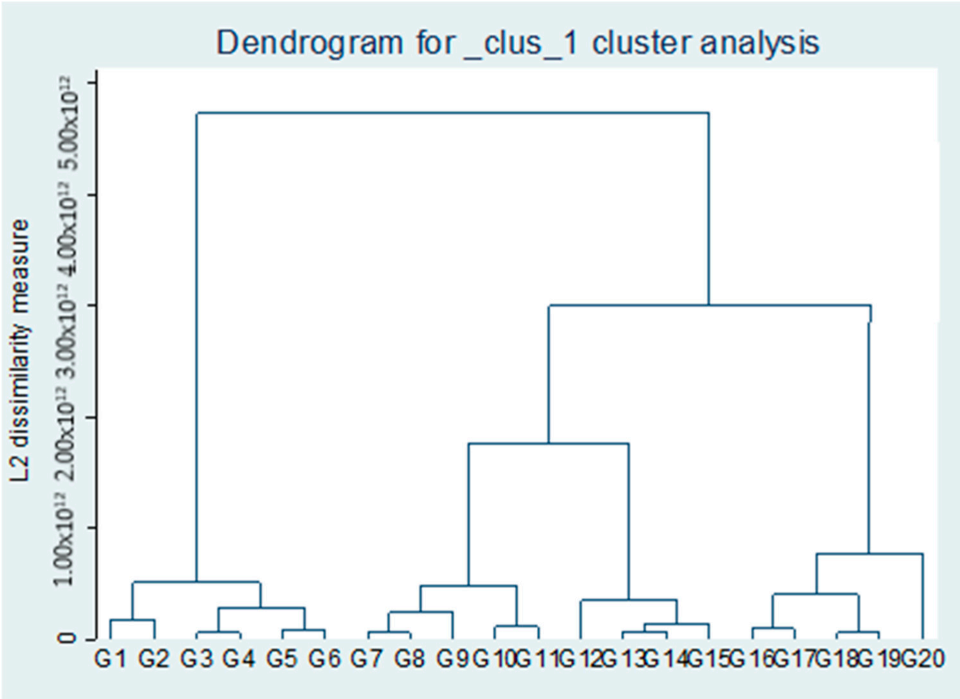

Figure 6. Hierarchical structure tree of the distribution of energy consumption drivers.

The dispersion analysis results (Table 8) proved the expediency of distinguishing four clusters of countries, depending on the scenarios of energy consumption policy reform. Thus, based on the analysis of the values of inter-group (between SS) and intra-group (within SS) characteristics of dispersion, it can be concluded that the highest quality grouping of countries can be achieved by dividing countries into four clusters. For all indicators of social, economic, and environmental development, the estimated values of the p-level were below the critical level (0.05), which indicated the high quality of the clustering of countries within the four groups.

Table 8. Countries clustered into four groups based on variance analysis results.

	Analysis of Variance (Spreadsheet2.sta)					
Variable	**Between SS**	**df**	**Within SS**	**df**	**F**	**Signif. *p***
$ECDI_1$	0.55890	3	1.20249	44	6.88388	0.000143
$ECDI_2$	0.97417	3	0.56692	44	25.45018	0
$ECDI_3$	0.44635	3	0.27079	44	24.41312	0
$ECDI_4$	0.32585	3	0.54007	44	8.93615	0.000015
EDI_1	0.34104	3	0.72609	44	6.95668	0.000132
EDI_2	0.77930	3	1.00212	44	11.51768	0.000001
EDI_3	0.25865	3	0.69881	44	5.48195	0.000755
EDI_4	56.31921	3	9.66702	44	86.28662	0
EDI_5	1.40614	3	0.88895	44	23.42766	0
EDI_6	1.66946	3	1.05482	44	23.44098	0
EDI_7	1.25594	3	0.84283	44	22.06998	0
EDI_8	1.48733	3	1.00024	44	22.02333	0
SPI_1	2.13140	3	0.91791	44	34.39121	0
SPI_2	2.37471	3	1.00163	44	35.11435	0
SPI_3	2.33585	3	1.04161	44	33.21392	0

Source: own compilation.

Values of intragroup and intergroup dispersion, Fisher's criterion, and p-criterion when dividing countries into five clusters indicated a slight improvement in the quality of this process. For some indicators (compared to the selection of three clusters), the calculated values were less than the critical value (p-level = 0.05). However, in general, the obtained values testified to the deterioration of the quality of the clustering process and allowed us to draw a conclusion about the expediency of dividing countries according to the scenarios of ensuring sustainable energy development in four clusters (clusters 1–7; clusters 2–6; clusters 3–9; and cluster—6):

Cluster 1: Cyprus, Denmark, Finland, Greece, Ireland, Italy, and Luxembourg;

Cluster 2: Bulgaria, Croatia, Estonia, Malta, and the Netherlands;

Cluster 3: Czech Republic, Greece, Hungary, Lithuania, Latvia, Slovak Republic, Slovenia, Romania, and Poland;

Cluster 4: Austria, Belgium, France, Portugal, Spain, and Sweden.

