

Article

Territorial Variation of Energy Poverty and Good Health and Well-Being in European Union Countries—A Spatial Analysis

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Abstract

Energy poverty (EP) is a complex socio-economic phenomenon of growing importance in European Union (EU) countries. The level of EP, along with the health of the population and the level of perceived well-being (H&W), is a fundamental element of socioeconomic development and a determinant of the quality of life of individuals and entire societies. In this study, two main research objectives were set: a comparison of country classification results obtained using a classical method (QGIS) and a method based on artificial intelligence (SOM) and assessment of the complementarity of both approaches in studying the diversity of EU countries in terms of EP and H&W. The classification results made it possible to demonstrate changes in the studied phenomena over time. The analysis was carried out using data from the Eurostat database from 2019 and 2023. The results presented in this study indicate that countries with the highest EP levels are located in two distinct regions: Eastern and Southern Europe. Countries with the lowest EP levels are located in Northern and Central Europe. In the case of H&W, higher levels were observed in northern and western European countries, while lower levels were observed in eastern and central European countries. The use of an AI-based method in socio-economic research and the comparison of the results with those obtained using the traditional method provides a more complete picture of the diversity of EU countries in terms of EP and H&W, broadening knowledge in empirical and methodological terms.

Keywords: energy poverty; good health and well-being; classification; SOM; QGIS

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1. Introduction

In recent years, issues of energy poverty (EP), inequalities in access to healthcare, and disparities in well-being (H&W) have gained prominence in community socioeconomic policies. These phenomena, the result of complex interactions between economic, environmental and institutional factors, reveal the structural weaknesses of individual economies. Contemporary challenges, such as the energy crisis, climate change, growing social inequality, and the effects of the COVID-19 pandemic and Russia's invasion of Ukraine have further highlighted and deepened existing disparities among EU member states.

In our study, two main research objectives were set:

1. Comparison of EU country classification results in terms of EP and H&W obtained using the classical method (QGIS) and a method based on artificial intelligence (SOM).

2. Assessment of the complementarity of both approaches in studying the diversity of EU countries in terms of EP and H&W.

In preparing the study, especially at the stage of reviewing the subject literature and data characterizing the studied phenomena, the authors formulated the following research questions:

1. Are there any differences between the results of the classification of EU countries in terms of EP and H&W obtained using the classical method (QGIS) and the AI-based method (SOM)?
2. Can shifts between EU country groups be observed in terms of EP and H&W between 2019 and 2023?
3. Is the improvement in EP reflected in higher H&W levels of EU residents?
4. Does the use of the AI (SOM) method allow for the identification of new patterns in the classification of EU countries compared to the results obtained using the classical approach (QGIS) in terms of EP and H&W?
5. Does the complementarity of the classical method (QGIS) and AI (SOM) allow for a more complete understanding of EP and H&W patterns in EU countries?

The study was conducted using data from 2019 and 2023, which were obtained from the Eurostat database (including the EU-SILC survey). The motivation for undertaking this study was the need to identify and understand the scale and nature of EP and H&W disparities among EU member states. Many researchers assess EP and H&W but rarely combine the two dimensions in a single comparative analysis. This paper presents results describing EP and H&W in unidimensional and multidimensional terms, which allowed a thorough evaluation of the categories in the EU space and distinguishing classes of countries similar in terms of the level of the studied phenomena. The study also takes into account the time factor, presenting phenomena at two points in time. This study adds new value to the literature on the subject, filling the following gaps: it contains a current comparative analysis of EU countries in 2019–2023 in terms of EP and H&W, introduces artificial intelligence (SOM) into environmental analysis, which has rarely been used in this field to date, and compares the results obtained using SOM with classic QGIS tools. Thanks to a complementary approach, it has been shown that combining both methods provides a more complete picture of the diversity of EU countries, contributing both empirically and methodologically.

The structure of the article is organized as follows: the introduction outlines the authors' motivation for conducting the research, along with the study's aims, research questions, data sources, and methodological approach. The second section provides a review of the literature, focusing on the issue of EP as one of several aspects of poverty, discussed within the context of H&W. The third section details the data utilized and the methods applied in the analysis. The fourth section presents a thorough account of the research findings. Finally, the article ends with a discussion and concluding remarks.

2. Energy Poverty as a Dimension of Poverty in the Context of Good Health and Well-Being—A Literature Review

“Poverty is a disgrace to democracy” [1]. It is one of the most important socio-economic problems and challenges of the modern world [2,3]. It causes misery in the lives of many people, restricts their basic rights, reduces their chances of reaching their full potential, creates high social costs, and hinders sustainable development [4].

The United Nations General Assembly has declared the eradication of poverty an ethical, political, social, and economic imperative for humanity [5]. Combating poverty and social marginalization is now one of the EU's social priorities. The 2030 Agenda recognizes the eradication of poverty in all its forms as a top priority and a prerequisite for

sustainable development [6,7], listing this goal as the first among the 17 Sustainable Development Goals (SDGs). Action to eradicate poverty is the most promising strategy that can ultimately ignite a positive cycle of progress toward the SDGs [8]. Given the synergy of these goals, achieving one brings progress toward the other [9]. Indeed, poverty reduction is linked to progress on SDG3 (good health and well-being), SDG4 (quality education), SDG5 (gender equality), SDG6 (clean water and sanitation), SDG10 (reducing inequality), SDG12 (responsible consumption and production), and SDG13 (climate action) [10]. This is forcing EU governments to intensify their efforts to combat this phenomenon more effectively.

Despite many years of research on poverty, there is still no uniform definition of it [11], which demonstrates the multifaceted and dynamic nature of this phenomenon. Poverty is most often understood as the lack of adequate monetary resources necessary to meet a certain level of socially acceptable essential needs, combined with limited access to goods and services [12]. However, it cannot be associated only with insufficient income or low consumption. It should be considered in a broader context, as it is also associated with inadequate healthcare, nutrition, literacy, access to basic media [13,14], impaired social relationships, insecurity, low self-esteem, and powerlessness [15]. It is a phenomenon that encompasses many different aspects that can affect the quality of life of individuals and communities.

