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Indicator-based assessment of sustainable energy performance in the European Union

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ABSTRACT

The COVID-19 and the resulting global energy crises highlighted the importance of decarbonization and the necessity of shifting the economy from fossil fuels towards renewable energy sources. Sustainable energy transition is also a key element of circular economy, social welfare and justice. In this paper we developed an indicator set and we compiled a composite indicator to measure the performance of the EU Member States regarding the sustainable energy transition between 2007 and 2019. Our results show significant differences which do not follow the usual East-West division of the integration. Both convergence and divergence can be revealed.

Keywords

Sustainable energy;
Energy transition;
Composite indicator;
Benchmark;
Energy policy

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1. Introduction

Energy is a key sector on the road towards sustainable development. The value chain of production, distribution and consumption of energy is decisive to social welfare, economic development and environmental protection. However, energy-related social, economic and environmental impacts (e.g. energy poverty, low energy productivity, greenhouse gas emission) often represent unsustainable patterns [1] and significant barriers to achieving sustainable energy transition [2]. The eminent role of energy is recognized in the United Nations (UN) Sustainable Development Goals (SDGs) and in the European Sustainable Development Strategy [3], as well. Sustainable energy transition is also a key element of low carbon and circular economy, as well as social welfare and justice.

The energy transition aims to transform the global energy sector from fossil-based to zero-carbon [4]. But it is much more than just replacing fossil fuels by renewable energy sources. It also means the integration of new energy technologies, carbon storage, improving energy efficiency and encouraging energy savings in a sustainable way [5]. Its implementation is also complicated by the fact that both top-down and bottom-up approaches are needed at the same time [6]. The sustainable energy transition goes beyond this and it emphasizes the approach of sustainability. It means meeting the emerging needs of energy transitions ensuring sustainable development [7]. It is ”a controlled process that leads to an advanced, technical society to replace all major fossil fuel primary energy inputs with sustainably renewable resources while maintaining a sufficient final energy service level per capita” [8]. Here we note, that in this study the sub-national scale is not taken into consideration, the analysis of the so-called local energy transition is not part of it.

It should be noted that the sustainable energy transition is an ongoing process, takes a long time and characterized by both accelerating and decelerating phases [2]. Recent shocks (e.g. COVID-19) and latest energy trends

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(e.g. increasing energy prices, threat of a European gas shortage, regional differences in utilization of renewables, existing and new fossil fuel hot-spots in certain EU Member States) on the one hand have tended to favor the slowing down of that, on the other hand may also highlight the importance of the indicator-based assessment of sustainable energy performance in the European Union. Our article has a double purpose. Firstly, we develop representative indicators covering the three dimensions (i.e. economic and development-related dimension, human and social dimension, and natural resource-related and environmental dimension) of sustainable energy performances in the EU Member States. Secondly, we assess the progress in sustainable energy transition, determining the temporal and spatial distribution of the sustainable energy performance indicators.

The rest of this paper is organized as follows. Section 2 reviews the relevant literature. Section 3 introduces the applied data (databases) and methodology. The process of data collection and data testing (normality, multicollinearity, stationarity) are presented. The indicator set is climate corrected and there are no missing values. A composite indicator is built to measure the sustainable energy performance of the EU Member States. Section 4 presents the results. We set up four clusters highlighting the inequalities among the examined countries. Conclusions are presented in Section 5.

2. Literature review

Seeing the existing states and the trends based on changes in the past is necessary for the process of decision-making. Indicator sets are a way to quantify, evaluate and compare these processes [9]. Given the nature of indicators, they show only a part of a process, and they are based on imperfect models, but they are suitable tools to show the long-term changes in complex and evolving systems, such as sustainable development [10]. Indicator sets aim for a comprehensive and balanced assessment of the performance of diverse countries or regions. Composite statistical indices have proven to be a particularly useful method to inform policymakers about the state and trends of energy transitions. There are a large number of indicator sets and composite indices, each highlighting different aspects of sustainability, climate change mitigation and sustainable energy systems. Their common feature is that most studies have been a posteriori (ex post evaluation) [2].

One of the first attempts to collect and provide information was made by the UN in 2001. The Indicators for Sustainable Development included more than 50 indicators grouped in four dimensions. This large set was difficult to use effectively, therefore a new set was developed based on it. The Energy Indicators for Sustainable Development (EISD) has less indicators grouped in three groups (social, economic, environmental). It has been designed to help decision making and provide information on energy trends. The EISD indicator set's purpose is for countries to assess their sustainability, and it's expected to be further developed [11]. Another example of sustainable energy indicators is the Sustainable Energy Development Index. It was developed in 2015 to rate countries based on the sustainability of their energy system and to give an indication on their performance in the development of a sustainable energy system. Unlike most of the indicator sets dealing with sustainability, it has five dimensions (technical, economic, social, environmental and institutional). It was compared with the Human Development Index (HDI) and the Energy Development Index (EDI), and it has a positive correlation with both of them [9].

There are several indicator sets that are focusing on the environmental aspect of sustainability. Although energy related indicators also appear, but subordinate to environmental objectives. The purpose of environmental composite indices is to quantify ecosystem quality or damage. The Composite Index of Environmental Performance was developed by das Neves Almeida and García-Sánchez [12] based on the Driving−Force−Pressure−State−Exposure− Effect−Action (DPSEEA) methodology. The Environmental Performance Index (EPI) is one the most recognized among environmental indices. It was developed as a joint project by multiple organizations. The purpose of the EPI is to rank countries based on their ecological performances, and it concentrates on policy issues rather than sustainability [12]. The Living Planet Index (LPI) also focuses on the ecosystem, but with a different approach. It was developed by the World Wide Fund for Nature (WWF), and it tracks the population of various mammal, bird, fish, reptile and amphibian species. The changes and emerging trends enable the measuring of biodiversity [13].

