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Sustainable Energy in European Countries: Analysis of Sustainable Development Goal 7 Using the Dynamic Time Warping Method

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Abstract: At a time of rapid climate change and an uncertain geopolitical situation caused by the war in Ukraine, the problem of access to energy is a serious issue. The use of renewable energy sources and ensuring the highest possible energy independence are becoming important. They are in line with the seventh Sustainable Development Goal (SDG7). The aim of our research is to compare European countries in terms of the degree of SDG7 implementation and its dynamics from 2005 to 2020. We assess the SDG7 implementation using the COPRAS method and compare its dynamics using the Dynamic Time Warping (DTW) and hierarchical clustering. In years 2005, 2009 and 2020, we present rankings of countries in terms of the SDG7 implementation. Norway, Denmark, Sweden, Croatia, and Estonia were ranked the best, and Luxembourg, Belgium, Bulgaria, Lithuania, Iceland, and Cyprus—the worst. We obtained eight clusters with respect to dynamics of the degree of SDG7 implementation. In Poland, Romania, Belgium, Luxembourg, Latvia, and Ireland, the relative dynamics was increasing, while in the Nordic and South European countries, it was decreasing. The novelty of our research is combining the COPRAS (assessment of SDG7 implementation) and DTW methods (selection of similar countries with respect to its dynamics).

Keywords: sustainable development goal 7; COPRAS method; multi-criteria decision support; Dynamic Time Warping (DTW); hierarchical clustering

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1. Introduction

At the summit in New York on 25–27 September 2015, leaders of UN member states, signing the document "Transforming Our World: The 2030 Agenda for Sustainable Development", made a commitment to take action to reduce poverty in all its forms, to ensure access to education, to food and to clean water, to take action for equality of opportunity, to promote human rights, peace and stability in the world, to protect the environment, to mitigate climate change, to access sustainable energy sources. The document contains 17 Sustainable Development Goals and associated 169 actions to be achieved by all parties—national governments, international organisations, non-governmental organisations, the scientific and business sectors, as well as citizens. Any crisis situation, especially those of an international or even global nature, poses a threat to the achievement of these goals. Rapid climate change and the uncertain geopolitical situation caused by the war in Ukraine make the problem of access to energy one of the most serious challenges. According to The Sustainable Development Goals Report 2022, the world continues to make progress towards sustainable energy goals. However, the current pace of progress is insufficient and the achievement of the SDG7 target of 'Ensure access to affordable, reliable, sustainable and modern energy for all' by 2030 is at risk. Energy efficiency improvements are needed to meet the climate target (reducing greenhouse gas emissions). Hundreds of millions of people still do not have access to electricity. An estimated 2.4 billion people lack the ability to cook cleanly, which affects their health. Huge disparities in access to modern, sustainable energy persist. In some countries, the COVID-19 pandemic has undermined or reversed progress already made. Increasing commodity, transport and energy prices have raised the cost of manufacturing and transportation of photovoltaic modules, wind turbines and biofuels worldwide. Achieving energy and climate goals will be impossible without sustained policy support. Large-scale mobilisation of public and private capital for clean and renewable energy will be necessary, especially in developing countries. Strategic policy support, political will and institutions able to take decisive, sustained action are needed [1].

A particularly important aspect of the implementation of SDG7 is the development of renewable energy sources. The rising cost of energy from non-renewable sources can have a debilitating effect on national economies. Reasons for this increase include the impact of coronavirus on socio-economic phenomena and the rising cost of CO_2 emission allowances. The energy crisis in European countries has been exacerbated by the outbreak of war in Ukraine. This is especially true for countries that benefit to a large extent from hydrocarbon resources imported from Russia. The development of RES is therefore a fundamental direction of energy development [2]. Gas supply problems have forced an increase in fossil fuel production, delaying the transition to renewable energy. Many governments are abandoning efforts to phase out the use of coal. The impact of war on global resource markets will grow, as will the potential for 'ripple effects' or 'risk cascades' on economies and societies around the world [3]. Research by Alam et al. [4] confirms strong responsiveness behaviours among all commodities and capital markets, more specifically among EU markets.

Much contemporary research focuses on the problem of energy access. There is also a strand of research on the implementation of Sustainable Development Goals. The added value of our article is to link these two issues and build rankings and analyse the similarities of European countries in terms of the degree of implementation of SDG7. Our study also has the advantage of using the Dynamic Time Warping (DTW) method, which allows for the comparison of time series.

There is a research gap in the literature on the undertaken topic. There are emerging studies related to the implementation of SDG7. They often concern single countries, selected regions of the world, or selected energy sources [5–9]. There is a lack of a study analysing the degree of implementation and dynamics of the SDG7 for 30 selected European countries. This manuscript fills this gap.

The purpose of the article is twofold. The first one is the comparison of selected European countries in terms of the degree of SDG7 implementation. The second one is the comparison of the relative dynamics of SDG7 achievement between 2005 and 2020. We also put the research question: how did the crisis periods (financial crisis 2007–2009 and COVID-19 pandemic 2020) affect the degree of the SDG7 implementation and its dynamics?

The manuscript is organised as follows: Section 2 presents the literature review, and in Section 3 we present the materials and research methods. Section 4 presents the results of the empirical analysis. In Section 5 we present the discussion of obtained results. The manuscript ends with conclusions.

2. Literature Review

Energy is sustainable if it meets the needs of the present without compromising the ability of future generations to meet their own needs [10–13]. It is therefore energy that can meet the needs of all sections of society and that can be available to present and future generations.