Among these aspects is EP, which is considered a critical socioeconomic challenge [16] that hinders the social inclusion of EU citizens [17]. This problem is increasingly considered one of the most pressing issues that will likely affect societies soon [18]. This is because energy is a basic resource necessary for daily human functioning, and access to it is becoming crucial not only for individuals and households but also for the development of society and the economy [19].

The EU is committed to fighting EP and protecting vulnerable consumers. This is evident in successive EU initiatives and directives whose goals have evolved over time [17,20–22]. Many documents have been produced diagnosing the existence of the problem and giving it a key role (Appendix A, Table A1), but the problem is far from solved. Indeed, the EU has encountered serious challenges in its implementation, including soaring energy prices and increased volatility in global energy markets, influenced primarily by Russia's invasion of Ukraine [23]. The sudden rise in energy prices has triggered a series of serious global consequences, leading to a general increase in prices worldwide, heightened geopolitical tensions, a slowdown in economic growth, rising inflation, and increased debt [24,25]. Such conditions are not conducive to effectively combating EP. Eurostat reports indicate that 9.3% of the EU population faced challenges in heating their homes adequately in 2022. Furthermore, already in 2020, around 15% lived in homes with problems such as leaks, damp, or rot [26]. In addition, 26.3% of the population had difficulty paying utility bills [27].

In its broadest sense, EP implies a household's inability to achieve a socially and materially necessary level of energy services [22,28,29]. Thus, it is a situation in which a household is unable to provide a restful level of service for heating, cooling, lighting, going, and appliance power [30–32]. It is widely accepted that EP occurs wherever there is a lack of affordable, reliable, high-quality, safe, environmentally friendly, and supportive energy services [33]. Confirmation of this understanding by the EP can also be found in the Directive of the European Parliament and of the Council on energy efficiency of 13 September 2023 (Art. 2, p. 52) [34]. It follows from the content of this directive that the root causes of EP are limited income, high energy costs, or low energy efficiency of buildings. Thus, it is not only a matter of limited physical access to energy services, but also of excessive energy expenditures due to rising energy costs [35,36], inability to maintain adequate thermal conditions in dwellings, which is related to the effects of climate variability

[16,37–39], and low energy efficiency of homes [1], or technical limitations [40,41], which can be the result of aging infrastructure [42,43]. Among other causes of EP, attention is paid to geography, household characteristics, gender, health status of household members, and specific energy and transportation needs [44]. It is also worth noting the causes related to attitudes toward efficient energy use, which occur when improper use of appliances leads to significant energy losses and, consequently, to increased energy expenditures beyond what the household can afford. The group of these causes has cognitive, behavioral, and emotional dimensions. In this area, the main moderator of behavior is the knowledge of efficient use of heating and electrical appliances, or the knowledge of investing in higher energy-efficiency appliances (energy-saving light bulbs, thermal insulation of buildings, etc.) [45].

EP, due to the strategic importance of energy, affects many zones of functioning of societies, economies and the environment (Figure 1).

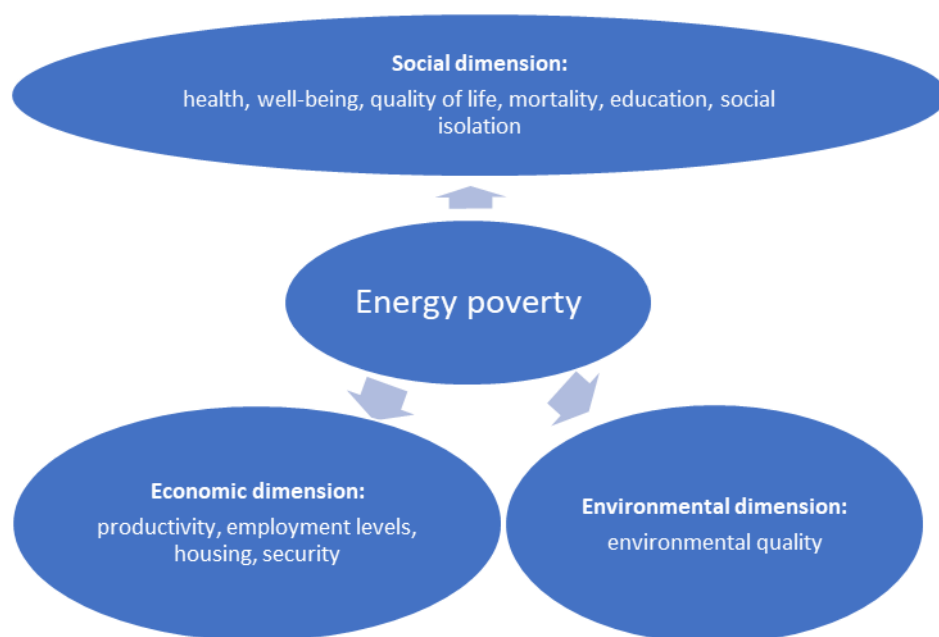


Figure 1. EP impact zones.

Households in poverty-stricken areas typically practice “under-consumption” of energy, resulting in inadequate heating measures in winter or cooling choices in summer [40]. This is directly linked to health risks, including respiratory diseases, cardiovascular problems, and higher mortality rates in severe weather [46–48]. To heat their homes or prepare meals, such households are often forced to use inadequate energy sources, such as poor-quality fuel or garbage burning. This contributes to increased air pollution. Emissions of harmful substances (carbon dioxide, dust or toxic compounds) not only negatively affect the quality of life of those directly involved but also the local community. Increased air pollution can also lead to increased health problems [1]. Due to inadequate building quality and low energy efficiency of homes, EP is closely linked to housing poverty [17]. At the same time, residents spend too much time searching for fuel and reduce time for education and recreational activities, which will lead to a decline in social status and damage to family welfare [49]. In addition, EP has a significant impact on economic growth. It determines productivity [50] and employment opportunities [51]. Access to energy in poverty-stricken areas can significantly reduce the cost of transporting it and significantly reduce energy consumption for the operation of industrial equipment and the production of products. Improving energy infrastructure can enhance the development

of distinctive industries in poverty-stricken areas, strengthen the engine of independent regional development and bring the advantages of these areas into play [49]. EP elimination is key to increasing the resilience of households, but also to achieving truly comprehensive energy security considered through the lens of accessibility, affordability, acceptability, and social equity [52]. This is particularly important considering the ongoing Russian-Ukrainian war, one of the many effects of which is rising energy prices [53,54] affecting people's livelihoods, already weakened by the serious socio-economic consequences of the COVID-19 pandemic [55]. These are important for the functioning of households in terms of energy costs [56–58], energy insecurity [59,60], poverty [35,61], and human needs and well-being [62]. There is no doubt, therefore, that measures to reduce EP should be taken at every level of decision-making, as they contribute to activating economic growth, improving health outcomes, and enhancing overall quality of life, while reducing the negative impact on the environment [63].