Other nature-centered composite indexes and indicator sets measure climate change. One example is the Climate Change Performance Index (CCPI), which tracks climate protection performance on a national level. CCPI evaluates countries' performance in four categories: GHG emissions, renewable energy, energy use and climate policy. There are 14 indicators in total. The CCPI was updated in 2017 to include the goals of the 2015 Paris Agreement. It aims to track the countries' performance in climate protection and compare the results with the benchmarks [14]. Another indicator set with a similar aim is the Climate action tracker, which also tracks climate performance and measures it against the Paris Agreement, but with more focus on governmental action. It assesses countries' climate change mitigation policies, action on emission, and also the impact of their targets. Only 39 countries and the EU are evaluated with this method [15]. The Climate Action Network also evaluated countries' performance in reaching their climate and energy targets and a set of climate and energy indicators in a 2018 report. The report focused on the EU member states, assessing their behavior in setting and increasing both European and domestic targets. Supporting climate strategies and promoting them is also in this indicator set [16]. The European Climate Foundation's evaluation is an assessment of the EU member states' national energy and climate plans. This is also an indicator-based assessment tool which ranks countries based on their performance in climate change mitigation. The guiding ideals were the need for these plans to be transformative, in line with the Paris Agreement and transparent, facilitating the decisions of stakeholders [17].

There are indicator sets focused specifically on energy sustainability. One example is the World Energy Council's World Energy Trilemma Index (WETI). The energy trilemma means that to achieve the sustainability of energy systems, three core dimensions have to be balanced, which are energy security, energy equity and environmental sustainability. The WETI evaluates and ranks 128 countries [18]. The Renewable Energy Country Attractiveness Index (RECAI) is focused on energy sustainability as well [19].

Indicator sets quantifying and evaluating countries' transition to a more sustainable energy system emerged only in the recent years. The Energy Transitions Index (ETI) was developed by the World Economic Forum. There are 40 base indicators, which are aggregated into one composite index. The indicators are assigned to two major groups, transition readiness and system performance [20]. Kuc-Czarnecka et al. [21] suggested changes to improve the methodology by including sensitivity analysis and spatial error models. Another indicator set focusing on sustainable energy transition readiness was developed by Nefytou et al. [22]. In this indicator set, there are eight evaluation criteria, sorted in four groups that are based on the pillars of sustainability (social, political, economic and technological). The methodology is based on multi-criteria evaluation.

Sustainability and especially energy transitions are extremely complex processes involving different social, political, technological, environmental and economic aspects [2]. One of the most comprehensive and widely recognized indicator sets in evaluating countries' sustainability is the UN SDGs. There is a total of 115 SDGs, and countries are ranked based on their performance in 17 of them. The assessment covers the 193 UN Member States [23]. Considering the scope of our article the SDG7 and SDG13 are the most relevant. SDG7 is based on the basic approach that the current form of global energy use is unsustainable. It is about 'ensuring access to affordable, reliable, sustainable and modern energy for all', it calls for energy efficiency improvement and for increasing the share of renewable energy sources. Among the sub-goals, energy justice and declining energy poverty can be found too, as well as the transition to a low-carbon energy system. SDG13 aims to 'take urgent action to combat climate change and its impacts'. Greenhouse gas emission is in focus, and some spillover effects are also identified.

3. Data and methods

Three main types of energy transition studies can be identified: quantitative system modelling, initiative based learning (e.g. local energy transitions) and socio-technical analysis (e.g. Modern Portfolio Theory) [2], [24]. Composite indicators belong to the third category and they aim to compare country performance regarding a specific economic area. The method is widely-used, corruption perceptions index [25], world competitiveness ranking [26] or smart city index [27] are good examples. One of their main advantages is the easy interpretation and their ability to concentrate many individual indicators and dimensions into one index. Providing a holistic approach and showing the bigger picture, the composite indicators are quite useful for benchmarking different countries [28]. However, determining the indicator set and weights is a critical issue, many times the data availability or political interests have a great influence on them, which should be avoided.

Building the sustainable energy performance index (Figure 1) the main steps suggested by OECD et al. [28]