Tucho and Kumsa [14] highlight that the achievement of SDG7 is linked to the interconnectedness of socio-economic, cultural and technical factors. The achievement of this goal is hampered by unforeseen circumstances that arise. Achieving the SDG7 target with access to affordable and sustainable modern cooking energy will be very difficult. While private investments and government expenditures in developed countries focus on achieving efficiency and renewable energy production, developing countries are focused on gaining access to electricity and clean energy sources [15]. These challenges may be greatest in sub-Saharan Africa, where the majority of the population still lacks access to improved cooking energy services [6]. Better policies are needed, along with economic incentives to invest in energy projects and support households.

The Sustainable Development Goals are interrelated. Pakkan et al. [16] examined the correlation between SDGs. SDG7 (affordable and clean energy) with SDG12 (responsible consumption and production) show synergetic relations with ρ values greater than 0.8. Coenen et al. [17] in their study indicated strong links between SDG7, SDG9 (industry, innovation and infrastructure), and SDG11 (sustainable cities and communities). These links often relate to climate actions in urban areas, particularly energy efficiency in urban transportation. Elavarasan et al. [18] emphasise that the SDG7 and SDG9 goals can have a positive impact on the rest of them.

Countries are differentiated by their degree of achievement of the SDGs. Villavicencio Calzadilla and Mauger [19] claim that in order to achieve Goal 7 without leaving anyone behind, energy justice issues need to be taken into account in the design and implementation of renewable energy policy and development. Policies on reducing energy demand should incorporate newly formed economic models, digitalisation, and consumer awareness trends. Yu et al. [20] analysed the interaction of these three trends with SDG7 by measuring the energy efficiency of OECD countries from 2005 to 2017. In their study, they showed that Austria and Korea had the highest energy efficiency rates, while Canada and Chile had the lowest. Çağlar and Gürler [21] showed that countries in Europe, North America, as well as China and Australia have made the largest progress towards the SDGs (including SDG7). The big problem in achieving this goal is in African and most Asian countries. Touitou [22] using panel data estimated the relationship between CO_2 emissions, real GDP, and energy consumption in order to find out the coefficients of this relationship over the long term. He showed that in the long term, economic growth in MENA countries is one of the determinants of climate change. Their governments should aim to increase the use of renewable energies and develop more efficient energy policies. Solar energy is among the most important renewable energy resources available in the MENA region. Efforts to reduce reliance on inefficient solid fuel stoves have been underway for several decades, but with inadequate progress. WHO's 2016 assessment found that on a global basis, population growth has largely offset the progress made in reducing the fraction of households that burn solid fuels to meet cooking and heating needs [11]. Major international initiatives that are currently underway to convert households to cleaner fuels include the United Nations-led Sustainable Energy for All (SE4All) program [23]; the Global Alliance for Clean Cookstoves, hosted by the UN Foundation [24]; and the Climate and Clean Air Coalition based out of the United Nations Environment Program [25].

In studies related to the impact of the COVID-19 pandemic on the SDGs, researchers highlight the positive and negative effects on SDG7 [26]. Positive factors include increased use of renewable energy and lower base lending rates. Higher need for energy, disturbances in supply chains, reduced electricity demand, and non-affordability of basic energy services are mentioned as negative factors. Analysing the combined impact of all these factors on SDG7, Fulzele et al. concluded that the pandemic did not have a negative impact on this SDG, although there was a slowdown in the achievement of this goal.

One of the main tasks in the implementation of SDG7 is the development of renewable energy sources: water gravity energy (hydropower) [27], wind power [28,29], solar energy [30], biofuels (bioenergy) [31] and geothermal energy [32,33]. Renewable energy sources (RSE) are a better alternative to non-renewable sources. They are considered interminable because their resources are constantly replenished naturally. Furthermore, their extraction and utilisation remain environmentally friendly [34]. The Renewable Energy Systems (RES) sector is expected to grow steadily in the coming years. As Pietrzak and Kuc-Czarnecka [35] state, this is not an easy task, as the focus of the RES sector should not be on stand-alone renewables, but on the energy mix. The biggest challenge seems to be the formal regulation of the sale of co-generation from different renewable energy sources. A mix of RES makes it possible to meet the energy needs of a region or even an entire country. Further development of RES means increased national energy security. In the face of the war in Ukraine, this becomes particularly important [36].

Matenga [37] assessed the health of energy markets at global, regional, and country levels. He assessed both energy access and energy quality. He concluded that in order to achieve SGD7 globally, global markets need to focus on sustainability and modern energies. The study confirmed poor performance for energy markets in Sub-Saharan Africa and high performance for markets in Europe and North America, At the same time, the author pointed to the lack of significant strides in achieving sustainability in some of the developed economies such as the United States and China. In the case of the United States, the level of access to energy is high, while its quality is poor.

Sousa et al. [38] conducted a systematic literature review on multiple-criteria decision-making (MCDM) methods in terms of their application to the achievement of SDGs. They noted that for SDG7 the MCDM methods are primarily used to plan and manage clean energy projects. In particular the AHP method is the most applied one. Most of these studies were conducted as part of environmental impact assessments. The COPRAS method was also among the applied ones [39,40]. This method is also used to examine the extent to which the other SDGs are being implemented [41–43]. In the case of our study, the novelty is the use of the COPRAS method and its subsequent combination with the DTW method.

3. Materials and Methods

3.1. Materials

We used data from Eurostat in the study. The period of the analysis is 2005–2020. The data covers all EU-27 countries plus Iceland, Norway, and the United Kingdom.

Progress towards the targets is measured, monitored, and evaluated through 17 indicators. SDG7 has a total of five targets. They are [44]: "by 2030, ensure universal access to affordable, reliable and modern energy services (7.1); by 2030, increase substantially the share of renewable energy in the global energy mix (7.2); by 2030, double the global rate of improvement in energy efficiency (7.3); by 2030, enhance international cooperation to facilitate access to clean energy research and technology, including renewable energy, energy efficiency and advanced and cleaner fossil-fuel technology, and promote investment in energy infrastructure and clean energy technology (7a); by 2030, expand infrastructure and upgrade technology for supplying modern and sustainable energy services for all in developing countries, in particular least developed countries, small island developing States and landlocked developing countries, in accordance with their respective programmes of support (7b)".