The results from the clustering of countries using agglomerative methods (Table 9) allowed us to describe the key vectors of the country's energy development within each cluster in terms of economic, environmental, and social indicators of the country's development, in particular:

- The average social development indicator values in the countries from the first cluster were the highest and consistently decreased from the first to the fourth cluster;
- Within the parameters of economic development: when moving from the first to the fourth clusters, the average values of gross capital formation (% of GDP), industry (including construction) value added (annual % growth), GDP per capita (current USD$), foreign direct investment, net inflows (BoP, current USD$), imports of goods and services (% of GDP), exports of goods and services (% of GDP), and research and development expenditures (% of GDP) gradually increased, while the rest of the indicators decreased;
- Within the parameters of ecological development, the average values of renewable energy consumption (% of total final energy consumption) within cluster 1 were the lowest and gradually increased when moving from one cluster to another. The average values of the remaining indicators were reduced.

Table 9. Clustering of countries according to energy policy reform scenarios within the average values of input indicators.

Variable	Cluster 1	Cluster 2	Cluster 3	Cluster 4
$ECDI_1$	3.957778	7.967174	12.6674	18.79458
$ECDI_2$	9.858889	8.68	8.576087	7.645875
$ECDI_3$	4.62×10^9	1.16×10^9	4.86×10^8	4.80×10^8
$ECDI_4$	43.13797	37.43519	34.63907	40.66555
EDI_1	21.65069	22.10064	22.11167	24.34707
EDI_2	23243.16	37932.65	39684.59	47230.26
EDI_3	2.99×10^9	7.68×10^{10}	2.80×10^{10}	3.17×10^{11}
EDI_4	2.176125	0.316304	0.945343	1.338889
EDI_5	15.6875	15.42174	14.37726	12.67333
EDI_6	53.3848	51.55711	50.70253	61.88923
EDI_7	52.344	55.63731	55.64425	68.77751
EDI_8	1.324631	1.877699	1.647639	1.900871
SPI_1	100	100	100	100
SPI_2	5.318857	4.410568	4.084318	4.429696
SPI_3	86233.75	383365.2	252570.8	270391.1

Source: own compilation.

In the next stage, with the help of classification trees, we formalized the portraits of the selected clusters of countries depending on the sustainable energy development scenario (in terms of economic, ecological, and social indicators).

The classification of countries, according to the scenarios of sustainable energy development given in Table 10 (node numbers, number of child vertices on the left and right branches, number of objects in the classes, and the branching condition (split variable)), as well as the data in Figure 7, allowed us to conclude that the first cluster included five countries, the second—seven, the third—seven, and the fourth—three. The distribution of countries by vertices 2 and 3 was carried out depending on the value of the variable edi1, which must not have exceeded 23.0211 for the countries in cluster 4, or be greater than this value for the countries in cluster 2. Within cluster 4, a further grouping of countries was based on the indicator edi4, a value that should not have exceeded 1.0421 for countries in cluster 4. Otherwise, the country could be assigned to cluster 3. Further clustering of countries was carried out, taking into account the value of variable edi5. If the value of variable edi5 exceeded 13.854, then the country should have been assigned to cluster 4, otherwise—to cluster 2. The analysis of the right branch of the classification tree confirms that cluster 2 included 12 EU countries, which combined countries from clusters 1 and 2. Attribution of a country to cluster 1 was possible if the value of variable edi1 did not exceed 21.9753, while cluster 2 included countries with the value of variable edi1 exceeding 21.9753.

Table 10. Classification tree structure according to the scenarios of sustainable energy development modeling.

Node	Left Branch	Right Branch	N in cls Cluster 1	N in cls Cluster 2	N in cls Cluster 3	N in cls Cluster 4	Predict. Class	Split Constant	Split Variable
1	2	3	5	9	7	3	Cluster 2	−23.0211	EDI_1
2	4	5	0	2	7	3	Cluster 4	1.0421	EDI_4
3	6	7	5	7	0	0	Cluster 2	21.9753	EDI_1
4			0	0	7	0	Cluster 3		
5	8	9	0	2	0	3	Cluster 4	13.8534	EDI_5
6			0	7	0	0	Cluster 2		
7			5	0	0	0	Cluster 1		
8			0	2	0	0	Cluster 2		
9			0	0	0	3	Cluster 4		