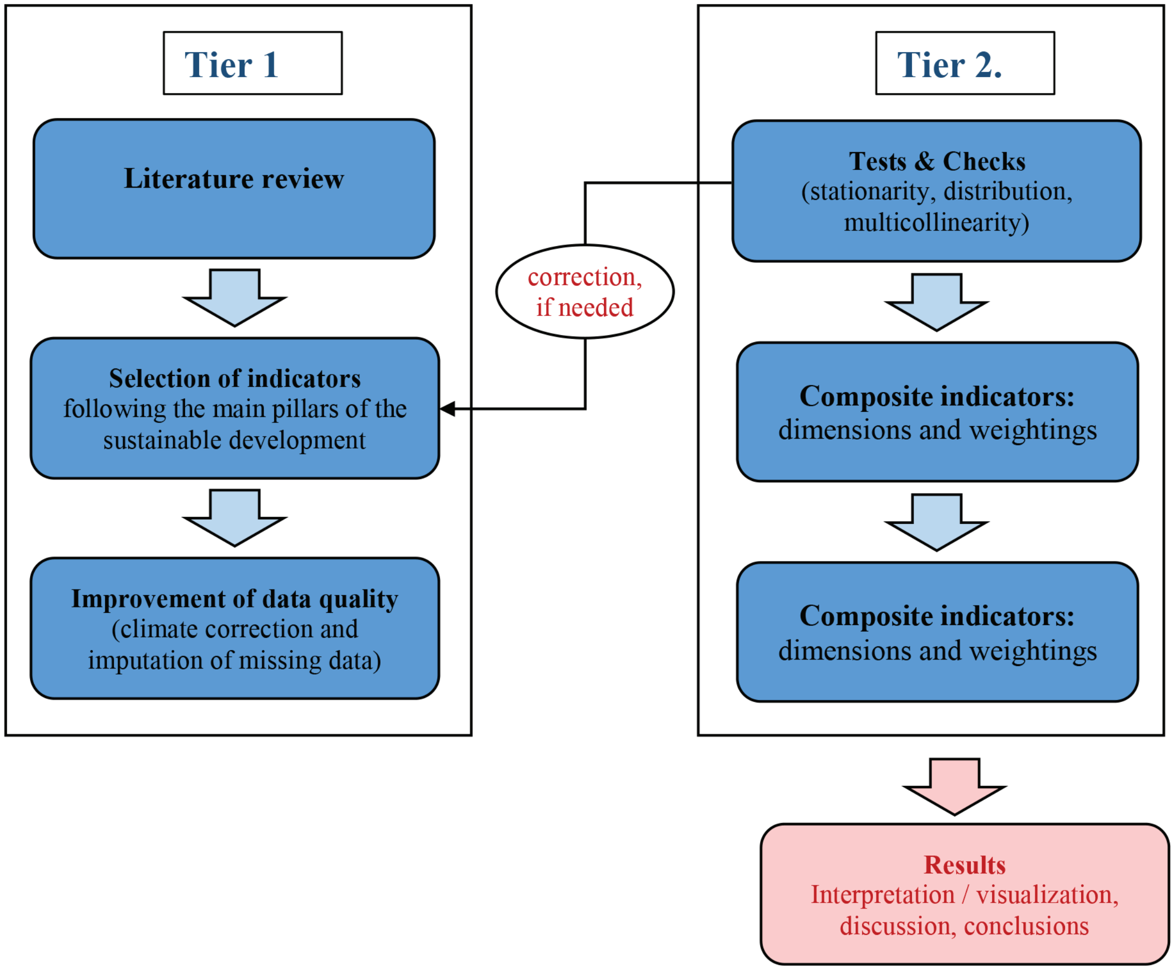

Figure 1: Research model

are followed. After the solid theoretical background, we put a strong emphasis on the selection of indicators including the imputation of missing data. The overall structure of the dataset was analyzed through correlation analysis, stationarity and normality tests. Standardization was carried out to make the variables comparable with different units. Respecting the main dimensions of the theory of sustainable development the weighting factors were determined and the composite indicator was calculated. The process of data collection and data testing with the partial results are presented in detail in our previous study [29]. Hereinafter only the main steps are summarized for ease of interpretation and we put the focus on the introduction of the composite indicator.

To avoid the problem of 'indicator rich but information poor' and keeping the balance among the main dimensions of the sustainable development the indicators were carefully selected and revised following the principle of relevance, accuracy, timeliness, accessibility, interpretability and coherence [28]. Considering these principles and the special circumstances of quantification of sustainable energy performance we set the following criteria for indicator's selection:

- Coverage and significance: the indicators should properly represent EU Member States' energy systems and clearly reflect the EU sustainable development policy, as well as the UN SDGs.
- Availability and reliability: the data should be quality controlled and available in public databases. We selected Eurostat as the primary data source.
- Representativeness: the indicators should be in nexus by the social, economic and environmental dimensions of sustainable development

- Comparability: the indicators should be appropriate for comparisons (specific values, i.e. per capita or per gross domestic products (GDP) indicators, percentage values) and transformable to the same dimensionless scale.

One of our main goals is to compare the annual results of the sustainable energy performance index and analyzing the shifts. To do that, the data has to be climate corrected, so the heating degree days are used to normalize the climate dependent data. For dealing with the problem of missing data case, deletion and single imputation are also applied. The normality, multicollinearity and stationarity of data series are tested. For this latter augmented Dickey-Fuller, the modified Dickey–Fuller t test (DF-GLS) and the Kwiatkowski–Phillips–Schmidt–Shin (KPSS) test were applied.

The data testing was repeated several times. As a result of that a solid indicator set was built which meets all our predetermined criteria. The detailed list of the indicators and data sources are shown in Table 1. The sample period is from 2007 to 2019.

SET-1 Residential electricity consumption per capita
Household's electricity consumption is one of the key end use indicators of the national energy systems [33] representing the general economic performance and the social welfare. This indicator is also a central element of the EU's energy efficiency policy (2012/27/EU Directive). Electricity consumption has controversial impacts on sustainable energy transition. On side, the higher residential electricity consumption per capita may indicate more electric appliances which leads to

Table 1: Data and their abbreviations

Abbreviation	Indicator	Source
SET-1	Residential electricity consumption per capita [MWh/capita] – climate corrected – Electricity consumption in the household sector [GWh] – Population [capita]	[30] [nrg_bal_c] [demo_pjan]
SET-2	Electricity price (Band-DC (Medium): annual consumption between 2500 and 5000 kWh) [EUR, Purchasing Power Parity (PPP) per kWh]	[30] [nrg_pc_204]
SET-3	Natural gas price (Band D2: 20 GJ < Consumption < 200 GJ) [PPP/GJ] – GDP at market prices (Current prices) [million EUR PPP] – Harmonized Index for Consumer Prices: Gas for Greece [Index 2015=100]	[30] [nrg_pc_202] [nama_10_gdp] [31], [32]
SET-4	Share of population affected by energy poverty [%] – Population unable to keep home adequately warm by poverty status [%]	[30] [sdg_07_60]
SET-5	Energy intensity in the economic sectors [GJ/million EUR] – Final consumption – industry sector [GJ] – Final consumption – transport sector [GJ] – Final consumption – other sectors – commercial and public services [GJ] – Final consumption – agriculture [GJ] – GDP (current prices) [million EUR, PPP]	[30] [nrg_bal_c] [nama_10_gdp]
SET-6	Energy import dependency by products [%] – Energy import dependency by products [%]	[30] [sdg_07_50]
SET-7	Share of fossil fuels in energy consumption [%] – Fossil fuels gross inland energy consumption [TJ] – Gross available energy [TJ]	[30] [nrg_bal_c] [nrg_cb_h]
SET-8	Share of unconditional renewables in energy consumption [%] – Hydro gross inland consumption [TJ] – Geothermal gross inland consumption [TJ] – Wind gross inland consumption [TJ] – Solar thermal gross inland consumption [TJ] – Solar photovoltaic gross inland consumption [TJ] – Tide, wave, ocean gross inland consumption [TJ] – Ambient heat (heat pumps) gross inland energy consumption [TJ] – Gross available energy [TJ]	[30] [nrg_bal_c]

Note: Eurostat statistical codes are in [] brackets more resource needs. On the other side, residential electrification (i.e. electricity heating, power supply of e-cars) may substantially contribute to minimizing air emissions.

SET-2, SET-3 Electricity and natural gas prices
The prices we pay for electricity and natural gas are basic components of a household's budget and important indicators of the affordable energy services. Energy prices also contribute to the social dimension of sustainability, even in case of less developed, emerging economies of the European Union. Energy affordability became a central part of social security policies in numerous Member States [34]. At the same time, higher energy prices may intensify the building retrofits and saving energy by using more efficient household's appliances.