The variables available from Eurostat to describe the implementation of SDG7 are:

- x_1 primary energy consumption (the total energy needs of a country excluding all non-energy use of energy carriers) in tonnes of oil equivalent (TOE) per capita;
- x_2 final energy consumption (the energy end-use in a country excluding all non-energy use of energy carriers) in tonnes of oil equivalent (TOE) per capita;
- x_3 final energy consumption in households per capita (how much electricity and heat every citizen consumes at home excluding energy used for transportation) in kilograms of oil equivalent (KGOE) per capita;
- x_4 energy productivity (the amount of economic output that is produced per unit of gross available energy) in purchasing power standard (PPS) per kilogram of oil equivalent;
- x_5 share of renewable energy in gross final energy consumption (the share of renewable energy consumption in gross final energy consumption according to the Renewable Energy Directive) in percentage;
- x_6 energy import dependency (the share of total energy needs of a country met by imports from other countries) in percentage;
- x_7 population unable to keep home adequately warm (the share of population who are unable to keep home adequately warm) in percentage.

Variable x_6 is an interesting one, as it is calculated as $\frac{\text{imports}-\text{exports}}{\text{gross available energy}}$. It means that it can take negative values. It is the case of Norway in the whole period and Denmark in the years 2005–2012. Negative values of the energy import dependency mean that a given country is a net exporter of energy. Although it is possible to use negative values of variables, this makes some calculations more difficult because negative values mean that the variable is measured on the weaker, interval scale. Therefore, we can assume that a country with such a value is independent of foreign sources, and in this case, we set the value as 0—this caused all variables to be measured on the strongest, ratio scale. It is also possible for variable x_6 to be higher than 100%—in this case, the energy products have been stocked. Then we set the value at 100%.

Variables x_1, x_2, x_3, x_6, and x_7 are destimulants, i.e., the lowest values are desirable. The remaining ones (x_4 and x_5) are stimulants (the highest values are desirable).

3.2. Methods

We perform the analysis in the following steps:

1. We assess the degree of implementation of SDG7 using the COPRAS method;
2. We present the rankings of countries with respect to the degree of implementation of SDG7 in the years 2005, 2009, and 2020 (the first and last years and the peak of the financial crisis of 2007–2009);
3. We compare the dynamics of SDG7 implementation by means of the Dynamic Time Warping method;
4. We apply the hierarchical clustering to obtain homogeneous groups of countries with respect to the dynamics of implementation of SDG7.

3.2.1. The COPRAS Method

The COPRAS method was proposed by Zavadskas et al. [45]. It is one of the multi-criteria decision-making methods. However, it can also be used in multivariate statistical analysis. It is based on the assumption that an object is directly proportional to a weighted sum of normalised stimulant variables and inversely proportional to a weighted sum of normalised destimulant variables.

The starting point of the COPRAS method is the observation matrix **X**:

$$\mathbf{X} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nm}, \end{bmatrix} \tag{1}$$

where: x_{ij}—value of j-th variable in i-th object ($i = 1, \ldots, n$, $j = 1, \ldots, m$), m—number of variables, n—number of objects.

Because variables are measured in different units and magnitudes, they need to be normalised. The original normalisation method used by Zavadskas et al. [45] was one of the quotient inversions:

$$z_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}}, \tag{2}$$

where: z_{ij}—normalised value of j-th variable in i-th object ($i = 1, \ldots, n$, $j = 1, \ldots, m$).

In the next step of the COPRAS method, we multiply the normalised values of variables (z_{ij}) by their weights (w_j), thus creating the normalised, weighed observation matrix $[t_{ij}]$:

$$t_{ij} = w_j z_{ij}, \quad i = 1, \ldots, n, \quad j = 1, \ldots, m, \tag{3}$$

where w_j—weight of the j-th variable ($j = 1, \ldots, m$), satisfying the conditions: $w_j \in [0, 1], \sum_{j=1}^{m} = 1$.

Then we calculate the weighted sums for the stimulant (S_i^+) and destimulant (S_i^-) variables for all objects:

$$S_i^+ = \sum_{j \in J^+} t_{ij}, \quad i = 1, \ldots, n \tag{4}$$

$$S_i^- = \sum_{j \in J^-} t_{ij}, \quad i = 1, \ldots, n, \tag{5}$$

where J^+—stimulant variables, J^-—destimulant variables.

Finally, we calculate the value of the synthetic variable:

$$q_i = S_i^+ + \frac{\sum_{i=1}^{n} S_i^-}{S_i^- \sum_{i=1}^{n} \frac{1}{S_i^-}}, \quad i = 1, \ldots, n. \tag{6}$$

The value of the synthetic variable $q_i \in [0, 1]$, $\max_i \{q_i\}$—the best object, $\min_i \{q_i\}$—the worst object.

3.2.2. The Dynamic Time Warping Method

To analyse similarities between the development of the variables describing the implementation of the SDG7 in 30 countries, the Dynamic Time Warping (DTW) method is used. The method was invented by Bellman and Kalaba [46] and was originally used for speech recognition [47–50]. It is currently being used in various fields, for example, in finance [51], in labour market analysis [52–54], in energy commodity market analysis [55], in studies of the development of the COVID-19 pandemic [56,57], or in insurance risk modelling [58].