Source: own compilation

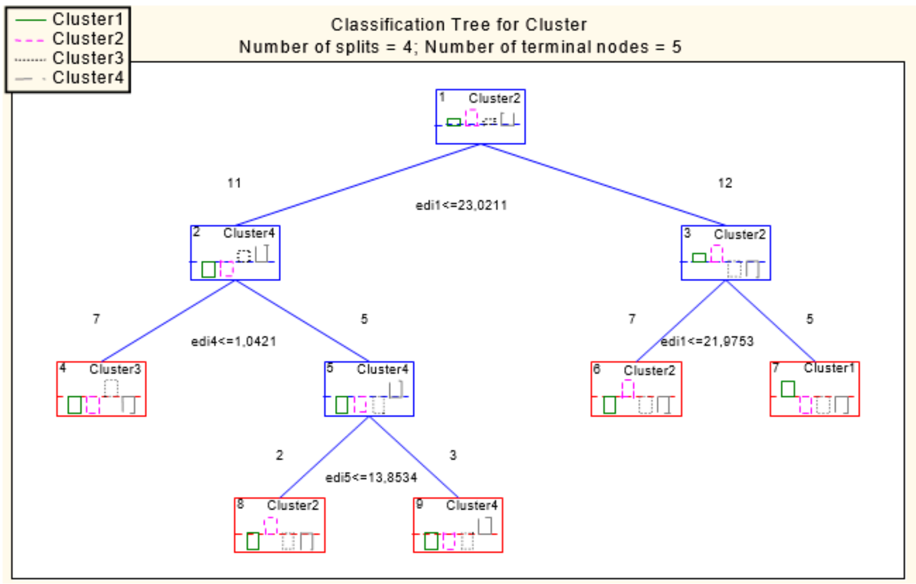

Figure 7. Classification tree of countries by modeling scenarios of sustainable energy development. Source: own data.

Thus, based on the analysis results, it is possible to formulate the following criteria for assigning a country to a certain cluster:

- The condition for assigning a country to cluster 1: the value of variable edi1 exceeds 21.9753;
- The condition for assigning a country to cluster 2: the fluctuation of the value of variable edi1 is within 23.0211–21.9753, and the value of variable edi5 is no more than 13.8534;
- The condition for assigning a country to cluster 3: the value of variable edi1 is less than 23.0211, and variable edi4—1.0421;
- The condition for assigning a country to cluster 4: the value of variable edi1 is less than 23.0211, variable edi4—more than 1.0421, variable edi5—more than 13.8534.

In the next stage, we ranked the drivers of energy consumption according to their influences on the clustering of countries. The ranking results presented in Figure 8 allowed us to conclude that GDP per capita (98 points), gross capital formation (97 points), industry (including construction) value added (annual % growth) (96 points), and manufacturing, value added (95 points) had the greatest influence on the clustering of countries. Greenhouse gas emissions (25 points) and deaths attributed to outdoor air pollution (27 points) had the least impacts on these processes.

