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Conceptual approach to valuation of climate change in EU countries through the prism of economic activities

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Abstract: Today, countries pursue not just to have higher or maintain economic growth, but society faces another challenge – to combat climate change: to have a slower increase in global temperature by decreasing the number of greenhouse gas emissions. Globalization processes have increased greenhouse gas emissions. The problem of climate change has become a widespread problem in all countries, as greenhouse gas emissions produced by any country have an overall impact on the earth's environment. Public administration and public policies face the problem of combating climate change, not constraining the economy too much. The purpose of the paper is to evaluate the extent to which EU countries are affected by climate change according to the economic and social factors of countries that can be seen as drivers of greenhouse gas emissions. The study relates intensity of greenhouse gas emission to the extent to which the country is possible to be exposed to climate change according to its data on industry, energy, waste, and agriculture of EU countries. The TOPSIS method is used to rank EU countries in extent of exposure to climate change. The conceptual approach to ranking climate change through the prism of countries' economic activities is developed. There are some research limitations – statistical data on industry, energy, waste, agriculture are limited in order to fulfil the tasks of the research.

Keywords: climate change, climate finance, intensity of greenhouse gas (GHG) emission, Paris agreement, multicriteria decision-making methods (MCDM), technique for order of preference by similarity to ideal solution (TOPSIS).

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1. Introduction

Today, countries are concerned not only with economic growth but also with the risks related to climate change. There are many programs, public policies, and agreements related to mitigation and adaptation to climate change that try to limit greenhouse gas emissions and take some action to adapt to changing climate conditions. Greenhouse gas emissions not only affect the country itself, but also affect the whole world. On the one hand, the country must seek economic growth, but on the other hand, the country must save the environment so that there are no arising risks (even economic risks) from climate change, maintain sustainable development, and save the earth for future generations. It is essential to mention the main agreements on climate change efforts. At the end of 2015 in Paris, climate negotiators reached an agreement called the Paris Agreement in which all parties of the conference agreed to participate. 177 nations signed the Paris Agreement, and 144 nations ratified it by April 2017 (Seo, 2017). The object of the agreement is to limit carbon concentrations, hold the increase in global average temperature well below 2 ° C above pre-industrial levels, and continue efforts to limit the temperature increase to 1.5 ° C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change (Cai et al., 2018; United Nations, 2015). Another essential document for EU countries is the European Green Deal European Climate law with the objective for Europe's economy and society to become climate neutral. This means achieving net-zero greenhouse gas emissions for EU countries as a whole, mainly by reducing carbon emissions, investing in green technologies and protecting the natural environment, presenting the roadmap meant to foster the transition of the European Union towards a climate-neutral economy (European Commission, 2020; Regulation (EU), 2021; Sikora, 2020).

The paper aims to determine the position of the EU countries in the efforts to combat climate change according to the economic factors of these countries. Valuation or ranking of these countries does not include the actual position of the country related to greenhouse gas emission, but rather ranks the countries according to a type of economy to what extent these countries could be exposed to climate change, based on the structure of their economy.

2. Methodology of the research

Chosen criteria will be used to rank EU countries according to the extent of exposure to climate change. The research will include 28 countries of the European Union. The research period is 2009-2018.

For the ranking of countries, the multicriterial method TOPSIS will be used. This will allow us to calculate a score of exposure to climate change in each country and rank the countries based on the scores received. The results received will be discussed and a comparison between the score of exposure to climate change and the intensity of greenhouse gas emission will be made. Additional information on GDP per capita of the analyzed countries will be used. Hwang and Yoon introduced the TOPSIS method in 1981. It is based on the concept that the best-chosen alternative has the shortest distance from the ideal positive solution and the longest distance from the negative ideal solution (Huang et al., 2021). The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is a classical multi-attribute decision-making method widely used in various fields for decision-making or evaluation (Jureviciene et al., 2020; Liao et al., 2020; Skica et al., 2020;). The principle of this method is to rank the alternatives by calculating the distance of each alternative from the ideal solution and the negative ideal solution for problems in decision-making, thus determining the optimum alternative (Chen, 2021).