The DTW method matches two time series to each other by performing local stretching or compression so that one resembles the other as closely as possible. In this way, similar but phase-shifted sequences are found [59]. The DTW algorithm measures the similarity between two temporal sequences $Y_1 = (y_{11}, \ldots, y_{1N_1})$ and $Y_2 = (y_{21}, \ldots, y_{2N_2})$ with respect to a local cost measure defined as:

$$c(y_{1i}, y_{2j}) = |y_{1i} - y_{2j}|, \quad i = 1, \ldots, N_1, \quad j = 1, \ldots, N_2. \tag{7}$$

This measure has small values if Y_1 and Y_2 are similar and big values when they are significantly different. By determining this measure for pairs of components in Y_1 and Y_2, we obtain a local coast matrix.

To discover the optimal alignment between Y_1 and Y_2 a warping path must be found, which is the vector $wp = (wp_1, \ldots, wp_K)$, where $wp_k = (n_{lk}, n_{2k}) \in \{1, \ldots, N_1\} \times \{1, \ldots, N_2\}$, for $k \in \{1, \ldots, K\}, K \in \{\max(N_1, N_2), \ldots, N_1 + N_2 - 1\}$. The path should satisfy three conditions: boundary (which enforces that the initial elements in Y_1 and Y_2 and the last elements are assigned to each other), monotonicity (which ensures that the path runs either upward, diagonally to the right and upward, or to the right from the current point), and step size (no component in Y_1 and Y_2 can be ignored and all pairs of indices in the path are different) [60].

We define the total cost $c_{wp}(Y_1, Y_2)$ of a warping path wp as:

$$c_{wp}(Y_1, Y_2) = \sum_{k=1}^{K} c(y_{1n_k}, y_{2n_k}) = \sum_{k=1}^{K} |y_{1n_k} - y_{2n_k}|. \tag{8}$$

The optimal warping path between Y_1 and Y_2 is a path wp^* of minimum total cost:

$$c_{wp^*}(Y_1, Y_2) = \min\{c_{wp}(Y_1, Y_2) | wp \in \text{set of all paths}\}. \tag{9}$$

The DTW algorithm utilises dynamic programming to find the optimal alignment between time series. It finds the optimal path wp^* by building a cumulative cost matrix **C**:

$$C(1,j) = \sum_{t=1}^{j} c(y_1, y_{2t}) \text{ for } j = 1, \ldots, N_2$$
$$C(i,1) = \sum_{t=1}^{i} c(y_{1t}, y_{21}) \text{ for } i = 1, \ldots, N_1 \quad (10)$$
$$C(i,j) = c(y_{1i}, y_{2j}) + \min\{C(i,j-1), C(i-1,j), C(i-1,j-1)\}$$
$$\text{for } i = 2, \ldots, N_1, j = 2, \ldots, N_2.$$

The distance between the series Y_1 and Y_2 in the DTW method is then equal to $C(N_1, N_2)$. The path wp^* can be traced by moving backward from this point to point $C(1,1)$, choosing neighbouring elements of minimum value along the way. Graphically, the optimal path follows the "valleys" of low costs and avoids the "mountains" of high costs [61]. If wp^* is above diagonal, the time series Y_1 precedes Y_2.

3.2.3. Hierarchical Clustering

Agglomerative hierarchical clustering was proposed by Joe H. Ward, Jr. in 1963 [62]. In this approach, every object creates a separate cluster (singleton). By moving up, we merge pairs of clusters. After $n-1$ steps (where n is the number of objects) all objects create one cluster. As a measure of dissimilarity between sets of observations, we use the DTW distance. As the linkage criterion for objects in clusters, we select Ward's criterion, which is the minimisation of the total within-cluster variance.

4. Results

4.1. Rankings of Countries with Respect to Degree of Implementation of SDG7

In the first step of the analysis, we assessed the implementation of SDG7 in selected European countries. Every year we evaluated it by means of the synthetic variable, calculated using the COPRAS method (Equations (1)–(6)). It is based on weighted sums of variables. We assumed equal weights for all variables. The reason for this was the fact that the weights assigned by means of statistical methods (based on the level of variability or correlations between variables) would be different each year. On the other hand, applying expert methods for assigning weights would create a high degree of subjectivity. Because we do not know, if any variables are more important than others, we assume equal weights. We present the rankings of countries for 2005, 2009, and 2020 in Table 1.

Table 1. Rankings and values of synthetic COPRAS measure (in parentheses) of European countries with respect to the degree of implementation of SDG7 in the years 2005, 2009, and 2020. Source: own elaboration.

Country	2005	2009	2020
Belgium (BE)	28 (0.1587)	27 (0.1734)	25 (0.1835)
Bulgaria (BG)	29 (0.1537)	29 (0.1354)	28 (0.1732)
Czechia (CZ)	14 (0.2339)	12 (0.2444)	13 (0.2368)
Denmark (DK)	4 (0.2886)	2 (0.3151)	4 (0.2753)
Germany (DE)	17 (0.2280)	19 (0.2212)	22 (0.2102)
Estonia (EE)	3 (0.2926)	3 (0.2858)	3 (0.2796)
Ireland (IE)	24 (0.2165)	22 (0.2124)	5 (0.2714)
Greece (GR)	13 (0.2362)	20 (0.2162)	24 (0.1970)
Spain (ES)	10 (0.2453)	11 (0.2539)	16 (0.2323)
France (FR)	12 (0.2390)	15 (0.2319)	15 (0.2347)
Croatia (HR)	2 (0.2965)	5 (0.2809)	8 (0.2685)
Italy (IT)	16 (0.2281)	18 (0.2250)	17 (0.2305)
Cyprus (CY)	27 (0.1667)	28 (0.1676)	29 (0.1689)
Latvia (LV)	9 (0.2512)	13 (0.2433)	7 (0.2700)
Lithuania (LT)	22 (0.2181)	25 (0.2094)	27 (0.1789)