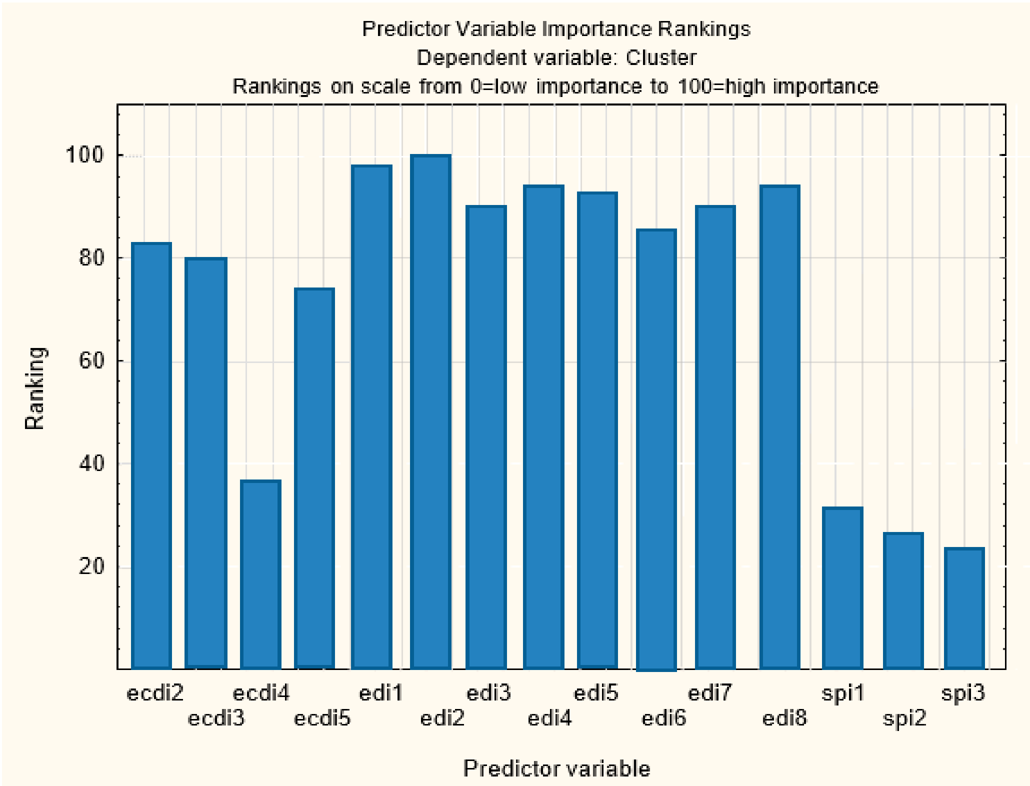

Figure 8. Ranking of indicators by influence on the clustering of countries, depending on the sustainable energy development scenarios. Source: own data.

Thus, the basis of formalizing a country's energy policy reform scenario (in the context of ensuring its sustainable energy development) should consider the country belonging to a certain cluster and its ability to move to another (better, in terms of indicators) under the influence of endogenous and exogenous factors. Depending on the nature and speed of change in the country's position under the influence, the following scenarios for reforming the country's energy policy can be distinguished:

- Neutral scenario—a scenario in which the country does not change its position;
- Scenario of slow transformation—a scenario in which the country changes its own position by one point (one cluster);

- Moderate scenario—a set of measures in which the country's position changes by two points (transition to two clusters);
- Responsive scenario—a scenario in which the country changes its position by three points (three clusters).

The basis for selecting a scenario (for reforming the country's energy policy) should be the assessment of the sensitivity of energy consumption indicators to the consequences of measures implemented in the country.

5. Conclusions

This study analyzed the problem of the constant growth of energy consumption and the consequences of these processes for the environment. Based on the bibliographic, trend, cluster, and correlation analysis results, the article substantiates the feasibility of formalizing a set of the most effective tools for ensuring sustainable energy development, considering global triggers of the influence of socioeconomic development indicators on energy consumption indicators in EU countries.

In general, the following conclusions can be drawn based on the study results.

Energy consumption volume has a positive relationship with the level of access to electricity, deaths attributed to outdoor air pollution, greenhouse gas emissions, gross capital formation, GDP per capita, industry (including construction) value-added, manufacturing, exports of goods and services, CO_2 emissions, energy depletion, CO_2 emissions from electricity, and heat production. The results prove the importance of using an effective toolkit for reforming the energy market in the EU. Reducing the influence of individual indicators on the volume of energy consumption (access to electricity, gross capital formation, GDP per capita, industry (including construction) value-added, manufacturing, exports of goods and services) should be carried out—not at the expense of quantitative transformation, but by qualitative impacts: the production volume growth and the level of access of the population to electricity with a simultaneous increase in the share of renewable energy sources.

Instead, foreign direct investment, imports of goods and services, research and development expenditures, and renewable energy consumption negatively affect the resulting indicator. This was confirmed by the estimation of regression parameter results with fixed and random effects, as well as the GMM test. Thus, the results of the study prove that EU countries have the potential to reduce energy consumption, switch to energy-saving technologies and renewable energy sources by attracting additional investments in this industry, directing a significant amount of funds to the development of new (or the introduction of already existing) energy-saving technologies. Thus, the change in priorities regarding the financing and development of technologies in the direction of energy saving, and the attraction of additional financial resources, should serve as priority directions in the energy policies of EU countries.

Considering the above, the obtained empirical results from the bases for the development of economically-justified and environmentally effective policies to reform the energy market, which are of key importance to achieving the sustainable development goals and increasing the energy security of EU countries. According to the indicator rankings of economic, social, and environmental development results, according to their degrees of influence on the grouping of countries, GDP per capita (98 points), gross capital formation (97 points), industry (including construction) value added (annual % growth) (96 points), manufacturing, value added (95 points), they have the greatest influence on the clustering of countries. Thus, regarding their activities, the governments of these countries should pay more attention to economic development issues, production stimulation, and gross capital formation (with simultaneous transitions of most industry sectors to energy-saving technologies). The key role in this should belong to the growth of investment attractiveness of these enterprises and sectors of the economy, growth of green investments for the transition to renewable energy sources, support of energy-saving projects and initiatives, etc.