Quality of life, as an overarching goal of sustainable development strategies, is the sum of the do-goodness (standard of living) and well-being (experiences, feelings, well-being) of individuals. The standard of living is a term associated with the objective, material sphere, while the quality of life still includes the sphere of people's experiences and judgments [64], i.e., the subjective sphere.

EP, while influencing the presented spheres of functioning of individuals and communities, at the same time influences H&W, which are among the components of the broadly defined quality of life. The link between EP and H&W is very strong and multifaceted [65,66]. Through several mechanisms, such as exposure to inadequate indoor temperatures or deteriorating housing conditions, it increases mortality and worsens physical health by causing respiratory (pneumonia, asthma, cold, allergy) and cardiovascular (heart attacks and strokes) diseases, as well as rheumatic and dermatological problems [67–69]. People in the EP crisis are also more likely to suffer from anxiety disorders (constant worry about making life comfortable, obtaining money for energy payments) and depression (lack of thermal comfort often discourages meeting people at home, which increases loneliness and feelings of exclusion, lack of energy access can prevent use of the Internet, media and communication tools). The EP phenomenon is also associated with difficulties in performing everyday tasks, including work and study, as well as stigmatization by those around them, which worsens the health and financial situation of those affected by EP [70–75]. As a result, EP, like poverty in general, can create a vicious cycle [76].

Given the importance of the process of combating EP to the development of societies, economies and the environment, accurate measurement of the phenomenon is needed to inform policies designed to effectively address the problem [17]. Measuring EP and its contexts is not just a scientific issue, but a political and administrative decision with important social and economic consequences [70] to help vulnerable populations cope with EP that adversely affects H&W [77].

3. Materials and Methods

3.1. Selection of Indicators

The study assessed EP and selected aspects of H&W in 27 EU countries in 2019 and 2023. Two criteria were used to select the study period. The year 2019 was the last year before the outbreak of the COVID-19 pandemic, and the year 2023 reflects the current situation after the most severe effects of the pandemic have subsided. In addition, the information for 2023 is the most recent data available in the Eurostat database, which increases the practical value of the study's conclusions. The adopted period allows for comparison and identification of changes in the level of EP and H&W in EU countries.

When selecting indicators related to energy poverty, we relied on information obtained from a review of the literature [16,17,19,78–80] and relevant documents [34]. The

study primarily considered indicators available in the Eurostat database and used by EU Member States to estimate EP in their energy and climate plans. The selected indicators provide direct or indirect information on various aspects of this phenomenon.

The indicators included in this study refer to the economic dimension (electricity prices, electricity expenditure, arrears in payments, at-risk-of-poverty rate, or housing cost overburden), infrastructure (population unable to keep their homes adequately warm, total population considering their dwelling as too dark, total population living in a dwelling with a leaking roof, damp walls, floors, or foundation, or rot in window frames or floor), or social (severe housing deprivation rate and at-risk-of-poverty rate).

Furthermore, the indicators used to assess EP are either objective or subjective in nature. Objective indicators include those that provide information on, for example, arrears in utility bills, energy expenditure, prices, heating degree days, and cooling degree days. Subjective indicators, on the other hand, mainly refer to self-assessment of housing conditions.

Indicators related to H&W were also considered to achieve the objective of this study. As indicated in the literature review, well-being refers to subjective well-being, i.e., how people assess their lives, how they feel, and whether they experience satisfaction and happiness. Based on this assessment, but also on the availability of data for 2019 and 2023, information was obtained on overall life satisfaction, self-rated health, and happiness. In the manuscript, in addition to information on well-being, data on subjective health assessment is also provided. This approach is also present in the SDGs as SDG3—Good health and well-being.

Tables 1 and 2 present the indicators characterizing the studied phenomena: EP and H&W.

Table 1. Indicators used to measure EP in EU countries.

Indicator		
No.	Objective Approach	Unit
1	Arrears on utility bills	%
2	Severe housing deprivation rate	%
3	Expenditure on electricity, gas, and other fuels as a proportion of the total household expenditure	%
4	Arrears on mortgage or rent payments	%
5	Overcrowding rate by poverty status	%
6	Average annual electricity prices for household consumers (with consumption from 2500 kWh to 4999 kWh)	%
7	At-risk-of-poverty rate	%
8	Heating degree days	Number
9	Cooling degree days	Number
10	Housing cost overburden rate	%
11	Final energy consumption in households per capita	Kilogram of oil equivalent
Subjective Approach		
12	Population unable to keep home adequately warm	%
13	Population living in dwellings with leaks, damp, or rot	%
14	Households making ends meet with great difficulty	%
15	Total population considering their dwelling as too dark	%
16	Total population living in a dwelling with a leaking roof, damp walls, floors or foundation, or rot in window frames or floor	%

Table 2. Indicators used to measure H&W in EU countries.

No.	Indicator	Unit
1	Overall life satisfaction	%
2	Self-perceived health	%
3	Self-reported unmet need for medical examination and care	%
4	Share of people with good or very good perceived health	%
5	Healthy life years	Year
6	Standardized preventable and treatable mortality	Rate
7	Happy Index	0–10

In the case of data collection for H&W, there were major difficulties in its accessibility. This is especially true for satisfaction with various aspects of life, e.g., work.