Table 1. *Cont.*

Country	2005	2009	2020
Luxembourg (LU)	30 (0.1193)	30 (0.1330)	30 (0.1582)
Hungary (HU)	26 (0.2146)	14 (0.2383)	14 (0.2349)
Malta (MT)	15 (0.2313)	26 (0.2090)	20 (0.2260)
Netherlands (NL)	18 (0.2262)	16 (0.2313)	21 (0.2179)
Austria (AT)	8 (0.2541)	7 (0.2567)	12 (0.2459)
Poland (PL)	19 (0.2223)	17 (0.2305)	11 (0.2611)
Portugal (PT)	21 (0.2183)	21 (0.2158)	19 (0.2268)
Romania (RO)	25 (0.2152)	6 (0.2738)	2 (0.2938)
Slovenia (SL)	6 (0.2708)	8 (0.2565)	10 (0.2659)
Slovakia (SK)	23 (0.2174)	9 (0.2551)	18 (0.2285)
Finland (FI)	20 (0.2184)	24 (0.2099)	23 (0.2045)
Sweden (SE)	5 (0.2808)	4 (0.2854)	6 (0.2712)
Iceland (IS)	11 (0.2437)	23 (0.2113)	26 (0.1827)
Norway (NO)	1 (0.3487)	1 (0.3225)	1 (0.3038)
United Kingdom (UK)	7 (0.2657)	10 (0.2549)	9 (0.2678)

In all three years, Norway was the best country in the area of SDG7 implementation. During the whole analysed period, high positions were occupied also by Denmark, Estonia, Croatia, Latvia, Sweden, and the United Kingdom. Luxembourg was always the worst country in this regard. Other countries, for which the degree of implementation of the SDG7 was amongst the worst were: Belgium, Bulgaria, Cyprus, Lithuania, and Finland. Positions of some countries noted a high increase—Ireland, Hungary, Poland, and—most visibly—Romania. Greece and Iceland were the countries whose positions deteriorated to the highest degree.

4.2. Assessment of Dynamics of Countries with Respect to the Degree of SDG7 Implementation

In the next step of the analysis, we compared the relative dynamics of the degree of implementation of SDG7 by means of the DTW method. We used the synthetic measure obtained by the COPRAS method to assess the implementation of the SDG7 in every year of the analysis. Although all time series are comparable with respect to their units and magnitude, we normalised them before further proceeding. We selected the *z*-normalisation from the `data.Normalization` function in the `clusterSim` package [63]. We used the `dtw` function in the `dtw` package [64] to obtain the distance matrix. After applying the DTW method (Equations (7)–(10)) and obtaining the distance matrix we performed the agglomerative clustering (Figure 1). We applied the `NbClust` function in the `NbClust` package [65] for the selection of the number of clusters. We distinguished 8 clusters by using the Beale index. The dendrogram was created by means of the `fviz_dend` function in the `factoextra` package [66].

There was one cluster with two countries. It was created by Ireland and Latvia (further named cluster 1—C1). After an initial period with stable and low levels of degree of SDG7 implementation, their values started to increase and improved until the end of the observation period. We have four clusters with three countries each. The first one was created by Czechia, Denmark, and Slovakia (cluster 3—C3), the second one by Estonia, Italy, and Slovenia (cluster 4—C4), the third one by the Netherlands, Spain, and Sweden (cluster 7—C7), and the fourth one by Germany, the United Kingdom, and Malta (cluster 5—C5). In the first of these clusters, the degree of implementation of the SDG7 increased at the beginning of the observation period, then it was steady and declined at the end. In the second cluster, we observed fluctuations throughout the whole period. The third one was characterised by a steady value at the beginning of the observation period, there was a drop in the middle and a steady, lower value until the end. The fourth one had steady levels of the degree of implementation of the SDG7 with a big decline in the middle of the observation period. We had two clusters with four countries each. The first one was created by Belgium, Luxembourg, Poland, and Romania (cluster 2—C2), and the second by Bulgaria, Cyprus, Hungary, and Portugal (cluster 6—C6). In the first cluster, we can observe a more or less steady increase in the degree of implementation of SDG7 throughout the whole period. The second cluster had periods of longer-lasting increases and declines in the degree of SDG7 implementation. Countries belonging to this cluster also showed a decline in the period of financial crisis 2007–2009. Finally, we have the largest cluster with 7 countries: Austria, Croatia, Finland, Greece, Iceland, Lithuania, and Norway (cluster 8—C8). In this cluster, the relative (with respect to other countries) degree of implementation of the SDG7 decreased throughout the observation period. Of course, we should not consider that the absolute situation of any country increases-decreases by analysing changes in the synthetic measure. Our analysis is concerned with relative dynamics. Therefore, looking at Norway, for example, we see that the values of the variables in this country have improved, but for other countries, the values have improved even more—the value of the synthetic measure for each country is calculated taking into account all the others. That is why the value of the composite measure in Norway had a decreasing trend.