Based on the analysis of the impacts of these indicators on the key vectors for reforming a country's energy policy (e.g., investment volume in renewable energy sources, the population's readiness for their introduction, the country's financial capabilities), a clustering of EU countries was conducted and scenarios for ensuring sustainable energy development were formalized. This made it possible to identify (on the basis of agglomerative methods of minimum dispersion) four clusters of countries according to scenarios that ensured sustainable energy development (cluster 1—Cyprus, Denmark, Finland, Greece, Ireland, Italy, and Luxembourg; cluster 2—Bulgaria, Croatia, Estonia, Malta, and the Netherlands; cluster 3—Czech Republic, Greece, Hungary, Lithuania, Latvia, Slovak Republic, Slovenia, Romania, and Poland; cluster 4—Austria, Belgium, France, Portugal, Spain, and Sweden).

The cluster analysis results can serve as a basis for finding and using the best practices of reforming the energy market in countries belonging to the fourth cluster, including the introduction of green bonds into circulation, support for green initiatives, state support, and encouragement of environmental projects, etc.

Despite the contributions of this study to the processes of reforming the global energy sector, this study has shortcomings that can be taken into account in future studies. First, the lack of data for a significant number of countries determined the choice of the research objects (EU countries). However, taking into account the importance of energy problems at the global level, future research should be devoted to the analysis of the energy markets in more countries throughout the world, the comparison of energy development trends of countries with low, medium, and high levels of economic development, taking into account the scenario formation personalities to ensure the sustainable energy development of a country (depending on the level of its economic development). In addition, based on the research results, we concluded that selecting a country's energy policy reform scenario should be based on the results of assessing the sensitivity of energy consumption indicators to the consequences of measures implemented in the country. Thus, future studies should study the influences of specific indicators on the processes of clustering countries. In addition, in the study, we focused on a small number of indicators of the country's ecological development (renewable energy consumption, CO_2 emissions, energy depletion, CO_2 emissions from electricity, and heat production). Future studies should take into account a larger number of indicators of the country's energy development.

Author Contributions: Conceptualization, N.A., I.T. and Y.K.; methodology, S.B., T.W. and O.D.; software, T.W. and O.D.; validation, N.A., I.T., S.B. and Y.K.; formal analysis, N.A. and O.D.; investigation, I.T. and Y.K.; resources, S.B. and T.W.; data curation, N.A., I.T. and O.D.; writing—original draft preparation, N.A., I.T. and O.D.; writing—review and editing, S.B., T.W. and Y.K.; visualization, N.A. and S.B. All authors have read and agreed to the published version of the manuscript.

Funding: The research was funded by the Ministry of Education and Science of Ukraine (grant numbers 0120U102002, 0122U000769, and 0122U000777).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

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

References

1. Samusevych, Y.; Vysochyna, A.; Vasylieva, T.; Lyeonov, S.; Pokhylko, S. Environmental, energy and economic security: Assessment and interaction. *E3S Web Conf.* **2021**, *234*, 00012. [CrossRef]
2. Louis, R. A new economic order for global prosperity. *SocEcon Challeng.* **2017**, *1*, 52–59. [CrossRef]
3. Bilan, Y.; Srovnalã-KovÃi, P.; Streimikis, J.; Lyeonov, S.; Tiutiunyk, I.; Humenna, Y. From shadow economy to lower carbon intensity: Theory and evidence. *Int. J. Glob. Env. Issues.* **2020**, *19*, 196–216. [CrossRef]
4. Potapenko, V.; Kornatovskyy, R.; Shylkina, A. "Green" economy modernization of Ukraine. *Mark. Man. Innov.* **2017**, *2*, 344–358. [CrossRef]
5. Us, Y.; Pimonenko, T.; Lyulyov, O. Energy efficiency profiles in developing the free-carbon economy: On the example of ukraine and the V4 countries. *Pol. Energ.* **2021**, *23*, 49–66. [CrossRef]