3.2. Spatial Analysis Tools

Spatial analyses play an increasingly important role in socio-economic and environmental research, providing tools for the description and interpretation of complex systems. The Geographic Information System (GIS) enables the integration and visualization of data, while artificial intelligence (AI) methods support the identification of patterns in complex datasets. The combination of both approaches, including the use of Self-Organizing Maps (SOM), makes it possible to simultaneously represent spatial structures and classify objects according to their characteristics, which is applicable in research on energy transition, climate change, and public health, as well as in supporting EU energy and climate policy.

In the next stage of the study, a classical approach was applied, based on a synthetic measure obtained using the TOPSIS method, which belongs to the group of multi-criteria decision-making methods (MCDM). This method was introduced by C.L. Hwang and K. Yoon [81]. The TOPSIS method is frequently employed to rank various objects according to different criteria and enables a synthetic assessment of a phenomenon described by multiple features. The procedure involves determining the Euclidean distances of each evaluated object from both the development standard and the anti-standard, which distinguishes it from other conventional methods. The procedure for determining the synthetic measure is presented in numerous studies [82–86]. The measure obtained using the TOPSIS method provides a ranking of decision alternatives by simultaneously minimizing the distance to the Positive Ideal Solution (PIS) and maximizing the distance to the Negative Ideal Solution (NIS), which also explains its wide application due to its simplicity.

Based on the values of the synthetic measures, the classification of units was carried out in the QGIS environment using the Natural Breaks (Jenks) method. This approach made it possible to obtain a spatial representation of the differentiation of the analyzed objects. In parallel, AI methods were applied, using SOM to group units according to the similarity of their characteristics and to identify hidden patterns in multidimensional data. The comparison of results obtained using the classical approach and AI methods enabled both spatial visualization and an in-depth analysis of the phenomena under study.

3.2.1. Spatial Classification in the QGIS Environment

Spatial classification consists of assigning territorial units to categories based on their quantitative characteristics, which enables the identification of patterns and the grouping of areas with similar properties. In this study, the classification was carried out in the QGIS environment, which, as an open and flexible tool, allows for the integration of spatial and tabular data and offers various methods of numerical classification [87–89]. Among the available methods, the Natural Breaks (Jenks) method proved particularly useful, as it

corresponds to the specificity of synthetic data and the limited sample size (27 EU countries). Its objective is to minimize the variance within classes and maximize the differences between them, while the effectiveness of the classification is measured by the Goodness of Variance Fit (GVF) coefficient, calculated according to the formula:

$$GVF = \frac{s_t^2 - s_w^2}{s_t^2}, \quad (1)$$

where GVF —the measure of classification fit, s_t^2 —the total variance of the dataset, s_w^2 —the sum of within-class variances.

The GVF value indicates how well the division into classes reflects the data structure—the closer it is to 1, the better the fit [89–92].

The classification process in QGIS involves the integration of spatial data with numerical attributes, the selection of the method and number of classes, cartographic styling, and the presentation of results on thematic maps. The logic of the entire process is illustrated in Figure 2.

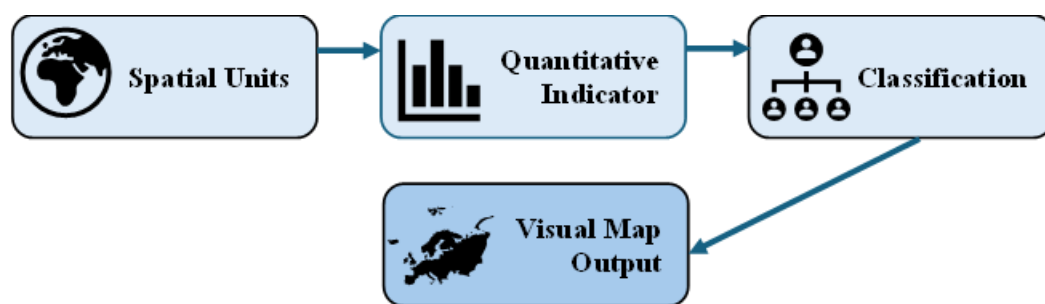


Figure 2. Conceptual model of spatial classification in QGIS.

The choice of the number of classes has a significant impact on the readability of maps. Too few classes may lead to excessive generalization, while too many may result in overloaded cartographic content [93]. The selection of the classification method depends on the purpose of the analysis and the characteristics of the data distribution. In practice, it is recommended to compare different techniques to assess the stability of the obtained visualizations [88,90]. Classification in QGIS is widely applied in geography, urban planning, and socio-economic analyses, and serves as a starting point for further quantitative research, including spatial autocorrelation analysis, the identification of statistically significant areas, and regression modeling [94,95]. De Smith, Goodchild, and Longley [96] emphasize its importance for revealing spatial structures, while Fischer and Getis [97] highlight its conceptual nature. Classification supports the detection of clusters, outliers, and types of regions, constitutes the basis of thematic maps, and combines statistical analysis with spatial visualization [98–100].

In recent years, GIS tools, including QGIS, have been widely used in socio-energy research, covering analyses of energy vulnerability and poverty, assessment of building efficiency, adaptation to climate change, and community initiatives [101–115]. They have also been applied in studies of settlement structures and land use [116,117], as well as in research on health and social well-being, where both quantitative and qualitative data were integrated [118–123]. The literature review indicates that QGIS constitutes a flexible tool enabling the integration of diverse information sources and supporting processes of visualization, classification, and interpretation of complex spatial phenomena.

3.2.2. Spatial Classification with Self-Organizing Maps

The SOM method, also known as Kohonen networks, belongs to the group of unsupervised machine learning algorithms and is primarily used for dimensionality reduction

and visualization of complex data. Its essential advantage lies in the ability to represent relationships between the analyzed units in such a way that those with similar characteristics are positioned close to each other on a two-dimensional neuron grid [124,125]. During the learning process, each data vector is assigned to the neuron with the best fit, referred to as the BMU (Best Matching Unit). This enables the formation of groups of elements with similar profiles and the identification of hidden relationships that are difficult to capture using traditional classification methods [126]. In studies concerning EU countries, SOM has been applied to analyze similarities and differences in the field of energy and the environment, which allows for the identification of typologies of states and the formulation of conclusions for climate and energy policy [127,128].