The TOPSIS method includes several steps (Aan et al., 2017):

creating a decision matrix of criteria:

$$x_{ij} = \begin{bmatrix} x_{11} & \dots & x_{1n} \\ \dots & \dots & \dots \\ x_{m1} & \dots & x_{mn} \end{bmatrix}, \quad (1)$$

where n is criteria, m is alternative; normalizing the decision matrix:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}, \quad (2)$$

where i= 1, 2, … m; j = 1, 2, …, n; calculating the weighted decision matrix;

$$y_{ij} = w_i r_{ij}, \quad (3)$$

calculating the positive and negative ideal solution using normalized weighted rank (y_{ij}):

$$A^+ = (y_1^+, y_2^+, \dots, y_n^+), \quad (4)$$

where A^+=ideal positive solution, for the ideal positive solution, maximum value of maximized criteria and minimum value of minimized criteria are chosen:

$$A^- = (y_1^-, y_2^-, \dots, y_n^-), \quad (5)$$

where A$^-$=ideal negative solution, for the ideal negative solution, minimum value of maximized criteria and maximum of minimized criteria are chosen:

$$V^* = \left\{(\max_j w_i \tilde{r}_{ij} / i \in I_1), (\min w_i \tilde{r}_{ij} / i \in I_2)\right\}, \quad (6)$$

$$V^- = \{V_1^-, V_2^-, \dots, V_m^-\} = \left\{(\max_j w_i \tilde{r}_{ij} / i \in I_1), (\min w_i \tilde{r}_{ij} / i \in I_2)\right\} \quad (7)$$

calculating the distance with an ideal positive solution:

$$D_i^+ = \sqrt{\sum_{j=1}^n (y_{ij} - A_j^+)}, \quad (8)$$

calculating the distance with the ideal negative solution:

$$D_i^- = \sqrt{\sum_{j=1}^n (y_{ij} - A_j^-)} \quad (9)$$

calculating the preference value:

$$V_i = \frac{D_i^-}{D_i^- - D_i^+}, \quad (10)$$

The value received will be higher if the countries' exposure to climate change is higher.

3. Data of the research

The data for the calculation are received from Eurostat, and it comprises data on 28 European Union countries from 2008 to 2018. There is a wide variety of factors that could be included in the valuation or ranking of countries, but in order to simplify the calculations and provide a general view of each country, the research is limited to several of them.

Nieto et al. (2018) examine the feasibility of the Paris Agreement regarding the Intended Nationally Determined Contributions and its economic and environmental constraints, including such criteria as socio-economic impact of the transition, focus on energy management, the substitution of non-renewable sources, the role of technology, equality of the transition, and compliance with emission reductions.

The central policies in INDCs can be grouped according to sectors: energy, industry, waste, LULUCF, and agriculture. Among the top policies of the countries analyzed, Nieto et al. (2018) emphasize: renewable deployment, efficient technologies, avoiding deforestation, afforestation and reforestation, off and on-grid roof solar panels, solar thermal and small hydro, mass public transport, encouraging the acquisition of hybrid and efficient vehicles, improve landfill management, construct new ones and promote compost, substitute charcoal by electricity/electrification, transform waste to energy, combined cycle power stations, switch to natural gas, enhanced technologies for heating and cooking (substitution of charcoal), reduce, reuse, recycle, promotion and research on biofuels, improve the overall efficiency of the industry. After reviewing those policies, the factors for the analysis are chosen and presented in Table 1. Weights are calculated according to experts' valuation. Some of the criteria are minimized, and others are maximized. The higher score received in the evaluation would mean greater exposure to climate risk. The first two criteria are related to the energy sector: energy productivity and renewable energy. The objective is to reduce carbon emissions; higher energy productivity would lead to fewer emissions. Many authors investigated the relationship between renewable energy and greenhouse gas or CO2 emissions (Antonakakis et al., 2017; Cai et al., 2018; Squalli, 2017).