6. Lyeonov, S.V.; Vasylieva, T.A.; Lyulyov, O.V. Macroeconomic stability evaluation in countries of lower-middle income economies. *Naukov Visn Nat. Hirn Univer.* **2018**, 138–146. [CrossRef]
7. Kolosok, S.; Bilan, Y.; Vasylieva, T.; Wojciechowski, A.; Morawski, M. A scoping review of renewable energy, sustainability and the environment. *Energies* **2021**, *14*, 4490. [CrossRef]
8. Didenko, I.; Volik, K.; Vasylieva, T.; Lyeonov, S.; Antoniuk, N. Migration, environment, and country safety: Analysis of touchpoints. In Proceedings of the E3S Web of Conferences, Kota Semarang, Indonesia, 12–13 August 2020; Volume 202. [CrossRef]
9. Starchenko, L.; Lyeonov, S.; Vasylieva, T.; Pimonenko, T.; Lyulyov, O. Environmental management and green brand for sustainable entrepreneurship. *E3S Web Conf.* **2021**, *234*, 00015. [CrossRef]
10. Vasylieva, T.; Machová, V.; Vysochyna, A.; Podgórska, J.; Samusevych, Y. Setting up architecture for environmental tax system under certain socioeconomic conditions. *J. Int. St.* **2020**, *13*, 273–285. [CrossRef]
11. Mentel, G.; Vasilyeva, T.; Samusevych, Y.; Vysochyna, A.; Karbach, R.; Streimikis, J. The evaluation of economic, environmental and energy security: Composite approach. *Int. J. Glob. Envir. Issues.* **2020**, *19*, 177–195. [CrossRef]
12. Letunovska, N.; Saher, L.; Vasylieva, T.; Lieonov, S. Dependence of public health on energy consumption: A cross-regional analysis. *E3S Web Conf.* **2021**, *250*, 04014. [CrossRef]
13. Sedmíková, E.; Vasylieva, T.; Tiutiunyk, I.; Navickas, M. Energy consumption in assessment of shadow economy. *Europ. J. Interdisc. Stud.* **2021**, *13*, 47–64. [CrossRef]
14. Melnyk, L.; Matsenko, O.; Kubatko, O.; Korneyev, M.; Tulyakov, O. Additive economy and new horizons of innovative business development. *Prob. Persp. Manag.* **2022**, *20*, 175–185. [CrossRef]
15. Taliento, M.; Netti, A. Corporate Social/Environmental Responsibility and Value Creation: Reflections on a Modern Business Management Paradigm. *Bus. Ethics Leader.* **2020**, *4*, 123–131. [CrossRef]
16. Kaya, H.D. Business Friendliness, Firm Performance and Owner's Optimism. *Fin. Mark., Instit. Risks.* **2020**, *4*, 13–23. [CrossRef]
17. Yashkina, O.; Pedko, I. Models of inventory management for industrial enterprises under energy resources price increase. *Mark. Man. Innov.* **2016**, *4*, 315–324. [CrossRef]
18. Enerdata. EnerMonthly: Monthly Energy Database. 2022. Available online: https://yearbook.enerdata.net/total-energy/world-consumption-statistics.html (accessed on 20 September 2021).
19. Polcyn, J.; Us, Y.; Lyulyov, O.; Pimonenko, T.; Kwilinski, A. Factors influencing the renewable energy consumption in selected european countries. *Energies* **2022**, *15*, 108. [CrossRef]
20. Kuzior, A.; Kwilinski, A.; Hroznyi, I. The factorial-reflexive approach to diagnosing the executors' and contractors' attitude to achieving the objectives by energy supplying companies. *Energies* **2021**, *14*, 2572. [CrossRef]
21. Kuzior, A.; Staszek, M. Energy management in the railway industry: A case study of rail freight carrier in poland. *Energies* **2021**, *14*, 6875. [CrossRef]
22. Kuzior, A.; Lobanova, A.; Kalashnikova, L. Green energy in ukraine: State, public demands, and trends. *Energies* **2021**, *14*, 7745. [CrossRef]
23. Polyakov, M.; Khanin, I.; Bilozubenko, V.; Korneyev, M.; Shevchenko, G. Factors of uneven progress of the european union countries towards a circular economy. *Prob. Persp. Manag.* **2021**, *19*, 332–344. [CrossRef]
24. Matvieieva, Y.T. Modelling and Forecasting Energy Efficiency Impact on the Human Health. *Health Econ. Manag. Rev.* **2022**, *2*, 78–85. [CrossRef]
25. Pilia, G. Estonia and Lithuania in transition: A compared analysis of the change and its costs and benefits. *Bus. Ethics Leader.* **2017**, *1*, 12–19. [CrossRef]
26. Brych, V.; Zatonatska, T.; Dluhopolskyi, O.; Borysiak, O.; Vakun, O. Estimating the Efficiency of the Green Energy Services' Marketing Management Based on Segmentation. *Mark. Man. Innov.* **2021**, *3*, 188–198. [CrossRef]
27. Lyulyov, O.; Lyeonov, S.; Tiutiunyk, I.; Podgórska, J. The impact of tax gap on macroeconomic stability: Assessment using panel VEC approach. *J. Int. St.* **2021**, *14*, 139–152. [CrossRef]
28. Samusevych, Y.; Maroušek, J.; Kuzmenko, O.; Streimikis, J.; Vysochyna, A. Environmental taxes in ensuring national security: A structural optimization model. *J. Int. St.* **2021**, *14*, 292–312. [CrossRef]
29. Štreimikienė, D.; Samusevych, Y.; Bilan, Y.; Vysochyna, A.; Sergi, B.S. Multiplexing efficiency of environmental taxes in ensuring environmental, energy, and economic security. *Env. Sc. Pollut. Res.* **2022**, *29*, 7917–7935. [CrossRef]
30. Kolosok, S.; Vasylieva, T.; Lyeonov, S. Machine analysis of the UK electrical energy initiatives based on the e-petitions tothe UK government and parliament. In Proceedings of the CEUR Workshop Proceedings, Lviv, Ukraine, 22–23 April 2021; Volume 2870, pp. 1562–1573. Available online: http://ceur-ws.org (accessed on 5 May 2022).
31. European Parliament. Renewable energy. Fact Sheets on the European Union. 2021. Available online: https://www.europarl.europa.eu/factsheets/en/sheet/70/renewable-energy (accessed on 2 September 2022).
32. World Bank Data. 2022. Available online: https://data.worldbank.org (accessed on 2 September 2022).
33. Keliuotytė-Staniulėnienė, G.; Daunaravičiūtė, K. The Global Green Bond Market in the Face of the COVID-19 Pandemic. *Fin. Mark. Instit. Risks* **2021**, *5*, 50–60. [CrossRef]
34. Yarovenko, H.; Bilan, Y.; Lyeonov, S.; Mentel, G. Methodology for assessing the risk associated with information and knowledge loss management. *J. Bus. Econ. Manag.* **2021**, *22*, 369–387. [CrossRef]
35. Lyulyov, O.; Vakulenko, I.; Pimonenko, T.; Kwilinski, A.; Dzwigol, H.; Dzwigol-Barosz, M. Comprehensive assessment of smart grids: Is there a universal approach? *Energies* **2021**, *14*, 3497. [CrossRef]