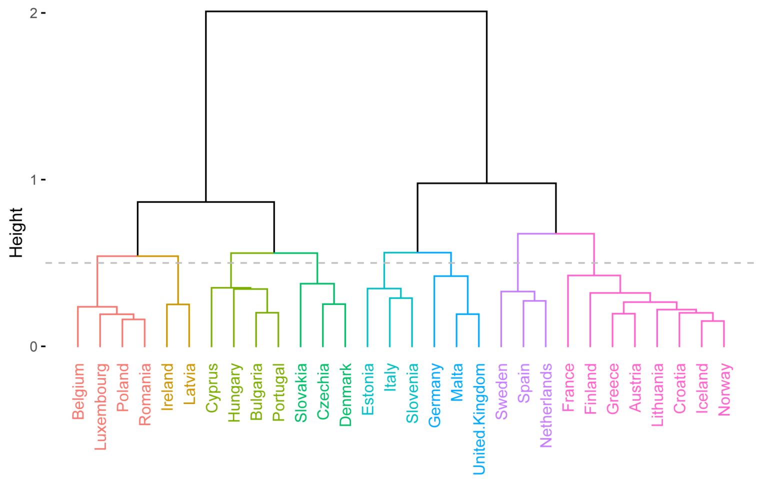
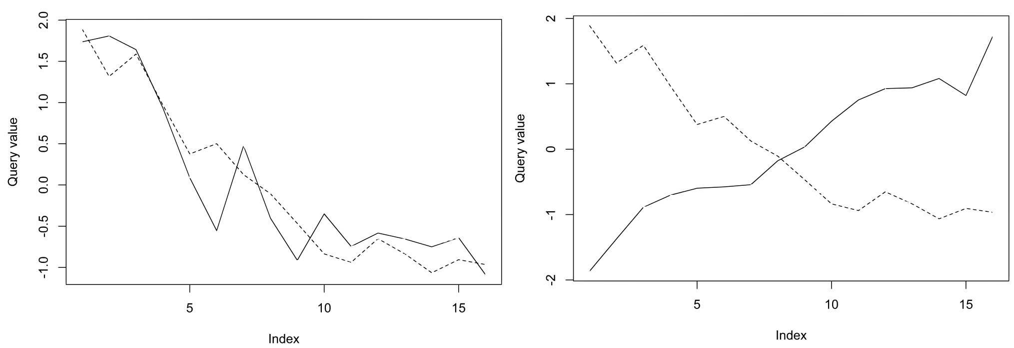


Figure 1. Clusters of countries with respect to relative dynamics of the degree of SDG7 implementation. Source: own elaboration.

In order to further illustrate the similarities and dissimilarities in the relative dynamics of the degree of SDG7 implementation, we present two-way alignment plots with the two most similar (Norway and Iceland) and two dissimilar (Luxembourg and Iceland) countries in Figure 2 (Iceland is marked with a dashed line in both graphs).



Norway and Luxembourg are marked with solid lines and Iceland is marked with a dashed line.

Figure 2. Two-way alignment plots for Norway-Iceland and Luxembourg-Iceland. Source: own elaboration.

Relative dynamics of the degree of implementation of the SDG7 for Norway and Iceland were virtually the same throughout the whole period—they were decreasing. When we look at the most dissimilar pair Luxembourg-Iceland, the directions were the opposite.

Because the rankings of countries presented in Table 1 do not correspond directly with the comparison of dynamics, presented in Figure 1, we present Table 2, which is the summary of obtained results. On the right-handside of graphs, there are the cluster numbers.

Table 2. Relation between relative dynamics of SDG7 implementation and ranking of countries in 2020. Source: own elaboration.

Clusters of countries	Relative Dynamics of SDG7 Implementation			⟶ Ranking of Countries with Respect to SDG7 Implementation in 2020 ⟶
↑	initial low level, then increase		C1	LV IE
↑	steady increase		C2	LU BE PL RO
↑	increase, then steady and decline at the end		C3	SK CZ DK
↑	fluctuations throughout the whole period		C4	IT SL EE
↑	steady with decline in the middle		C5	DE MT UK
↑	increases and decreases; 2007–2009 decline		C6	CY BG PT HU
↑	steady, then drop and low at the end		C7	NL ES SE
↑	decrease throughout the whole period		C8	LT IS GR FI FR AT HR NO

We can hardly see any connections between the membership of countries to clusters with respect to the relative dynamics of SDG7 implementation and ranking in 2020. Countries with a low level of the degree of SDG7 implementation (Lithuania, Iceland, or Greece) had similar relative dynamics as countries witha high degree (Norway and Croatia)—eighth cluster. A similar situation was found in the second cluster—Romania and Poland had a relatively high degree of SDG7 implementation and were characterised by its similar relative dynamics as countries with a low level of SDG7 implementation (Luxembourg and Belgium).

It is worth checking the dynamics of which indicators determined the membership of countries to clusters. All 30 countries had increasing values of variables x_4—energy productivity and x_5—share of renewable energy in gross final energy consumption. Therefore, these two indicators cannot determine the division of countries into clusters with similar relative dynamics of the degree of SDG7 implementation. One of the variables that influence this dynamics is variable x_3—final energy consumption in households per capita. In clusters 1, 2, 4 and 7 it was generally decreasing throughout the whole period. It corresponds negatively with the relative dynamics of the degree of SDG7 implementation in clusters 1 and 2 (where the trend was increasing) and positively in cluster 7, where the trend was decreasing. Indicator x_7—population unable to keep home adequately warm—was negatively connected with the relative dynamics of the degree of SDG7 implementation in clusters 1, 2, 4, 5, and 6, while did not have particular connections in the remaining clusters.

Realisation of SDG7 is just one of many aspects of sustainable development. Therefore, it is worth mentioning, how it corresponds with some aspects of social and economic development. We present the Spearman's rank correlation coefficients (ρ) between the values of the synthetic measure in analysed countries and selected socio-economic indicators. We selected the three aspects of social and economic development:

- general economic situation—GDP per capita in PPS in constant prices from 2020;
- situation in the labour market—unemployment rate;

- selected poverty indicator—in work at-risk-of-poverty rate.

Table 3 presents the minimum and maximum values of Spearman's rank ρ coefficients between the values of the synthetic COPRAS measure and values of analysed indicators for every cluster.

Table 3. Spearman's rank ρ coefficients between the values of the synthetic COPRAS measure and values of indicators. Source: own elaboration.