SET-4 Share of population affected by energy poverty
The indicator measures the share of the population whose homes are not adequately warm during the heating season. The indicator is part of the EU Sustainable Development Goals (SDG) indicator set and part of the progress monitoring of the European Green Deal. Energy poverty is a key pillar of energy justice keeping the social rights to access affordable energy services. Eradication of energy poverty may contribute to improving household's heating energy efficiency and spread of clean energy technologies, as well. Heating is without doubt the most important area toward achieving sustainable energy transition and reducing energy poverty [35].

SET-5 Energy intensity in the economic sectors
Energy intensity is defined as the ratio of energy input per economic output (GDP). Energy input is the aggregate of final energy consumption of all major sectors of the economy (e.g. industrial sector, transport, commercial and public services, agriculture, except for households). Economic output is gross domestic product measured in purchasing power standards (in current prices). Energy intensity is also a key sustainability indicator of the third target of SDG 7 (energy efficiency improvement) [36], as a marker of overall energy productivity of the economies.

SET-6 Energy import dependency
The indicator shows the ratio of net imports and the gross available energy. The energy import dependency represents the overall energy demands of a country met by imports from other countries. Energy import dependency is part of the EU Sustainable Development Goals (SDG) indicator set and is embedded in the European Commission's Priorities under the European Green Deal. Dependence on imports of energy carriers represents economic vulnerability to market anomalies (i.e. price volatility or supply shortages).

SET-7 Share of fossil fuels in energy consumption
The ratio of aggregates of coal, oil and natural gas energy carriers and gross inland energy consumption represents the fossil dependence of the national economies. The phase out of fossil fuels is the central element of the EU's ambitious climate change policy goal [37] and fossil resources remaining high in the long term may hinder the sustainable energy transition. Between 2007 and 2019, ten countries have improved their fossil fuel dependence by more than 10 percentage points, in case of Estonia, Finland, Malta and Denmark exceeded by 15 percentage points. However, Netherlands, Belgium, Germany, France and Poland were not able to reduce considerably the share of fossil fuels (the difference is less than 5 percentage points) while Lithuania has increased the fossil dependence by 6 percentage points.

SET-8 Share of unconditional renewables in energy consumption
Fuel switching to renewable energy sources is a fundamental step towards a clean energy future [38]. Share of renewables in gross available energy is part of the EU Sustainable Development Goals (SDG) indicator set. However, there are reasonable doubts on the sustainability of solid biomass [39] and biofuels [40]. Therefore, SET-8 indicator is selected as the ratio of the sum of hydropower, tide (wave), solar, wind, geothermal and ambient heat inland consumption in gross available energy.

Within the database, the majority of the data needed for indicators SET-1, SET-5, SET-7 and SET-8 were obtained from the Energy balances table, except for auxiliary indicators needed for calculation, such as the population or GDP of the EU member states. SET-4 (share of population affected by energy poverty) and SET-6 (energy import dependency by products) are both listed as sustainable development indicators in the database under 'Goal 7 – Affordable and clean energy', therefore these didn't need to be calculated, only standardized. The two energy price indicators, SET-2 and SET-3 were derived from Eurostat tables containing bi-annual data for electricity and gas prices for household consumers.

Methods of weighting

In some cases, some changes were required in the course of the interpretation of indicators (components) and of the development of a complex indicator due to the different scaling of the indicators. If the metrics were not scaled properly (such as when lower values are associated with better positions of the countries as energy import dependency), negative weights were assigned to indicators. Here we note, that in these cases the adjusted variables are negatively correlated with the composite indicator [41].

In present research, we focus on three core dimensions of sustainable energy transition [9], namely (1) economic and development-related dimension, (2) human and social dimension and (3) natural resource-related and environmental dimension. These dimensions appropriately represent the cross-sectoral and interdisciplinary character of energy sustainability [11]. Dimensions of sustainable energy transition are affected by the SET indicators, to varying degrees. We assumed that indicator's allocation to a single dimension may disregard significant nexus among the indicators and sustainable energy performance. For example, per capita electricity consumption is a strong positive driver of the human and social dimension (i.e. welfare), a weaker positive driver of the economic dimension (i.e. improving business performance of energy industry and household equipment producers), whilst this indicator has a slight negative impact on environment and natural resources.

As a first step of weightings, an interaction matrix is established, based on expert panel evaluation to determine the driving factors of the SET indicators on the dimensions of sustainable energy transition (Table 2). The experts have cross-cutting competences in energy and sustainability disciplines and experiences in indicator-based assessments.

In the second step of weighting, we assumed that the relative importance of the three dimensions within the overall sustainable energy performance is equal.

Table 2: Quantitative assessment of SET indicator's impact on the dimensions of sustainable energy performance

SET indicators		Indicator's impact scores on the dimensions		
		Human and social	**Economic development**	**Environment and natural resources**
SET-1	Residential electricity consumption per capita	++	+	-
SET-2	Electricity prices	-	+	+
SET-3	Natural gas prices	-	+	+
SET-4	Share of population affected by energy poverty	- -	-	-
SET-5	Energy intensity in the economic sectors	~ 0	- -	-
SET-6	Energy import dependency	~ 0	- -	~ 0
SET-7	Share of fossil fuels in energy consumption	-	~ 0	- -
SET-8	Share of unconditional renewables in energy consumption	++	+	++

where:

Score value	Description
++	if the indicator positively and firmly supports the improvement of the given dimension's sustainability performance
+	if the indicator's impact is weakly positive or indirect on the given dimension's sustainability performance
~ 0	net zero effect, if the indicator has both beneficial (positive) and adverse (negative) effects, or effect is negligible in the context of the given dimension's sustainability performance
-	if the indicator has a slight or indirect counter-effect on the given dimension's sustainability performance
- -	if the intervention has a direct adverse effect and hampers the improvement of the given dimension's sustainability performance

Table 3: Weighting factors of the SET indicators

		Human and social dimension	Economic development dimension	Environment and natural resources dimension
SET-1	Per capita household's electricity consumption	+7.4%	+3.7%	-3.7%
SET-2	Household's electricity prices	-3.7%	+3.7%	+3.7%
SET-3	Household's gas prices	-3.7%	+3.7%	+3.7%
SET-4	Share of population affected by energy poverty	-7.4%	-3.7%	-3.7%
SET-5	Energy intensity in the economic sectors	0.0%	-7.4%	-3.7%
SET-6	Energy import dependency	0.0%	-7.4%	0.0%
SET-7	Share of fossil fuels	-3.7%	0.0%	-7.4%
SET-8	Share of non-biomass renewables	+7.4%	+3.7%	+7.4%
SUM		-3.7%	-3.7%	-3.7%

Assignment of equal weights to the dimensions and the quantitative assessment of SET indicator's impact on the dimensions of sustainable energy performance (Table 2) determines clearly the weighting factors of the SET indicators, as shown in Table 3.