36. Serpeninova, Y.S.; Makarenko, I.; Plastun, A.; Babko, A.; Gasimova, G. Mapping of the responsible investments instruments in sdg 3 'good health and well-being' financing: EU and US experience. *Health Econ. Manag. Rev.* **2020**, *1*, 106–115. [CrossRef]
37. Vasylieva, T.; Pavlyk, V.; Bilan, Y.; Mentel, G.; Rabe, M. Assessment of energy efficiency gaps: The case for ukraine. *Energies* **2021**, *14*, 1323. [CrossRef]
38. Kyrychenko, K.; Laznenko, D.; Reshetniak, Y.V. Green University as an Element of Forming a Sustainable Public Health System. *Health Econ. Manag. Rev.* **2021**, *2*, 21–26. [CrossRef]
39. Dave, H. An Inquiry on Social Issues—Part 2. *Bus. Ethics Leader.* **2017**, *1*, 45–63. [CrossRef]
40. Bhowmik, D. Decoupling CO2 Emissions in Nordic countries: Panel Data Analysis. *SocEcon. Challeng.* **2019**, *3*, 15–30. [CrossRef]
41. Gupta, R. Socioeconomic challenges and its inhabitable global illuminations. *SocEcon. Challeng.* **2017**, *1*, 81–85. [CrossRef]
42. El Amri, A.; Oulfarsi, S.; Boutti, R.; Sahib Eddine, A.; Hmioui, A. Carbon Financial Markets Underlying Climate Change Mitigation, Pricing and Challenges: Technical Analysis. *Fin. Mark. Instit. Risks* **2021**, *5*, 5–17. [CrossRef]
43. Precht, P. *Technology and Innovation in Sustainable Energy Transition', Commonwealth Sustainable Energy Transition Series 2021/02*; Commonwealth Secretariat: London, UK, 2021.
44. Coady, D.; Flamini, V.; Sears, L. *The Unequal Benefits of Fuel Subsidies Revisited: Evidence for Developing Countries*; IMF Working Paper WP/15/250; IMF: Bretton Woods, NH, USA, 2015.
45. Malik, I.A.; Siyal, G.-A.; Bin Abdullah, A.; Alam, A.; Zaman, K.; Kyophilavong, P.; Shahbaz, M.; Baloch, S.U.; Shams, T. Turn on the lights: Macroeconomic factors affecting renewable energy in Pakistan. *Renew. Sustain. Energy Rev.* **2014**, *38*, 277–284. [CrossRef]
46. Gozgor, G.; Lau, C.K.M.; Lu, Z. Energy consumption and economic growth: New evidence from the OECD countries. *Energy* **2018**, *153*, 27–34. [CrossRef]
47. Zhao, P.; Lu, Z.; Fang, J.; Paramati, S.R.; Jiang, K. Determinants of renewable and non-renewable energy demand in China. *Struct. Chang. Econ. Dyn.* **2020**, *54*, 202–209. [CrossRef]
48. Li, J.; Omoju, O.E.; Zhang, J.; Ikhide, E.E.; Lu, G.; Lawal, A.I.; Ozue, V.A. Does Intellectual Property Ri000ghts Protection Constitute a Barrier to Renewable Energy? An Econometric Analysis. *Natl. Inst. Econ. Rev.* **2020**, *251*, 37–46. [CrossRef]
49. Sineviciene, L.; Sotnyk, I.; Kubatko, O. Determinants of energy efficiency and energy consumption of Eastern Europe post-communist economies. *Energ Env.* **2017**, *28*, 870–884. [CrossRef]
50. Thollander, P.; Danestig, M.; Rohdin, P. Energy Policies for Increased Industrial Energy Efficiency: Evaluation of a Local Energy Programme for Manufacturing SMEs. *Energ. Pol.* **2007**, *35*, 5774–5783. [CrossRef]
51. Solarin, S.A. An environmental impact assessment of fossil fuel subsidies in emerging and developing economies. *Env. Imp. Assess. Rev.* **2020**, *85*, 1–9. [CrossRef]
52. Balsalobre-Lorente, D.; Ibáñez-Luzón, L.; Usman, M.; Shahbaz, M. The environmental Kuznets curve, based on the economic complexity, and the pollution haven hypothesis in PIIGS countries. *Renew. Energ.* **2021**, *185*, 1441–1455. [CrossRef]