Clusters	GDP Per Capita		Unemployment Rate		In Work at-Risk-of-Poverty Rate	
	Min	Max	Min	Max	Min	Max
C1	0.6765	0.8176	−0.6059	−0.2428	−0.5449	−0.4130
C2	0.6176	0.9529	−0.4341	0.8095	−0.6284	0.8118
C3	−0.2529	−0.0794	−0.0162	0.6431	−0.0685	0.2417
C4	−0.6500	−0.1441	−0.6063	−0.0206	−0.7448	−0.0487
C5	−0.0882	0.3147	−0.7865	−0.0471	−0.1636	0.4559
C6	−0.0853	0.6088	0.3588	0.6740	−0.5881	0.2948
C7	−0.6000	−0.5382	−0.4035	0.2893	−0.6450	−0.2139
C8	−0.9206	0.7118	−0.7324	0.4283	−0.6278	0.5959

Values of correlation coefficients between the synthetic COPRAS measure (measuring the degree of SDG7 implementation) and all indicators vary across the clusters. Correlations between GDP per capita and the synthetic COPRAS measure in clusters 1 and 2 are strong and positive. GDP per capita has in most cases increasing trend, which correlates strongly and positively with the relative dynamics of the degree of SDG7 implementation, which is increasing in these two clusters. For cluster 3, it is weak and negative (as countries belonging to cluster 3 exhibit an increase and then a decrease of the synthetic COPRAS measure—Table 2). For cluster 4 the correlation is negative and on the average of medium strength—the relative dynamics of the degree of SDG7 implementation is fluctuating throughout the whole period. For clusters 5 and 6, the correlation varied from weak negative to strong positive—in these clusters, the relative dynamics of the degree of SDG7 implementation was fluctuating. Finally, in clusters 7 and 8, the correlation between the COPRAS measure was negative and strong (cluster 7) very strong (cluster 8, with the exception of Greece, which had fluctuating dynamics of GDP per capita).

The spread of values of correlation coefficients between the unemployment rate and the synthetic COPRAS measure was generally much higher than in the previous case. The reason for this was that the dynamics of the unemployment rate is characterised by much more fluctuations than the GDP per capita—in most countries we could observe the increase in the unemployment rate during the financial crisis of 2007–2009. In most cases the correlation was negative. The strongest correlations were in clusters 2, 6, and 8, and the weakest were in cluster 7.

Correlations between the degree of SDG7 implementation and in work at-risk-of-poverty rate had the highest spread. Cluster 1 had the most similar values of coefficients, indicating negative correlations with medium strength. In work at-risk-of-poverty rate in these countries had decreasing trend with fluctuations. Cluster 2 had the highest spread of the values of correlation coefficients. Only in the case of Poland, the correlation between the synthetic COPRAS measure and in work at-risk-of-poverty rate was negative, meaning that only in this country in this cluster the latter was decreasing. The strongest (and positive) correlation was in the case of Luxembourg. It means that this poverty measure in this country was increasing. Countries belonging to cluster 3 had the weakest correlations between the degree of SDG7 implementation and in work at-risk-of-poverty. The reason for this was that both indicators had fluctuations with no particular trend. In clusters 4 and 7 correlation between the in work at-risk-of-poverty rate and the synthetic COPRAS measure was negative. In these two clusters, the relative dynamics of the degree of SDG7 implementation was fluctuating and slightly decreasing, and the analysed coefficient measuring poverty was fluctuating and increasing. In cluster 5 the in work at-risk-of-poverty rate was generally increasing, and the degree of SDG7 implementation was steady with a decline in the middle of the analysed period. Therefore, the correlations in this cluster were generally weak. In cluster 6 the dispersion of correlation coefficients was big, but generally relations were of medium strength and positive. The degree of SDG7 implementation was generally increasing with the 2007–2009 decline, and the in work at-risk-of-poverty rate was more or less steady or increasing, but with fluctuations. Finally, in cluster 8 the situation was the most diverse, as it was the most numerous cluster. The relative dynamics of the degree of SDG7 implementation was generally decreasing, while the dynamics of in work at-risk-of-poverty rate differed across the countries.

5. Discussion

Evidence-based policymaking needs to be rooted in robust data and adequate models. Lafortune et al. [67] state that there is no single ‘correct’ way to assess whether the EU and EU Member States are on track to meet the Sustainable Development Goals (SDGs). The different results of this assessment are the result of certain methodological choices. Notably, the official SDG indicators have both conceptual and data gaps that need to be filled at the national level. Different organisations have provided different assessments of the EU’s distance and progress towards the SDGs. The estimated performance on SDG7 is also significantly higher in the OECD report [68] than in the SDSN report [69]. Some targets are more heterogeneous and thus much more sensitive to the choice of indicators. This is the case for biodiversity and other environmental goals (especially SDG7). Therefore, any ranking for European countries may differ depending on the assessment method adopted. In contrast, Clemente-Suárez et al. [70] attempted to assess the impact of COVID-19 on the achievement of the SDGs. They found out that One of the significant impacts of the pandemic is the loss of accuracy in the models used for forecasting energy consumption to plan the exploitation of energy systems. During the lockdown, while the global energy system saw a slight increase in renewable energy demand, demand for oil declined by 9% and demand for electricity by 2.5% [71]. Given the importance of electricity for economic, health, and other activities, several countries have issued policies guaranteeing uninterrupted energy supplies, allowing users to delay payments [72]. This has affected the predictive ability of the econometric models used. Similar conclusions were reached by Bissio [73]. He states that measuring progress towards SDGs has been elusive because lacking data or even an agreed methodology for more than half of them.

Firoiu et al. [74] analysed the dynamics of SDG7 implementation in the EU Member States 5 years after the adoption of the Paris Agreement crowning the 21st UN Climate Change Conference (United Nations Framework Convention on Climate Change, 21st Conference of the Parties). They applied the hierarchical cluster analysis to unveil latent association structures. EU countries were clustered in 2015 and 2019 on the basis of Eurostat data to identify and analyse key features. In 2015 the cluster of the best-performing countries consisted of four EU countries (Denmark, Finland, Romania, and Sweden). In 2019, their number increased to eight EU countries (Bulgaria, Czechia, Denmark, Estonia, Finland, France, Romania, and Sweden), simultaneously with an improvement in the indicators.