Figure 3 illustrates the logic of the SOM method, showing the subsequent stages of data processing—from preparation to the generation of the output map and its interpretation. The diagram depicts the course of the algorithm and highlights the importance of visualization and the practical applications of the classification results. The dashed line separates the part of the scheme related to the learning process, which is iterative in nature and constitutes a fundamental element in the formation of the map structure.

The literature review indicates that SOM has found wide application in energy, social, and environmental research. In the area of energy transition and security in the EU, this method has been used to classify countries according to the share of RES (renewable energy sources), emissions, or energy consumption, revealing clear regional differences [129–131]. In social analyses, SOM has supported the identification of patterns of household energy consumption and the examination of relationships between energy efficiency and socio-economic factors, allowing for the distinction of groups with varying levels of energy poverty risk [132–134]. In environmental research, the method has enabled the classification of countries according to emissions, energy mix structure, and decarbonization potential, identifying both leaders and states requiring more intensive action [135–137]. SOM has also been applied in energy policy analyses to classify countries according to emission structures and the degree of sustainable energy use, forming the basis for recommendations for EU policy [138–140]. Furthermore, SOM has been employed in assessing PV (photovoltaics) potential, managing smart buildings, and developing local RES (renewable energy sources) strategies [141–143]. The most recent studies have extended its application to areas related to health and well-being, including analyses of the impact of the COVID-19 pandemic on H&W indicators in OECD countries [144] and typologies of pro-environmental attitudes of citizens in Turkey [145]. The results of the cited studies confirm the flexibility of SOM in the analysis of multidimensional data and its usefulness in diagnosing regional differentiation, as well as in supporting energy, environmental, and social policy.

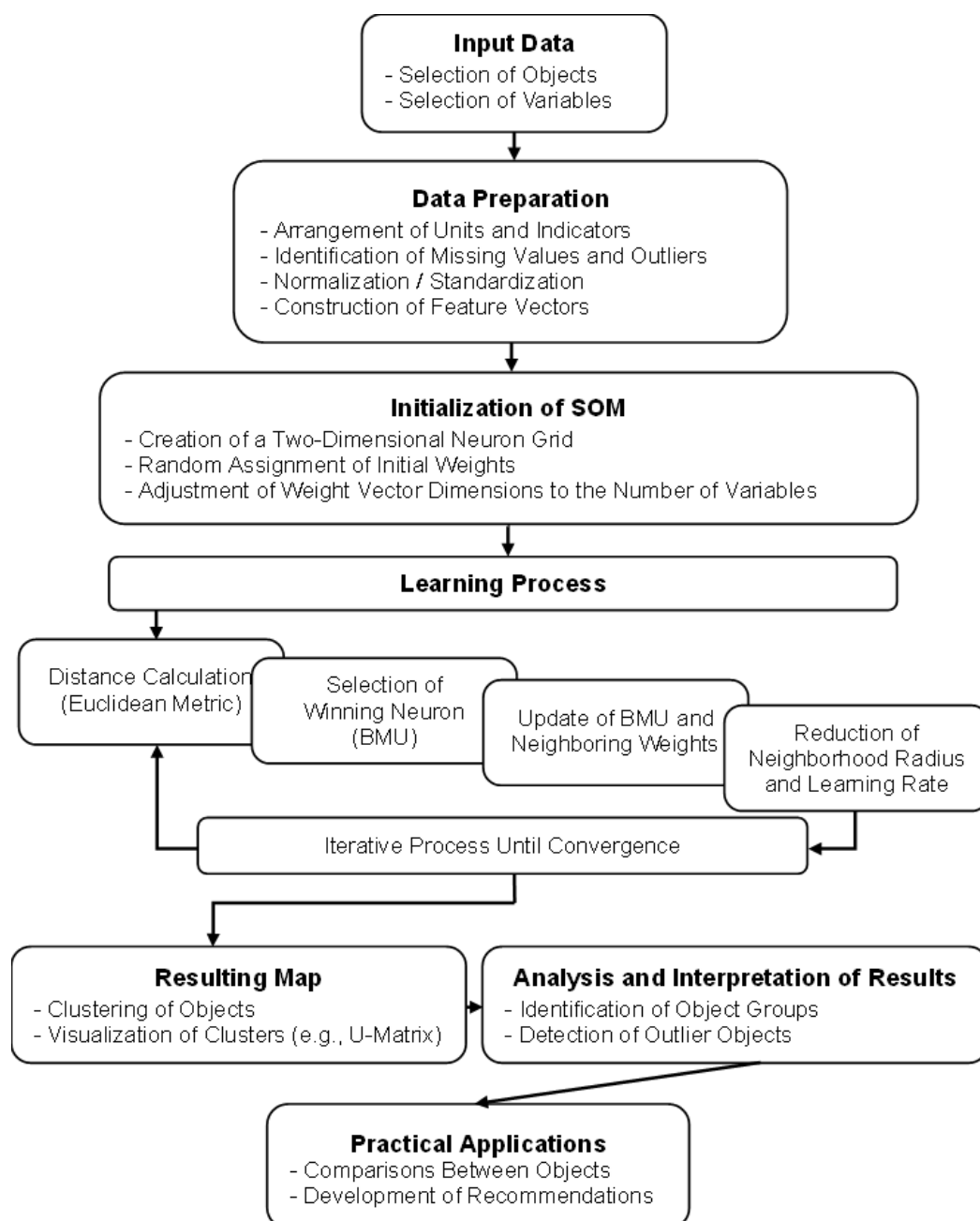


Figure 3. Schematic representation of the SOM method in object classification.

4. Results

The results obtained in our study refer to the following aspects:

1. Indicators adopted to assess the analyzed phenomena, i.e., EP and H&W.
2. Classification of EU countries using the classical method (QGIS) and a method based on artificial intelligence (SOM).

Statistical analyses were performed using Statistica 13.3 (including classification using SOM), while spatial classification was performed in QGIS (version 3.40.8) [88].

4.1. Statistical Analysis of EP and H&W Indicators

After conducting a two-stage process of selecting indicators, considering both the degree of variability and their mutual correlation, the final sets of indicators characterizing the phenomena under study, i.e., EP and H&W, were established. Table 3 presents the

indicators adopted for further study regarding EP and the values of basic descriptive parameters.