Table 1: Criteria for ranking EU countries

Factor/Sector	Measurement units	Weight	Optimization
Productivity of energy	Euro per kilogram of oil equivalent	0.06	minimizing
Share of renewable energy in gross final energy consumption	Percentage	0.11	minimizing
Agriculture	Gross value added of the agricultural industry to Gross domestic product	0.22	maximizing
Population density	Persons per square kilometer	0.27	maximizing
Research and Development	Research and Development expenditures compared to Gross domestic product at market prices	0.22	minimizing
Recycling	Recycling rate of municipal waste, percentage	0.12	minimizing

Source: the authors' own contribution

The spread of renewable energy leads to a decrease in greenhouse gas emissions, and renewable energy consumption has negative impacts on CO2 emissions (Bilgili et al., 2016; Ganda, 2019; Hao et al., 2021; Lyeonov et al., 2019). Both criteria (productivity of energy and share of renewable energy) are minimized, as a lower score on the rating means a higher exposure to climate risk. The agricultural sector is included in the valuation. It is one of the economic sectors that affects climate change and is a large source of greenhouse gas emissions (Agovino et al., 2019; Balafoutis et al., 2017; Bie et al., 2021; Waheed et al., 2018). Agriculture and climate change are characterized by a complex cause-effect (two-sided) relationship (Agovino et al., 2019; Bie et al., 2021). Agriculture is the branch of the economy most affected by ongoing processes. It is also a large emitter of greenhouse gases, and there are more and more voices about the need to reduce emissions (Bie et al., 2021). The valuation does not examine the efficiency of the agricultural sector in a country; it is more based on the structure of the economy in a country, and therefore the unit used in the calculation is the ratio of Gross value added to the agricultural industry to Gross domestic product. The criterion is maximizing, and a higher score would mean higher exposure to climate change. One more criterion chosen is population density. Population growth is believed to be one of the major factors for increased CO2 emissions (Rahman, 2017). Population growth expands energy demand in sectors such as housing, commercial floor space, transportation, and goods and services, in turn leading to increased energy consumption (Salim et al., 2019). The criterion is maximizing, the higher score would mean higher exposure to climate change. The next criterion is Research and Development expenditures. Some research shows that spending on research and development has a statistically significant negative relationship with carbon emissions (Ganda, 2019). Research and development spending contributes positively to the reduction of CO2 emissions for developed countries (Fernández Fernández et al., 2018). Research and development expenditures will be compared to the GDP of a country. The criterion is minimizing, as a higher value would mean a lower exposure to climate change. The last chosen criterion is recycling, which is expressed by the recycling rate of municipal waste. In the past, GHG emissions were mainly associated with energy generation. Today, it is frequently acknowledged that improved waste management can also mitigate these emissions (Camilleri-Fenech et al., 2018). The criterion is minimizing, the higher value would mean the lower exposure to climate change.

In the paper, the impact of climate change on countries will also be analyzed. There are different opinions on how the impact of climate change has to be evaluated. Aldy & Pizer (2016) analyze the effect of climate finance based on the impact on the environment: percentage change in emission, emission, emission reduction versus a forecast of future emission intensity, impact on economy: carbon price, energy prices and taxes, mitigation costs, negative cost. Burck et al. (2020) distinguish the valuation based on GHG emissions, climate policy, renewable energy, and energy use. The climate risk score is offered as a measure of successful climate change management (Eckstein et al., 2019). In the paper, the impact of climate change will be presented by the intensity of greenhouse gas emission, and the ratio of greenhouse gas emissions to GDP will be used.

4. Results of the research

The TOPSIS method was used to calculate a score of exposure to climate change in EU countries. The results are presented in Table 2. A higher score means a higher exposure of the country to climate change. Therefore, countries are ranked from minimum score to maximum.

The results were presented according to the ranking in 2018. A lower score indicates that the country is in a better position compared to other countries, and it is supposed to have a lower intensity of greenhouse gas emission. The higher the score of the country, the higher the risk that the country will have a higher intensity of greenhouse gas emission compared to other countries. The countries can be divided into three groups: green, yellow, and red. Intervals are calculated using 33% and 67% from the sum of minimum and maximum values and adding minimum values. The intervals for 2018 are presented in Table 3.

In 2018 the top 3 countries were Denmark, Sweden and Austria. They have the lowest score, which could be explained by a high proportion of renewable energy sources, a high recycling rate, a high energy productivity, and high R&D expenditures.