Compiling the composite indicator

First, we carried out the standardization of the values in order to ensure the comparability of the indicators with different units of measurement and scaling. The value of each subsystem was calculated as the sum of the weighted standardized values of the selected indicators. Then the so-called sustainable energy performance index, as a final result, could be calculated as the arithmetic mean of the values of the pillars, similarly to the methodology applied in other studies [27], [42], [43]. For better understanding the sustainable energy performance index results are normalized [44, p. 190] using Min-Max method (Eq. 3).

$$z = \frac{x - x_{min}}{x_{max} - x_{min}} \tag{3}$$

where x is the original value, x_{min} is the minimum value, x_{max} is the maximum value. The normalization rescales the values into a range of [0, 1].

4. Results of the study

Table 4 presents the summary statistics for SET1-SET8. These statistics are available from the authors upon request.

One fundamental task is to determine the location and variability of the data set (skewness and kurtosis). Positive skew (in all cases except SET-7 and SET-8) refers to a fatter tail on the right side of the distribution (which means that the mean is greater than the median). SET-7 and SET-8 show negative skew. The SET-2 and SET-6 represent negative excess kurtosis, which indicates a platykurtic distribution, while the other indicators with positive results are characterized by a leptokurtic distribution.

As a next step, the normality of data is checked. This should be done before calculating a linear regression model to avoid spurious regression. All data are tested against the null hypothesis (the distribution is normal), which cannot be rejected in any case. We have to accept that the data are normally distributed.

The SET indicators show a specific European spatial distribution and definite tendencies in the 2007-2019 time period (Figure 2) as summarized below. Here we note that it is not the purpose of this study to analyze each country individually but rather we strive to identify the main driving forces and tendencies.

SET-1 Residential electricity consumption per capita. Sweden and Finland have the highest per capita values, due to the use of electricity in the heating of households. Two countries (Austria and France) have made important progress in residential electrification: recently, they use 2.1-2.4 MWh/cap electricity and it has grown by 5-7% in the last decade. High rates of renewables or nuclear energy in the energy mix and moderate electricity prices are also common in these member states. Five other countries (Lithuania, Slovakia, Latvia, Poland and Romania) are characterized by low levels (0.7-1 MWh/cap) of annual electricity consumption, however, these Member States show the highest growth rate in the EU (10-37%/decade). Other (19) Member States have aver-

Table 4: Summary statistics (EU-27, 2007-2019)

Variable	Mean	Median	Minimum	Maximum	Std. Dev.	Skewness	Ex. kurtosis
SET-1	1.666	1.535	0.492	4.786	0.866	2.032	4.251
SET-2	0.194	0.195	0.099	0.313	0.043	0.120	-0.527
SET-3	18.958	18.506	6.3312	35.242	4.4500	0.308	0.973
SET-4	11.263	6.4000	0.30000	67.400	11.552	1.973	4.954
SET-5	2599.6	2484.1	1144.8	5007.7	675.26	0.836	1.423
SET-6	56.937	59.111	-24.247	104.14	25.393	-0.338	-0.118
SET-7	71.136	72.927	26.061	96.215	15.185	-0.982	0.890
SET-8	4.3766	3.473	0.044	19.071	3.876	1.240	1.191

age annual household's electricity consumption (1-2 MWh/cap) with a "diverse history" in improving it. A few member states (Belgium, Luxembourg, Ireland, Germany) reached significant improvement in household's electricity savings by more than 10% reduction since 2007.

SET-2 Electricity prices. Five countries (Hungary, Sweden, Malta, Luxembourg and Finland) have the lowest households' electricity prices, their price level is almost 25% below the EU average. Since 2007, electricity prices have increased in the majority of the EU Member States. In the case of Latvia, Greece, Spain, Belgium and France the rise in electricity prices has increased by 50% between 2007 and 2009. On the contrary, in the case of four countries (Slovakia, Poland, Luxembourg and Hungary) the electricity prices have dropped, due to government interventions to reduce the household's energy bills.

SET-3 Natural gas prices. Southern member states (Spain, Portugal, Italy, Bulgaria) and Sweden have the top natural gas prices which may be explained by a relatively moderate level of natural gas consumption in households' heating. Natural gas prices in Estonia, Germany, Latvia, Hungary, Belgium and Luxembourg are almost half of the most expensive countries, which highlights significant regional disparities in energy justice [45].

SET-4 Share of the population affected by energy poverty. In the case of six countries (Bulgaria, Lithuania, Cyprus, Portugal, Greece and Italy) the energy poverty level is above 10%. Considering the absolute number of affected inhabitants and the climate-driven heating demands, Bulgaria, Italy and Romania have the worst numbers. Almost half of the Member States have a low (less than 5%) energy poverty ratio. During the last decade, Poland, Portugal, Romania and Bulgaria made important progress in the alleviation of energy poverty decreasing by 19-37 percentage points of the ratio. However, in the case of Lithuania, Greece and Slovakia the share of the population affected by energy poverty has increased by 3-4 percentage points.