53. Acheampong, A.O.; Dzator, J.; Savage, D.A. Renewable Energy, CO2 Emissions and Economic Growth in Sub-saharan Africa: Does Institutional Quality Matter? *J. Pol. Model.* **2021**, *43*, 1070–1093. [CrossRef]
54. Koengkan, M.; Fuinhas, J.A.; Marques, A.C. *The Relationship between Financial Openness, Renewable and Nonrenewable Energy Consumption, CO_2 Emissions, and Economic Growth in the Latin American Countries: An Approach with a Panel Vector Auto Regression Model in The Extended Energy-Growth Nexus*; Fuinhas, J.A., Marques, A., Eds.; Academic Press: Cambridge, MA, USA, 2019; pp. 199–229. [CrossRef]
55. Soytas, U.; Sari, R. Energy consumption and GDP causality relationship in G-7 countries and emerging markets. *Energ. Econ.* **2014**, *25*, 33–37. [CrossRef]
56. Islam, M.M.; Irfan, M.; Shahbaz, M.; Vo, X.V. Renewable and Nonrenewable Energy Consumption in Bangladesh: The Relative Influencing Profiles of Economic Factors, Urbanization, Physical Infrastructure and Institutional Quality. *Renew. Energ.* **2022**, *184*, 1130–1149. [CrossRef]
57. Hao, L.-N.; Umar, M.; Khan, Z.; Ali, W. Green Growth and Low Carbon Emission in G7 Countries: How Critical the Network of Environmental Taxes, Renewable Energy and Human Capital Is? *Sci. Total Environ.* **2021**, *752*, 141853. [CrossRef]
58. Li, R.; Leung, G.C.K. The Relationship between Energy Prices, Economic Growth and Renewable Energy Consumption: Evidence from Europe. *Energ. Rep.* **2021**, *7*, 1712–1719. [CrossRef]
59. Marra, A.; Colantonio, E. The institutional and socio-technical determinants of renewable energy production in the EU: Implications for policy. *J. Ind. Bus. Econ.* **2022**, *49*, 267–299. [CrossRef]
60. European Bank for Reconstruction and Development. 2022. Available online: https://www.ebrd.com/home (accessed on 1 September 2022).
61. Leitão, N.C. The Effects of Corruption, Renewable Energy, Trade and CO_2 Emissions. *Economies* **2021**, *9*, 62. [CrossRef]
62. Bilan, Y.; Streimikiene, D.; Vasylieva, T.; Lyulyov, O.; Pimonenko, T.; Pavlyk, A. Linking between renewable energy, CO2 emissions, and economic growth: Challenges for candidates and potential candidates for the EU membership. *Sustainability* **2019**, *11*, 1528. [CrossRef]
63. Miśkiewicz, R. The importance of knowledge transfer on the energy market. *Polit. Energ.—Energ. Pol. J.* **2018**, *21*, 49–62. [CrossRef]
64. Vasylyeva, T.A.; Pryymenko, S.A. Environmental economic assessment of energy resources in the context of ukraine's energy security. *Act. Prob. Econ.* **2014**, *160*, 252–260.

65. Karan, M.; Kapusuzoglu, A. The Drivers of Energy Consumption in Developing Countries. Energ. Econ. *Finan. Mark.* **2013**, *1*, 49–69. [CrossRef]
66. Li, S.; Meng, J.; Zheng, H.; Zhang, N.; Huo, J.; Li, Y.; Guan, D. The driving forces behind the change in energy consumption in developing countries. *Env. Res. Let.* **2021**, *16*, 054002. [CrossRef]
67. Kumari, R.; Sharma, A.K. Determinants of foreign direct investment in developing countries: A panel data study. *Int. J. Emerg. Mark.* **2017**, *12*, 658–682. [CrossRef]