Table 2: Ranking of EU countries based on the score of exposure to climate change

Country	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Denmark	0.318	0.310	0.299	0.292	0.268	0.253	0.251	0.237	0.239	0.243
Sweden	0.197	0.208	0.223	0.247	0.234	0.247	0.284	0.275	0.315	0.333
Austria	0.288	0.276	0.287	0.287	0.283	0.283	0.343	0.332	0.371	0.373
Ireland	0.497	0.489	0.476	0.484	0.462	0.451	0.444	0.455	0.436	0.424
Finland	0.335	0.328	0.340	0.367	0.352	0.368	0.412	0.410	0.435	0.448
Germany	0.451	0.441	0.433	0.442	0.436	0.430	0.458	0.451	0.464	0.459
France	0.495	0.491	0.500	0.506	0.485	0.487	0.520	0.508	0.526	0.532
Luxembourg	0.528	0.532	0.527	0.549	0.522	0.516	0.529	0.522	0.535	0.534
Italy	0.534	0.526	0.520	0.519	0.500	0.492	0.531	0.525	0.541	0.546
Portugal	0.483	0.474	0.474	0.497	0.488	0.480	0.526	0.515	0.543	0.546
Belgium	0.565	0.556	0.544	0.558	0.538	0.533	0.565	0.558	0.567	0.566
Slovenia	0.515	0.493	0.476	0.485	0.467	0.489	0.527	0.534	0.560	0.567
Latvia	0.526	0.543	0.517	0.533	0.507	0.512	0.559	0.564	0.577	0.568
Netherlands	0.594	0.596	0.574	0.599	0.569	0.564	0.596	0.592	0.601	0.594
Estonia	0.556	0.547	0.513	0.553	0.560	0.571	0.588	0.583	0.606	0.597
Spain	0.547	0.540	0.545	0.566	0.542	0.548	0.583	0.579	0.595	0.599
Croatia	0.603	0.590	0.580	0.587	0.562	0.564	0.596	0.597	0.617	0.616
Czechia	0.612	0.607	0.596	0.603	0.576	0.575	0.606	0.614	0.624	0.616
Lithuania	0.624	0.617	0.611	0.635	0.601	0.596	0.622	0.617	0.635	0.632
Cyprus	0.648	0.635	0.625	0.643	0.618	0.623	0.647	0.654	0.656	0.641
Greece	0.627	0.621	0.619	0.641	0.608	0.617	0.644	0.638	0.646	0.643
Slovakia	0.637	0.634	0.623	0.645	0.628	0.625	0.634	0.651	0.659	0.648
Hungary	0.638	0.632	0.636	0.642	0.621	0.639	0.668	0.674	0.681	0.671
Poland	0.682	0.677	0.665	0.684	0.665	0.654	0.673	0.680	0.693	0.678
Romania	0.668	0.660	0.680	0.666	0.662	0.658	0.669	0.664	0.680	0.690
Bulgaria	0.706	0.691	0.694	0.704	0.678	0.690	0.699	0.700	0.711	0.708
Malta	0.758	0.752	0.729	0.766	0.733	0.743	0.775	0.781	0.782	0.768

Source: the authors' own contribution

Denmark is at the top of the ranking. It is second in energy productivity, fourth in renewable energy and R&D expenditures, and seventh in recycling rate. However, the overall rating, including all factors, leads Denmark to be a leader in the ranking with a value of 0.243. Sweden is a leader in the share of renewable energy and in R&D expenditures. However, the recycling rate is average compared to other countries (Sweden is the tenth), and the same is true for energy productivity (Sweden is the nineth). Still, the highest scores in the share of renewable energy and R&D expenditure lead the country to the second position with a score of 0.333. Austria, second in R&D expenditures, third in recycling rate and fifth in share of renewable energy and energy productivity, is third in overall ranking with a value of 0.373.

It is noticeable that the three countries are in the green group for 2009-2018.

Table 3: Grouping intervals for 2018

Group	Interval
Green group	< 0.416472
Yellow group	≥0.416472 and <0.595099
Red group	≥0.595099

Source: the authors' contribution

However, in the period 2009-2014, Sweden was the leader, from 2015 it has lost its position to Denmark. This could be explained by the best results in energy productivity, the share of renewable energy, and R&D expenditures. In 2015, energy productivity in Denmark had increased by 1.26% compared to a decrease of 2.46% in Sweden, the share of renewable energy in Denmark has increased by 3.84% compared to a 0.72% increase in Sweden, and R&D expenditures increased by 1.24% in Denmark and only 0.88% in Sweden.