Table 3. Descriptive statistics for the indicators of EP in the EU.

EP			
Indicator	2019	2023	
Descriptive Parameter			
Population unable to keep home adequately warm by poverty status			
Mean	8.20	9.47	
Coefficient of Variation	94.03	63.15	
Min–Max	1.80–30.10	2.10–20.80	
Expenditure on electricity, gas, and other fuels as a proportion of the total household expenditure			
Mean	21.60	22.32	
Coefficient of Variation	19.87	19.11	
Min–Max	12.30–29.20	13.90–30.20	
Average annual electricity prices for household consumers (with consumption from 2500 kWh to 4999 kWh)			
Mean	0.14	0.14	
Coefficient of Variation	20.39	19.59	
Min–Max	0.07–0.20	0.07–0.20	
At-risk-of-poverty rate			
Mean	21.04	16.18	
Coefficient of Variation	26.49	22.26	
Min–Max	12.10–36.10	9.80–22.50	
Heating degree days			
Mean	2638.52	2560.40	
Coefficient of Variation	41.71	45.03	
Min–Max	515.23–5482.97	392.62–5437.01	
Cooling degree days			
Mean	140.48	143.36	
Coefficient of Variation	141.23	145.79	
Min–Max	0.00–756.22	0.00–780.47	
Total population considering their dwelling as too dark			
Mean	5.22	5.56	
Coefficient of Variation	35.99	38.43	
Min–Max	2.60–10.00	2.90–10.60	
Total population living in a dwelling with a leaking roof, damp walls, floors, or foundation, or rot in window frames or floor			
Mean	13.61	13.84	
Coefficient of Variation	43.31	51.40	
Min–Max	4.10–31.10	4.80–31.60	
Housing cost overburden rate			
Mean	8.29	8.29	
Coefficient of Variation	78.39	59.44	
Min–Max	2.30–36.20	2.60–28.50	
Final energy consumption in households per capita			
Mean	559.19	521.96	

Coefficient of Variation	31.42	31.50
Min–Max	201.00–1020.00	206.00–982.00

Based on the results presented in Table 3, it can be concluded that the distributions of EP indicators in 2023 have changed compared to the distributions in 2019. A significant positive change can be observed in the case of the At-risk-of-poverty rate, whose average value decreased by almost 5 percentage points. The extreme values of this indicator have improved significantly compared to the year before the COVID-19 pandemic. A decrease in the average value of heating degree days has also been observed, which indicates a lower demand for heating buildings in 2023. At the same time, the demand for cooling buildings has increased, which is reflected in the average values of this indicator in 2023 and the maximum value. A positive trend was also observed for Final energy consumption in households per capita. This is reflected in lower average and maximum values in 2023. A worrying situation was noted in the case of the Population unable to keep home adequately warm indicator, whose average value increased compared to the 2019 average. A positive sign is the reduction in the diversity of EU countries in terms of this indicator and the reduction in the maximum extreme value by almost 10 percentage points compared to the maximum in 2019. Other indicators, such as: expenditure on electricity, gas, and other fuels as a proportion of the total household expenditure, average annual electricity prices for household consumers (with consumption from 2500 kWh to 4999 kWh), average annual electricity prices for household consumers (with consumption from 2500 kWh to 4999 kWh), or housing cost overburden rate are characterized by a rather stable situation in terms of average values in the years under review.

Table 4 presents the indicators adopted for further study regarding H&W and the values of basic descriptive parameters.

Table 4. Descriptive statistics for the indicators of H&W in the EU.

H&W		
Indicator Descriptive Parameter	2019	2023
Self-perceived health (from 16 to 64 years)		
Mean	67.16	66.95
Coefficient of Variation	14.05	12.40
Min–Max	46.20–84.30	48.10–80.80
Self-reported unmet need for medical examination and care		
Mean	2.47	2.56
Coefficient of Variation	126.87	95.80
Min–Max	0.00–15.50	0.10–9.10
Share of people with good or very good perceived health		
Mean	66.84	66.97
Coefficient of Variation	14.59	12.61
Min–Max	44.00–84.10	47.60–79.50
Standardized preventable and treatable mortality		
Mean	289.92	296.17
Coefficient of Variation	39.66	41.39
Min–Max	169.63–522.10	169.34–543.33
Happy Index		
Mean	6.44	6.63
Coefficient of Variation	11.12	8.22
Min–Max	5.01–7.77	5.47–7.80

An analysis of the descriptive parameters presented in Table 4 indicates consistency between their values in 2019 and 2023. There was a slight decrease in the average and

maximum self-perceived health for people aged 16–64 who reported good or very good self-perceived health. The average percentage of households reporting unmet needs for medical examinations and healthcare has increased. However, in this case, a significant decrease in the maximum value is observed in 2023. An increase in the mean and maximum values was also observed for standardized preventable and treatable mortality, which may indicate that preventive measures and health promotion do not work well enough. A positive sign is the increase in the average Happy Index score in 2023 and the reduction in differences between EU countries in terms of this indicator. This trend indicates a higher sense of happiness and a better perception of their life situation among EU citizens. However, it should be emphasized that this index is subjective and the assessments expressed depend on many factors.

4.2. Classification of EU Countries According to EP and H&W Using QGIS

Before proceeding with the classification of EU countries, the distributions of the indicators used to rank them in relation to EP and H&W for the years 2019 and 2023 were analyzed. All indicators exhibited slight positive skewness and did not significantly deviate from a normal distribution, with one borderline exception according to the adopted normality criteria. Preliminary analysis suggested that, depending on the distribution of each indicator, different classification methods could be appropriate—namely, standard deviation, Natural Breaks (Jenks), or quantile. However, adopting a single, unified classification method ensures consistency in comparisons across years and analytical dimensions. Ultimately, the Natural Breaks (Jenks) method was selected, as it adapts to the actual data distribution, performs well in the presence of slight asymmetry, and enables clear differentiation between classes, enhancing both readability and validity. The number of classes was determined using Ward’s hierarchical clustering method [146].