SET-5 Energy intensity in the economic sectors. The majority of the Member States (17 countries) show an average energy intensity of 2200 ±300 GJ/mi€. However, Finland has an exceptionally high value, while Denmark, Romania, Ireland and Malta have outstandingly low values. It is noted that this indicator also represents the structure of the economy. Countries with a relatively low share of energy-intensive industries (such as chemical, consumption material, steel and non-ferrous metal industries) have better overall energy intensity figures. Surprisingly, the former socialist countries from Central and Eastern Europe show a divergent view: i.e. Romania has one of the lowest energy intensity in Europe, while Bulgaria' number is higher than Romania by 75%. All Member States have reached important progress in improving energy intensity at least by 20%. Four former socialist countries with strong industrial sectors (Czechia, Romania, Estonia, Bulgaria) has improved their energy intensity by more than 30%

SET-6 Energy import dependency. Three smaller Member States (Malta, Luxembourg, Cyprus) have almost full dependence on external energy carriers and 13 other countries may be characterized by higher than 50% import dependency. Romania, Sweden and Estonia have the lowest energy import dependency values in Europe, mainly due to the high share of nuclear and renewable energy sources. Decadal trends in Member States' import dependency are controversial. Numerous countries with high population or economic potential (such as Germany, Poland, Netherlands, Denmark) significantly increased their import dependency, whereas other countries (Estonia, Ireland, Latvia, Bulgaria and

Figure 2: Overview about the trends of the eight selected indicators

Finland) improved their dependence by 10-20 percentage points since 2007.

SET-7 Share of fossil fuels in energy consumption. Almost half of the Member States have a relatively high dependence on fossil fuels (more than 70% of fossil energy carriers in the national energy mix.) Only four countries (France, Finland, Sweden, Malta) can be characterized as having a fossil fuel ratio of less than 50%, mainly due to high share of nuclear and renewables in power production, as well as to significant penetration of electricity use in the households' heating.

SET-8 Share of unconditional renewables in energy consumption. There are significant differences among the Member States in the share of non-biomass energy resources, mainly due to the large gap in national implementation of the EU's renewable policy. In the case of Sweden, Austria, Portugal, Denmark and Italy the ratio exceeds 10% and, in parallel, it grows more than 5 percentage points per decade. However, ten Member States can be characterized by less than 3% of the non-biomass renewables ratio, whilst these countries show the lowest growth rate in the SET-8 indicator.

The composition (social, economic and environmental dimensions) of sustainable energy performance in the year 2007 and 2019 is also analyzed (Figure 3). Sweden, Denmark and Austria show the best overall sustainability performance in Europe, mainly due to high scores, in both social, economic and environmental components. These countries can be characterized by a high share of renewables, low energy intensity and a low share of the population affected by energy poverty.

Certain countries show controversial positions in the three dimensions of the sustainable energy transition. For example, Finland is a leading country in the social dimension of sustainable energy performance, while their rankings in economic and environmental components are 15th and 19th, respectively. In the case of Romania, the social component is one of the weakest in Europe caused by the high energy prices. In parallel, Romania has a good position in the rank of economic dimension (3rd) and environmental dimension (8th). Spain is in top positions in economic and environmental dimensions (4th, both); however, their performance in the social component is in the third quarter among the Member States. These controversial features also highlight the option for upgrading the national energy policies in order to improve the overall sustainability performance.

A few countries (Cyprus, Bulgaria and Lithuania) have the weakest performance in all three of the social,

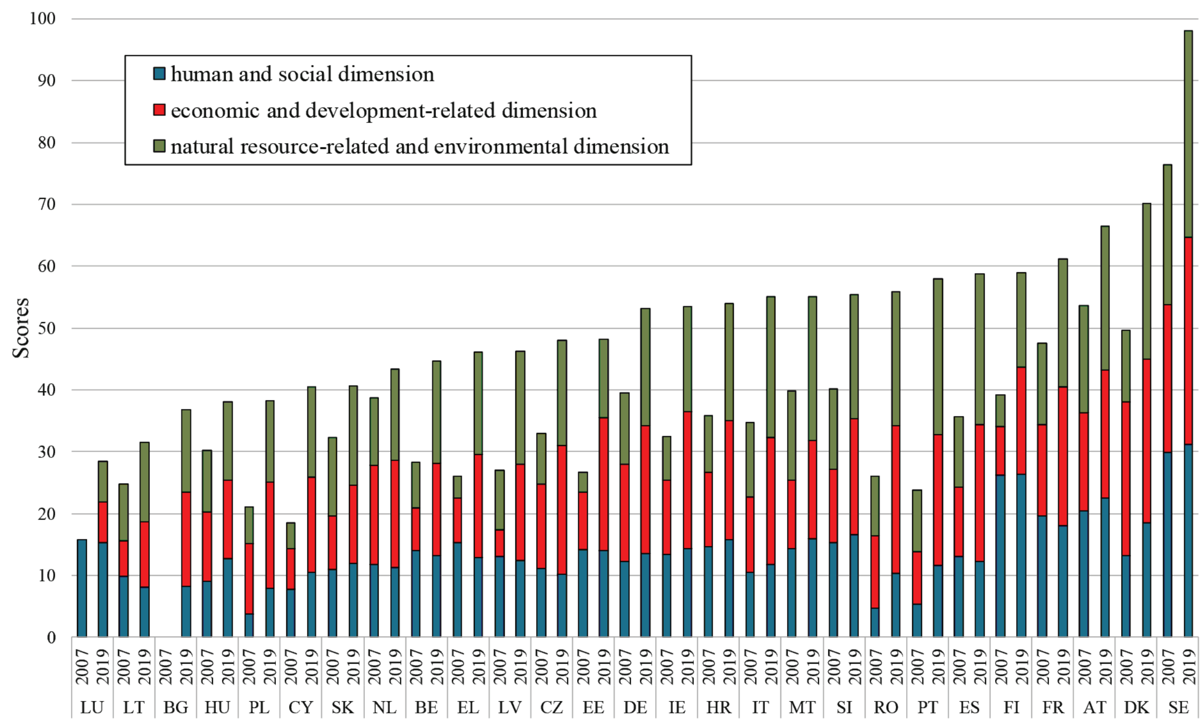

Figure 3: Components of the sustainable energy performance of EU Member States (2007 and 2019)

economic and environmental dimensions of sustainability performance. This unfavorable situation can be explained by high dependence on fossils and import energy sources, as well as relatively high energy intensity in these countries. It should also be noted that Bulgaria had the lowest starting position in 2007 and made important progress in improving their sustainability performance.

The overall sustainability performance and its temporal changes are assessed for the EU Member States (Figure 4) highlighting four main country groups and two outliers (i.e. Bulgaria and Sweden). Sweden has the highest value in the sustainability composite index, Bulgaria is catching up demonstrating the most significant improvement in the overall sustainability performance between 2007 and 2019 (its initial component's index was the lowest in Europe). Sweeden is also labelled as leader of the energy and environmental policy efficiency in [24].