Finland, for the period 2009-2016, was in the green group. The score value during these years was less than 33%. But from 2017 onward, the gap between Finland and the green group countries increased. For example, the 2009 score for Finland was 70% higher than the score for Sweden (the leader in that year); in 2016, the score for Finland was 73% higher than the score for Denmark (the leader of that year).

In 2018, there were 13 countries in the red group: Estonia, Spain, Croatia, Czech Republic, Lithuania, Cyprus, Greece, Slovakia, Hungary, Poland, Romania, Bulgaria, and Malta. This is the group in which countries are more likely to be affected by climate change. The group indicates relatively small expenditures in R&D, a small portion of the recyclable rate, a small share of renewable energy, and low energy productivity.

Romania, Malta, and Cyprus have the smallest expenditures for R&D (Romania has the lowest expenditures), and the lowest recycling rate (Malta is in the last place), the Netherlands, Malta, Luxemburg have the lowest share of renewable sources, Bulgaria, Estonia, and Malta have the lowest energy productivity (Bulgaria is in the last place).

From 2009 to 2013, the Netherlands was also included in the red group, but starting from 2014, the country succeeded in showing average results and joined the yellow group.

In 2018 there are 11 countries that have average scores and are included in the yellow group: Ireland, Finland, Germany, France, Luxemburg, Italy, Portugal, Latvia, Slovenia, Belgium, and the Netherlands.

The intensity of greenhouse gas emissions is shown in Table 4. Countries were ranked according to the intensity of greenhouse gas emissions in 2018.

The last column in Table 4 shows the trend of greenhouse gas emissions. There is a downward trend almost in each country, which shows the success of countries in trying to slow climate change, as each year there are fewer units of greenhouse gas emissions compared to GDP.

Table 4: Intensity of Greenhouse Gas Emission of EU countries

Country	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Trend
Sweden	0.193	0.178	0.151	0.138	0.131	0.128	0.123	0.120	0.116	0.116	
Denmark	0.284	0.271	0.245	0.221	0.224	0.203	0.188	0.189	0.174	0.170	
France	0.269	0.265	0.243	0.239	0.237	0.219	0.216	0.213	0.209	0.196	
Ireland	0.377	0.379	0.347	0.340	0.332	0.305	0.236	0.237	0.213	0.196	
Luxembourg	0.347	0.335	0.307	0.292	0.265	0.240	0.224	0.211	0.210	0.206	
Austria	0.285	0.293	0.272	0.256	0.253	0.235	0.234	0.229	0.228	0.211	
Malta	0.507	0.483	0.478	0.476	0.404	0.373	0.261	0.220	0.222	0.213	
Italy	0.324	0.324	0.310	0.303	0.283	0.268	0.271	0.263	0.255	0.248	
Finland	0.382	0.411	0.353	0.320	0.318	0.293	0.270	0.276	0.254	0.252	
Netherlands	0.340	0.350	0.323	0.316	0.312	0.296	0.301	0.293	0.278	0.259	
Germany	0.382	0.377	0.350	0.346	0.344	0.317	0.308	0.299	0.283	0.265	
Belgium	0.378	0.381	0.341	0.324	0.318	0.296	0.297	0.285	0.276	0.269	
Spain	0.360	0.346	0.349	0.353	0.331	0.330	0.327	0.308	0.308	0.292	
Portugal	0.431	0.399	0.399	0.407	0.391	0.385	0.395	0.372	0.380	0.349	
Slovenia	0.541	0.540	0.530	0.526	0.504	0.442	0.433	0.437	0.406	0.384	
Latvia	0.611	0.707	0.583	0.525	0.506	0.486	0.469	0.456	0.433	0.419	
Lithuania	0.750	0.750	0.691	0.646	0.582	0.556	0.553	0.533	0.495	0.454	
Cyprus	0.571	0.533	0.507	0.487	0.483	0.520	0.509	0.511	0.496	0.460	
Croatia	0.638	0.627	0.624	0.596	0.567	0.555	0.549	0.529	0.518	0.469	
Hungary	0.691	0.659	0.627	0.601	0.561	0.546	0.544	0.533	0.508	0.471	
Slovakia	0.715	0.683	0.643	0.589	0.577	0.536	0.526	0.524	0.516	0.486	
Greece	0.536	0.540	0.582	0.609	0.586	0.576	0.559	0.545	0.559	0.535	
Romania	1.026	0.994	0.982	0.950	0.811	0.775	0.731	0.677	0.628	0.570	
Czechia	0.931	0.898	0.849	0.837	0.819	0.815	0.767	0.743	0.674	0.613	
Estonia	1.170	1.421	1.260	1.116	1.155	1.051	0.879	0.902	0.885	0.778	
Poland	1.247	1.144	1.088	1.047	1.026	0.954	0.914	0.942	0.893	0.835	
Bulgaria	1.567	1.609	1.612	1.461	1.340	1.380	1.367	1.233	1.193	1.044	