4.2.1. Classification of EU Countries According to EP in 2019 and 2023 Using QGIS

Based on the synthetic EP indicators calculated for 2019 and 2023, four groups of EU countries were identified. The first class included countries with the most favorable situation in terms of EP, while the fourth class comprised those with the least favorable conditions in this dimension. The spatial differentiation of EP levels is presented in Figure 4.

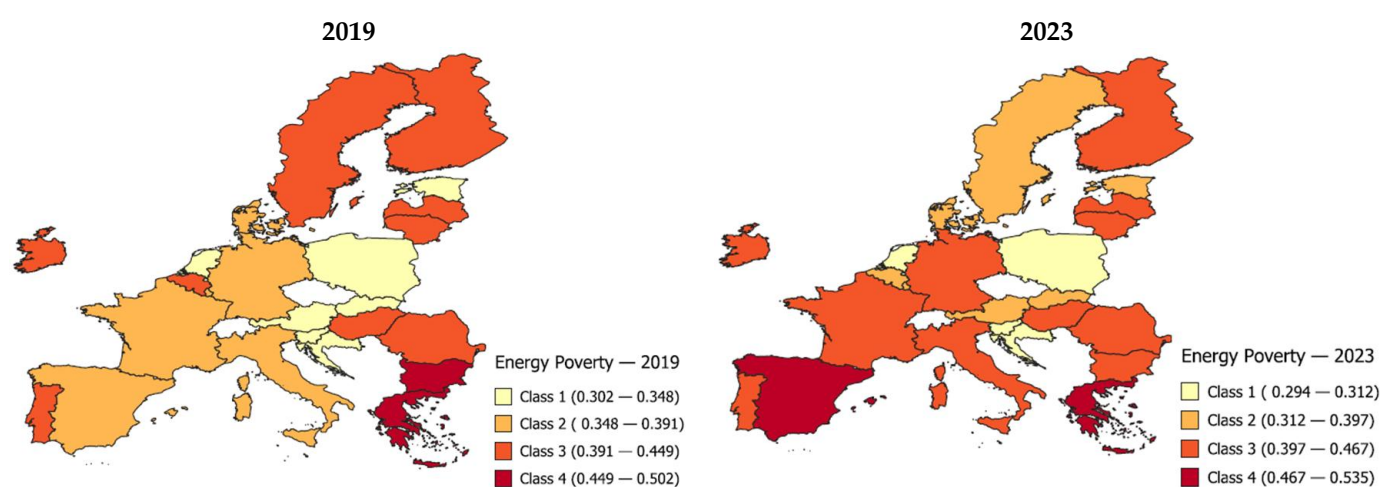


Figure 4. Spatial differentiation of EU countries according to EP in 2019 and 2023. The class intervals were determined using the Natural Breaks (Jenks) method in QGIS, based on the synthetic EP indicators.

For a more in-depth interpretation of the results, Appendix B (Table A2) presents the average values of ten diagnostic variables for each of the identified classes of EU countries.

Comparing these values with EU averages made it possible to define characteristic profiles for each class, differentiated in terms of the scale and determinants of EP.

The analysis of average values of diagnostic variables in each class for the years 2019 and 2023 revealed significant differences in the energy and housing profiles of EU countries. Class 1 included countries in the most favorable situation, characterized by low levels of energy poverty (EP), limited housing costs, and high-quality housing stock. The relatively high per capita energy consumption in this group may indicate minimal barriers to accessing energy resources. Class 2 was distinguished by moderate levels of EP and above-average energy consumption, which may reflect a higher standard of living and stable housing conditions. Class 3 comprised countries experiencing deepening energy deprivation, poorer infrastructure, and an increasing burden of energy-related expenditures. The least favorable profile was observed in Class 4, which included countries with low energy consumption, high costs, and significant infrastructural deficits. This suggests that EP in these countries has a persistent and structural character.

A comparison of the classification of EU countries by EP level in 2019 and 2023 revealed clear shifts in the positions of member states, reflecting diverse dynamics in energy and housing conditions. An increase in EP levels between 2019 and 2023 was observed in six EU member states: Austria, France, Germany, Italy, Slovakia, and Spain. In five of these countries, the change corresponded to a shift of one class in the overall classification. However, in Spain, the shift involved two classes, representing the most significant decline among the analyzed countries. This change reflects a marked deterioration in EP conditions, as Spain was classified in the fourth class—the least favorable in the adopted typology. In 2023, Spain was grouped with Greece, a country where a high, structurally rooted level of EP has persisted for years. A decline in classification position was also recorded in Germany, France, and Italy—the three largest EU economies by gross domestic product—which may suggest broader systemic challenges, partly driven by the energy crisis, inflationary pressures, and rising living costs during 2021–2022. Improvements were identified only in Bulgaria and Sweden. Although Bulgaria maintained an overall unfavorable position, in 2023 it moved from the fourth to the third class, possibly indicating improved infrastructure or a reduction in energy deprivation. In Sweden, an upward shift from the third to the second class may reflect continued high housing standards and energy efficiency. In 19 of the 27 EU member states, no changes in classification were recorded between 2019 and 2023, indicating relative stability in EP levels. This group included countries with favorable profiles (e.g., Croatia, the Netherlands, Poland) as well as those in less favorable classes (e.g., Hungary, Ireland, Romania). Overall, a trend of worsening conditions was observed in several Western and Southern European countries, while relative stabilization or improvement occurred in parts of Central and Eastern Europe and Scandinavia.

4.2.2. Classification of EU Countries According to H&W in 2019 and 2023 Using QGIS

Based on the values of the synthetic indicator representing the level of H&W, calculated for 2019 and 2023, EU countries were classified into four groups. Class 1 includes countries with the highest levels of H&W, while Class 4 comprises those with the lowest. The spatial distribution of H&W levels is presented in Figure 5.