Cheba and Bąk [75] presented a proposal to measure the relationship between Goal 7 of the 2030 Agenda for Sustainable Development and one of the areas included in the green growth concept: eco-efficiency of production. They showed that countries such as Belgium, and the Netherlands, despite their relatively high GDP per capita, are less successful in achieving Goal 7 of the Strategy for Sustainable Development. Their environmental production efficiency is also lower than that of other less-developed EU countries. Croatia, Latvia, Romania, and Spain, despite a lower GDP per capita than the EU average, achieved relatively high scores in the analysed areas.

Despite the differences in the resulting rankings and classifications, it is not uncommon for different methods to produce similar results. The results of our study coincide with those of the analysis carried out by Matenga [37]. He examined (among other things) the condition of the energy markets of four European countries. He indicated a high level for

Sweden in terms of both energy quality and access to energy. In contrast, Belgium, France, and Italy were influenced by a somewhat lower level of the analysed variable in terms of a fairly high level of access to energy, while the quality of energy was somewhat lower. Elavarasan et al. [76] proposed a novel SDG7 or Energy Sustainability Composite Index. It allowed the assessment of energy sustainability performance and ranking of European countries. The authors showed that in 2018, Iceland, Norway, and Sweden led the way in energy sustainability aspects. In contrast, Cyprus, Poland, and Luxembourg came last. These results are in line with our results, according to which Iceland and Norway were the most similar in the relative dynamics of the degree of SDG7 implementation, and Iceland and Luxembourg were the least similar countries (Figure 2). Chovancová and Vavrek [77] assessed the progress of EU countries towards the Sustainable Development Goal in terms of affordable and clean energy. Their study showed that Sweden ranked first on the list and Luxembourg last. Despite its first place, Sweden did not achieve the highest indicators in all analysed areas. In the three areas of energy consumption per capita, final energy consumption per capita, and energy import dependency, Romania scored highest, which coincides with the high position of this country also in our research. Additionally, an assessment of the progress of sustainable development based only on the development of renewable energy sources leads to slightly different results. Włodarczyk et al. [78] showed that Estonia, Belgium, Greece, Ireland, and Luxembourg rank high by improving their level of energy independence, especially based on RES. In contrast, Denmark, Bulgaria, Romania, Latvia, and Sweden recorded a decline in this respect.

6. Conclusions

The aims of our research were: the comparison of selected European countries in terms of the degree of SDG7 implementation and the comparison of the relative dynamics of SDG7 achievement between 2005 and 2020. We reached the first goal by creating rankings of countries using a synthetic variable obtained by the COPRAS method. Norway, Denmark, Estonia, Croatia, Latvia, Sweden, and the United Kingdom were the best countries, while Belgium, Bulgaria, Cyprus, Lithuania, and Finland were the worst ones. Romania was the country that improved its position to the highest degree and the position of Greece and Iceland deteriorated to the highest degree. The second goal—the comparison of relative dynamics—showed that Belgium, Luxembourg, Poland, and Romania belonged to a cluster in which the relative dynamics was steady and had increased during the whole period. At the other end were Austria, Croatia, Finland, Greece, Iceland, Lithuania, and Norway, whose relative dynamics showed a decline throughout the period. We also tried to answer the research question of whether crisis periods affected the dynamics of the degree of SDG7 achievement. This situation occurred in the case of the following countries: Bulgaria, Cyprus, Hungary, and Portugal.

SDG7 is just one of the 17 Sustainable Development Goals. As Chuliá-Jordán et al. [79] point out, it is important to educate and promote these goals, and even successfully incorporate them into the curriculum [80,81]. This could lead to the development of an interdisciplinary sustainability science [82,83].

In many cases, a limitation of the SDG7 implementation study is the lack of access to data. An example is the inability to include information on access to electricity in many analyses. As highlighted by Gao et al. [84], present access to survey-based electricity datasets is characterised by short time-frames, slow updating, high procurement costs, and lack of data regarding location. Electricity is one of the main drivers of scientific, technological, and economic development, and is key to the quality of life and economic development in poor countries [85,86]. Achieving SDG7 is possible through the development of renewable energy sources. In the context of the war in Ukraine, these sources offer an alternative not only to coal but also to gas and oil. This will promote energy security worldwide and foster sustainable development.

Our research allows us to assess which countries are leading the way in terms of the degree of implementation of SDG7 and can be a benchmark to which countries that are less compliant should aspire (rankings of countries). It also allows for assessing which countries are on the best path towards SDG7 implementation (analysis of dynamics). European countries are energetically interconnected, so it is in everyone's common interest to have access to cheap, clean, and sustainable energy. Isolating groups of countries with a lower degree of SDG7 achievement and with weaker dynamics in achieving SDG7 will allow for effective targeting of European countries' energy policies.

The research was completed in 2020. Unfortunately, no more recent data were available in the Eurostat database. This is the first limitation of our study. The second one is the lack of some other data for our selected countries, e.g., the cost of energy, which could have been additionally included. The lack of such data meant that only data recommended by Eurostat describing the degree to which the SDG7 was implemented appeared in our analysis.

The availability of full data for 2021–2022 will allow the analysis to be re-conducted and include the impact of COVID-19 on the analysed occurrences. Data from 2022 and beyond (2023 onwards) will allow us to assess the impact of the Russian-Ukrainian conflict on the degree of SDG7 implementation. These are future directions for our research.

In future research, we will try to overcome the limitations of the specification of the degree of SDG7 implementation obtained by the COPRAS method by comparing the results obtained by other ones (e.g. TOPSIS) and by the specification of weights of variables. Also, the stability of the results of cluster analysis will be compared to the results obtained by other methods (such, as divisive hierarchical clustering, or centroid-based clustering).

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