Source: the authors' own contribution

The countries are grouped into three groups using the same principle as in the previous table. Intervals are calculated using 33% and 67% from the sum of the minimum and maximum values and adding the minimum values. Even 16 countries are in the green group, which are the countries with the lowest intensity of greenhouse gas emission. The top 3 countries for 2018 are Sweden, Denmark, and France.

It is noticeable that the countries with the lowest exposure score to climate change in 2018 are in the green group for the intensity of greenhouse gas emission. And the countries with the highest emissions of greenhouse gas (Estonia, Poland, and Bulgaria) are included in the red group for the score of exposure to climate change.

It is quite interesting to see the result in Bulgaria. It has the highest rate of greenhouse gas emission, which is equal to 1.044; the country that has the closest result is Poland, but there is a gap between the values of 0.209. The intensity of greenhouse gas emission of Bulgaria is 25% higher than the intensity of greenhouse gas of Poland. To compare, there is a gap of 0.057 between Poland and the next country - Estonia; the intensity of greenhouse gas emission of Poland is 7.33% higher than the intensity of greenhouse gas emission of Estonia. So, Bulgaria is worth discussing in detail. The score of exposure to climate change for Bulgaria is 0.708. This is the second worst result among EU countries. The share of renewable energy in Bulgaria is 20.592 (that is below the average of EU countries – 21.475); energy productivity is the lowest at 2.42 euros per kilogram of oil equivalent, which is 66.7% less than the average, and even 87% less than the best result of Ireland among EU

countries; R&D expenditures compared to GDP are relatively small, the ratio is 0.007553, that is 54.14% less than the average of EU countries, and 77.63% less than the Sweden best result; recycling rate of municipal waste is 31.5%, which is below the average of EU countries (38.4%), and even 52% less than the leader (Germany) with 67.1%.

However, since different groups of the intensity of greenhouse gas emission and the scores of exposure to climate change include different numbers of countries, it is difficult to compare all countries in the groups. Still, it is worth mentioning that all countries in the green group of the intensity of greenhouse gas emission are in the green or yellow group of a score of exposure to climate change, with two exceptions: Spain and Malta. However, a score in Spain (0.599) is not far from the yellow interval (<0.595099). However, the results in Malta are the opposite. Malta has a low share of renewable energy, low energy productivity, low expenditures on R&D compared to GDP, and the lowest recycling rate among all EU countries. All this leads to receiving a quite high score of exposure to climate change – 0.768 – this is the worst result in EU countries for 2018. Although the intensity of greenhouse gas emission in Malta is relatively low, at 0.213, which is the middle result of the green group. That shows that the case of Malta should be analyzed separately, using other types of analysis, for example, PEST analysis.