Our results confirm that all Member States show progress toward sustainable energy transition. The cluster analysis reveals the hidden differences, determining the cluster of the best performers and laggards. Seven countries (see in green circle) have a leading role in the sustainable energy transition showing a relatively high (above average) sustainability performance, as well as significant improvement in it. Two countries show exceptional forwards: Portugal and Romania have reached the highest growth in this index, mainly due to their coherent energy policies committed to renewables, energy efficiency improvement and social justice.

A few countries (Cyprus, Estonia, Greece, Latvia, and Croatia, see in red circle) demonstrate slightly weak (just below the average) sustainability performance and low positive values in exchange for it. These emerging countries are on the road to the sustainable energy transition; however, the national energy policies are still not enough to boost the sustainability transition.

Four other countries (Malta, Slovenia, France and Austria, see in blue circle) have a relatively good position in overall sustainability performance (their composite indexes are above the EU average) but no robust progress have been noticed since 2007. It also means a signal to energy policymakers to strengthen mainstreaming sustainability.

A big array of Member States (Poland, Belgium, Czechia, Germany, Luxemburg, Slovakia, Hungary, Lithuania and the Netherlands) are increasingly lagging

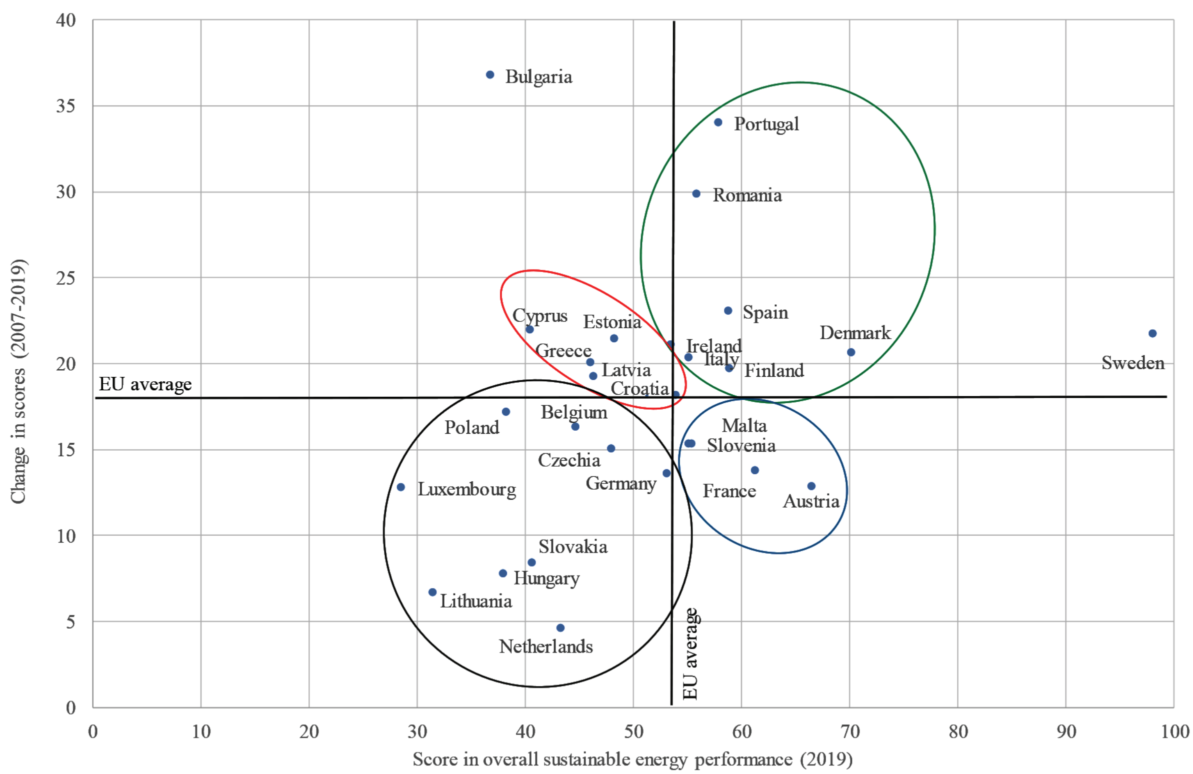

Figure 4: The Member States' overall sustainable performance vs. changes in 2007-2019

behind as regards sustainable energy transition. These countries have relatively low (below the average) sustainable performance indexes and similarly weak improvement between 2007 and 2019. The high share of these countries' population in the EU total (40.1% in 2019 according to the Eurostat 2021) highlights considerable concerns in the overall implementation of the EU's Sustainable Strategy. The countries in the worst position (Slovakia, Hungary, Lithuania and the Netherlands) are all smaller Member States and can be characterized by highest energy dependence, which underlines the reinforcement of energy saving and renewable policies, too.

5. Conclusion

One of our research questions focuses on the spatial structure of sustainable energy performance in Europe (Figure 5). Considering the countries' positions in ranking of their sustainable energy performance, we identified significant changes between 2007 and 2019. Sweden, Austria, Denmark and France were able to keep their leading positions during the whole period. Portugal, Romania and Spain have improved their relative position by 16, 13 and 5 in the rankings, respectively (and also their scores by 34.0, 29.9 and 23.1, respectively). However, Germany, the Netherlands, Slovakia and Hungary have seen a worsening of their relative positions to 7-11 (in the rankings). Substantive differences in the improvement of sustainable energy performance may highlight the essential role of success factors in mainstreaming sustainable development in national energy policies. Considering that not one of the Member States has broadened the performance gap between 2007 and 2019, the European Union is taking a definite step towards a sustainable energy future.