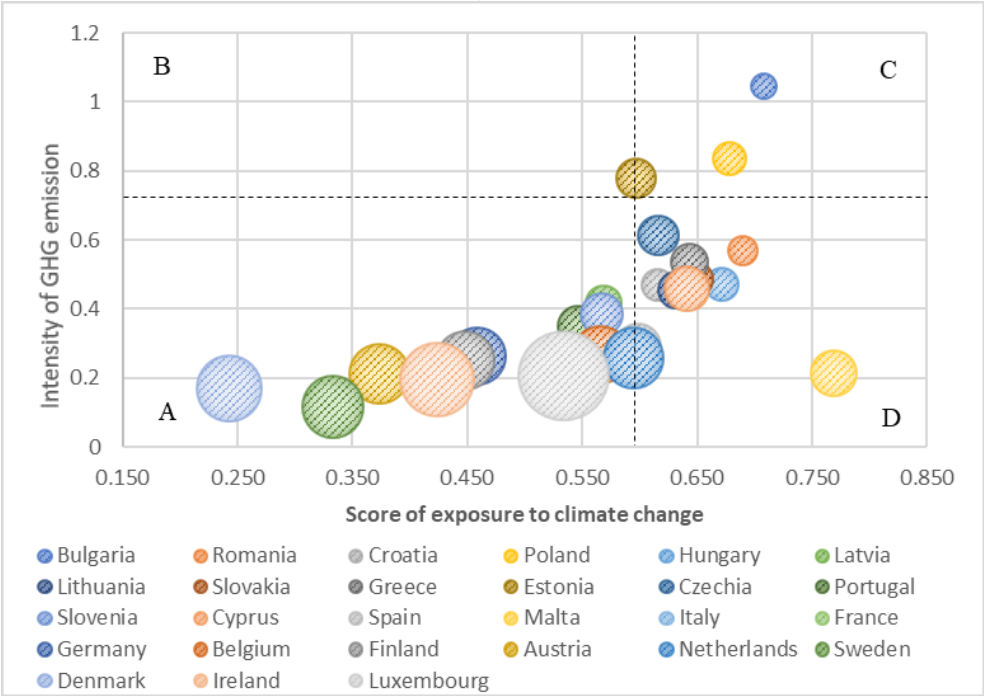
Data for the score of exposure to climate change and the intensity of greenhouse gas emission of EU countries for 2018 are also presented graphically (Figure 1).

Figure 1 is divided into four areas: A, B, C, and D. The horizontal line is drawn through the 0.7379 intensity of greenhouse gas emission, and the vertical line is drawn through the 0.595 scores of exposure to climate change.

The A area represents the relatively low score of exposure to climate change and low greenhouse gas emission; that area includes countries in the green group based on the score of exposure to climate change and the green and yellow group based on the intensity of greenhouse gas emission. The leaders are Denmark, Sweden, and Austria.

There are no countries in the B area, which clearly shows that there is no country in the EU that would have a high intensity of greenhouse gas emission while having a low score of exposure to climate change. There are three countries in area C: Estonia, Poland, and Bulgaria. These countries have the highest score of exposure to climate change (red group) and the highest intensity of greenhouse gas emission (red group). The D area includes countries with a high score of exposure to climate change (red group) but moderate or low intensity of greenhouse gas emission (yellow or green group). There are only two countries in that area of the green group based on the intensity of greenhouse gas emission, Spain and Malta. The position of Malta on a graph is far from that of all other countries. But that exception and the position of Spain have already been discussed in the paper. All other countries are concentrated in the upper left corner of area D.

Figure 1: Score of exposure to climate change and intensity of greenhouse gas emission of EU countries, 2018



Source: the authors' contribution

In most cases, the countries of that group have a higher intensity of greenhouse gas emission compared to the countries in area A. There is additional information about the countries in Figure 1 – the diameter of the circle. The diameter represents GDP per capita for each country, and the higher diameter indicates a higher GDP per capita. It is noticeable that in most cases countries with a high GDP per capita show good results in scores of exposure to climate change and have relatively low intensity of greenhouse gas emission. The top ten countries according to GDP per capita (Belgium, Germany, Finland, Austria, Netherlands, Sweden, Denmark, Ireland, Luxemburg, France) are in the A area (low score of exposure to climate change and low greenhouse gas emission).

5. Discussion

The results received have shown that most countries with a low score of possible exposure to climate change have relatively low intensity of greenhouse gas emission. Otherwise, countries that have received high scores have quite a high intensity of greenhouse gas emission, with several exceptions. However, it is worth mentioning that the research is limited to several criteria to have clear data from one database. There are more criteria that could be included in the research. One of them is forestry. There is a common belief that a forest is a carbon sink that helps reduce carbon dioxide in the environment. However, forests also contribute to an increase in carbon dioxide emissions in various ways (Waheed et al., 2018). It would be quite interesting to see the impact of forestry on greenhouse gas emissions, analyzing different data on it. One more criterion, no doubt, transport, could have a huge impact on greenhouse gas emissions.

In addition, the analysis of some chosen criteria could be broader. One of the criteria is population density. The weight of that criterion is rather small compared to other criteria in the research. Still, it is recommended to discuss it in more detail. Usually, the relationship of population density with greenhouse gas emission is analyzed through the urbanization level. There are many pieces of research that analyze the relationship between urbanization level and greenhouse gas intensity (Didenko et al., 2017; Rahman, 2017; Salim et al., 2019). Most authors agree that greenhouse gas emission correlates negatively with the urbanization level. However, there are some results that a high population density tends to be reflected in regions with higher economic levels to achieve the scale effects, resulting in lower emission elasticity, and environment problems first increase from low to intermediate urban development stages, then diminish with further development (Liu et al., 2017). One more criterion is expenditures on research and development. Most authors agree on the negative relationship between research and development investments and greenhouse gas emissions (Fernández Fernández et al., 2018; Ganda, 2019; Lyeonov et al., 2019; Miśkiewicz, 2021). However, the impact of these investments is different for different countries and regions. Also, the composition of research and development is important.

Another important finding is that countries with high GDP per capita usually have lower intensity of greenhouse gas emission. Many researchers investigate the relationship between GDP and greenhouse gas emissions (Adzawla et al., 2019; Antonakakis et al., 2017; Gizaw, 2016; Miśkiewicz, 2021). However, the relationship is different for countries with different levels of economic development. Usually, a higher GDP indicates higher greenhouse gas emissions. However, for the more developed countries, greenhouse gas emission grows slower than GDP.

In summary, there is a huge area for future research: more criteria could be added, the relationship of each criterion to greenhouse gas emission could be analyzed in more detail, and different countries could be ranked, grouping them according to economic development level.

6. Conclusions

Based on previous research, six criteria were chosen to rank countries according to their exposure to climate change: energy productivity, the share of renewable energy in gross final energy consumption, agriculture, population density, research and development, and recycling. The TOPSIS method was used to calculate a score of exposure to climate change in EU countries. Based on that method, countries are ranked by calculating the distance of each alternative from the ideal solution and the negative ideal solution to determine the optimum alternative.

All European Union countries were ranked according to the score of exposure to climate change for the period 2009-2018. Countries were divided into three groups: green (low exposure to climate change), yellow (medium exposure to climate change), and red (high exposure to climate change) groups. In 2018, Denmark, Sweden, and Austria showed the best results. These countries comprise the green group. This could be explained by a high proportion of renewable energy sources, a high recycling rate, a high energy productivity, and high R&D expenditures in these countries. These countries are also in the green group for the intensity of greenhouse gas emission. 11 countries

(Ireland, Finland, Germany, France, Luxembourg, Italy, Portugal, Belgium, Slovenia, Latvia, Netherlands) show medium results for exposure to climate change and the yellow group of exposure to climate change. All these countries are in the green group for the intensity of greenhouse gas emission. There are 13 countries in the red group: Estonia, Spain, Croatia, Czech Republic, Lithuania, Cyprus, Greece, Slovakia, Hungary, Poland, Romania, Bulgaria, and Malta. The group indicates relatively small expenditures in R&D, a small portion of the recyclable rate, a small share of renewable energy, and low energy productivity. Estonia, Poland, and Bulgaria have the highest score of exposure to climate change (red group) and the highest intensity of greenhouse gas emission (red group). All other countries in that group have moderate greenhouse gas emission intensity, with two exceptions: Spain and Malta. The score of exposure to climate change in Spain is extremely close to the results of the yellow group. However, the intensity of greenhouse gas emission in Malta is relatively low. That shows that the case of Malta should be analyzed separately in future research, using other types of analysis. There is no country in the EU that would have a high intensity of greenhouse gas emission at the same time and a low score of exposure to climate change.

In most cases, countries with high GDP per capita show good results in scores of exposure to climate change and have relatively low intensity of greenhouse gas emission. The top ten countries, according to GDP per capita (Belgium, Germany, Finland, Austria, Netherlands, Sweden, Denmark, Ireland, Luxembourg, France), have low scores of exposure to climate change and low intensity of greenhouse gas emission.

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