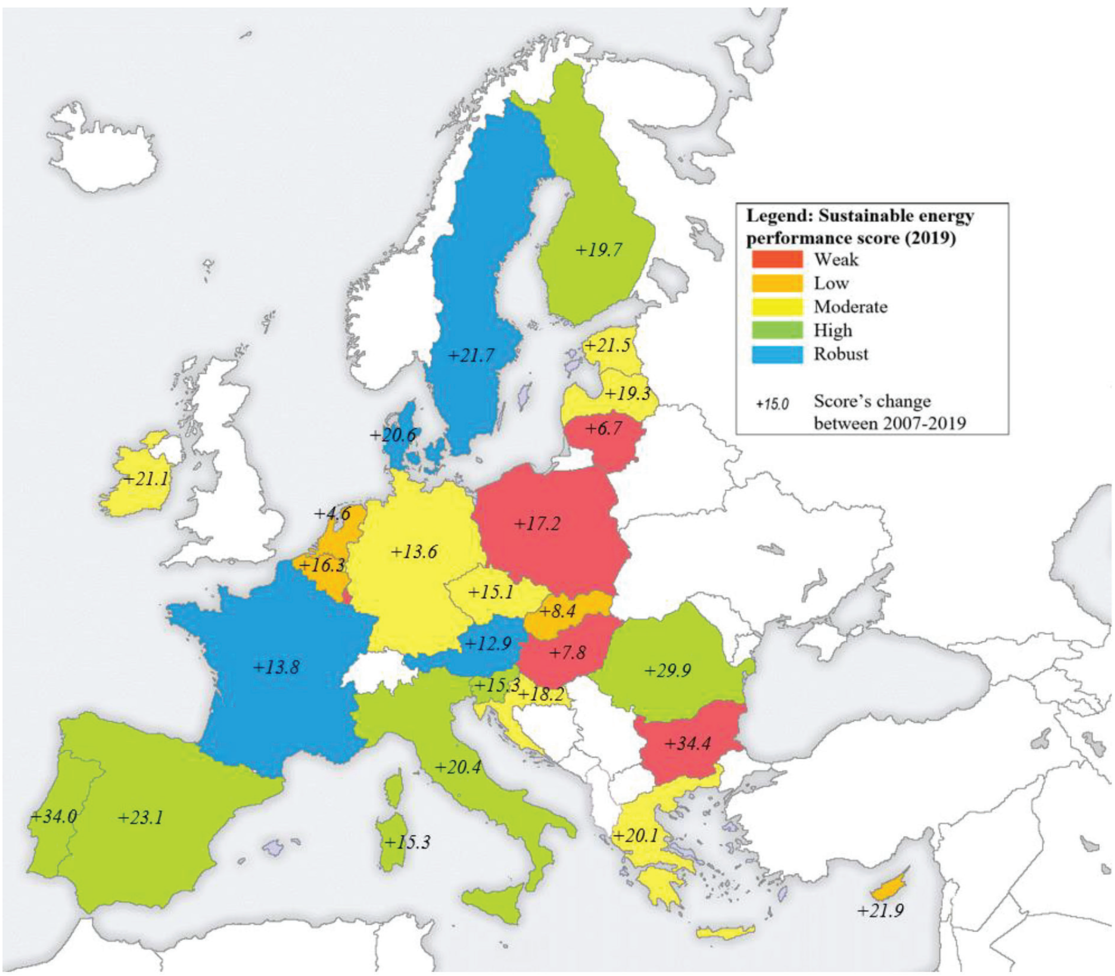

Figure 5: Geographical distribution of sustainable energy performance score (2019) and its change between 2007-2019

The European Union faces many challenges. Some of them are not new at all, many papers and official EU documents have pointed them out. However, the COVID-19 has not only brought to the surface new ones but amplified and exacerbated the existing problems, too. If we look at the key indicators of the SDG7 and SDG13 the long-term trends (15 years of 2004-2019) are promising regarding import dependency, energy efficiency, decarbonization, but in the short-term (5 years of 2014-2019) the development slowed down and significant movement away from the SDG goals can be observed [46].

These problems are not only reflected in the trend of indicators, but the consumers feel them directly. Globally the disruptions of the supply chains, soaring energy prices (i.e. electricity, natural gas, crude oil and coal), climate change and extreme weather make sustainable energy transition more urgent. The renewable electricity production showed significant resilience during the different waves of COVID-19. The energy price growth puts a pressure on the inflation rate in all EU Member States and it is hurting consumers and threatening the economic recovery from the global pandemic. It deepens energy poverty, and the number of vulnerable households and inequality increase, too.

Regarding the soaring energy prices, a wide range of policy instruments are available. However, there are significant differences among them regarding the time horizon. In the short term the national governments may provide income support to households in need and state aid for companies. Temporary tax reductions can be implemented, too. Medium term measures have to focus on supporting investments in renewable energy and energy efficiency improvements. It may lead to a decarbonized and resilient energy system. Establishing and strengthening energy communities and the decentralization of the energy policy may have a positive impact on the role of consumers in the energy market. In the long term the only solution is to accelerate the sustainable energy transition and the implementation of the European Green Deal making the European Union more resilient against future shocks.

However, it is important to provide feedback for the decision-makers about the stage of sustainable energy transition. One of the biggest advantages of the benchmark is to get an independent perspective about how the examined countries perform compared with each other. It enables us to see the source of the potential gaps and highlight the core areas. The regular monitoring may contribute to managing changes and achieving goals. To do that in this paper an indicator set was developed based on the three main dimensions of the sustainable energy transition (i.e. economic and development-related dimension, human and social dimension, and natural resource-related and environmental dimension). Our main goal was to create a benchmark and measure the performance of the EU Member States regarding the sustainable energy transition.

Our research results confirmed that there are significant differences among the examined 27 countries. However, these differences do not follow the well-known East-West geographical division. Four main country groups can be identified and the resulting clusters are highly heterogeneous. Bulgaria and Sweden are outliers, the former one shows strong convergence, the latter has the highest score and the best performance. All EU Member States improved their sustainable energy performance between 2007-2019.

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Annex

Table 5: List of abbreviations

CCPI	Climate Change Performance Index
DF-GLS	Modified Dickey–Fuller t test
DPSEEA	Driving–Force–Pressure–State–Exposure–Effect–Action
EDI	Energy Development Index
EISD	Energy Indicators for Sustainable Development
EPI	Environmental Performance Index
ETI	Energy Transitions Index
GDP	Gross Domestic Products
HDI	Human Development Index
KPSS	Kwiatkowski–Phillips–Schmidt–Shin test
LPI	Living Planet Index
PPP	Purchasing Power Parity
RECAI	Renewable Energy Country Attractiveness Index
SDGs	Sustainable Development Goals
WETI	World Energy Trilemma Index
UN	United Nations
WWF	World Wide Fund for Nature

Source: own compilation