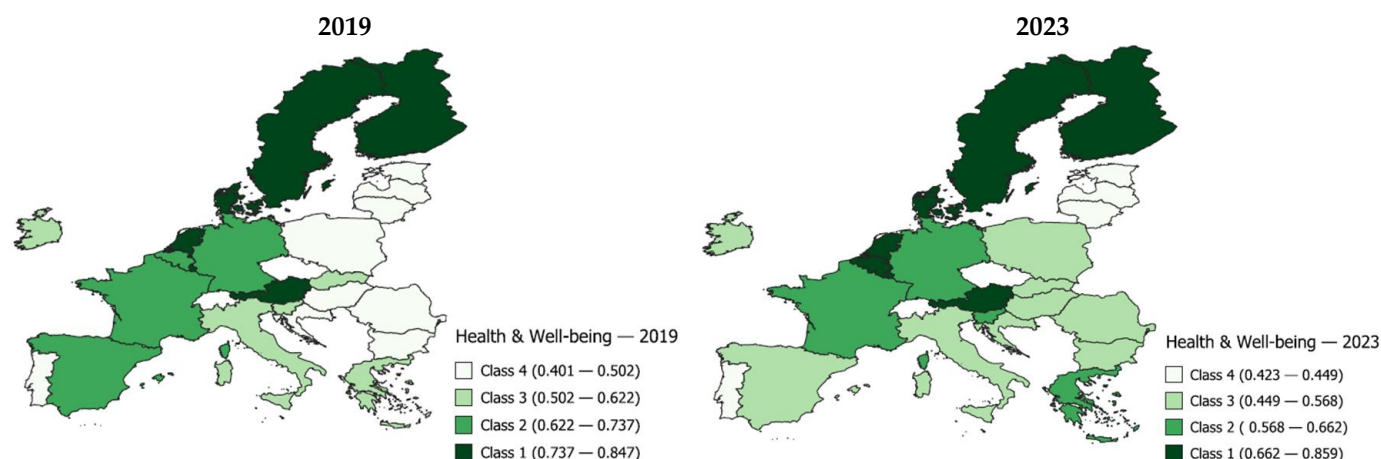


Figure 5. Spatial classification of EU countries by H&W level in 2019 and 2023. The class intervals were determined using the Natural Breaks (Jenks) method in QGIS based on the synthetic H&W indicators.

For a more in-depth interpretation of the classification results, Appendix B (Table A3) presents the average values of five diagnostic variables for each of the identified classes of EU countries. Comparing these values with the EU average makes it possible to identify characteristic profiles for each class, differentiated by the scale and determinants of H&W.

The analysis of average values of diagnostic variables in each class for the years 2019 and 2023 revealed clear differences in H&W levels across EU countries. Class 1 included countries in the most favorable situation, characterized by high satisfaction with healthcare services and a strong sense of happiness, as reflected by the Happy Index. Countries classified in Class 2 in both 2019 and 2023 demonstrated levels that can be considered satisfactory. The average values of the diagnostic variables in this group were close to EU averages, which may indicate adequate healthcare provision and a generally positive perception of well-being. Class 3 comprised countries with results indicating a deteriorating H&W situation in both years. The least favorable profile was observed in Class 4, which included countries reporting low self-assessed health status and a high level of unmet needs related to healthcare and living conditions. The severity of these issues was reflected in a low Happy Index score. A comparison of the classification of EU countries by H&W level in 2019 and 2023 revealed shifts in the positions of member states, reflecting diverse dynamics in the phenomenon under study. An analysis of the classification positions of EU countries based on H&W levels shows that by 2023, changes in the phenomenon resulted in nine countries being assigned to different classes than in 2019. These countries were Greece, Ireland, Slovenia, Bulgaria, Croatia, Hungary, Poland, Romania, and Spain. In all cases, the changes involved a shift of one class. For Spain, this meant a decline from Class 2 to Class 3, reflecting a deterioration in H&W conditions. This may be attributed to factors such as rising living costs, increased energy poverty, and strain on the healthcare system. An improvement in H&W levels that led to reclassification between 2019 and 2023 occurred in eight countries: Bulgaria, Croatia, Greece, Hungary, Ireland, Poland, Romania, and Slovenia. A shift from Class 4 to Class 3 was observed in Bulgaria, Croatia, Hungary, Poland, and Romania. As a result of improved values in the diagnostic variables, Greece, Ireland, and Slovenia moved from Class 3 to Class 2. These changes may reflect a combination of post-pandemic recovery, increased healthcare investment, and better housing and energy conditions. In 18 out of 27 EU countries, no change in class occurred during the study period, indicating relative stability in H&W levels. This group included countries that consistently remained in Class 1 in both 2019 and 2023: Austria, Belgium, Denmark, Finland, Luxembourg, Malta, the Netherlands, and Sweden. In the less favorable classes, the following countries retained their positions:

Cyprus, France, and Germany (Class 2); Italy and Slovakia (Class 3); and Czechia, Estonia, Latvia, Lithuania, and Portugal (Class 4). Overall, a general trend of stabilization or improvement in H&W was observed across most EU countries, with a notable deterioration in the case of Spain.

4.2.3. Alignment Between EP and H&W in EU Countries Using QGIS

The relationship between energy poverty (EP) and health and well-being (H&W) is significant from the perspective of public policy and sustainable development. Misalignment between these areas may deepen social inequalities and reduce the effectiveness of interventions in both domains. The analysis of EU country classifications by EP and H&W levels in 2019 and 2023 enabled an assessment of the degree of alignment between these two critical dimensions. Member states were assigned to four classes (from Class 1—the most favorable—to Class 4—the least favorable) in both categories, allowing for the identification of cases of strong consistency as well as notable discrepancies. The distribution of countries on scatter plots made it possible to distinguish consistent cases (located along the diagonal) from divergent ones (positioned further from the line of agreement).

According to the visualization presented in Figure 6, in 2019, Austria and the Netherlands were classified in the most favorable group, Class 1, for both health and well-being (H&W) and energy poverty (EP). France, Germany, and Spain were assigned to the less favorable Class 2 in both dimensions. Ireland and Bulgaria were placed in Class 3 and Class 4, respectively, indicating the simultaneous presence of unfavorable social and energy conditions. By 2023, the Netherlands maintained its high and consistent position in Class 1 for both indicators. Bulgaria, Italy, Romania, and Hungary were classified in Class 3 in both categories, confirming the persistence of challenging conditions in both health and energy domains.

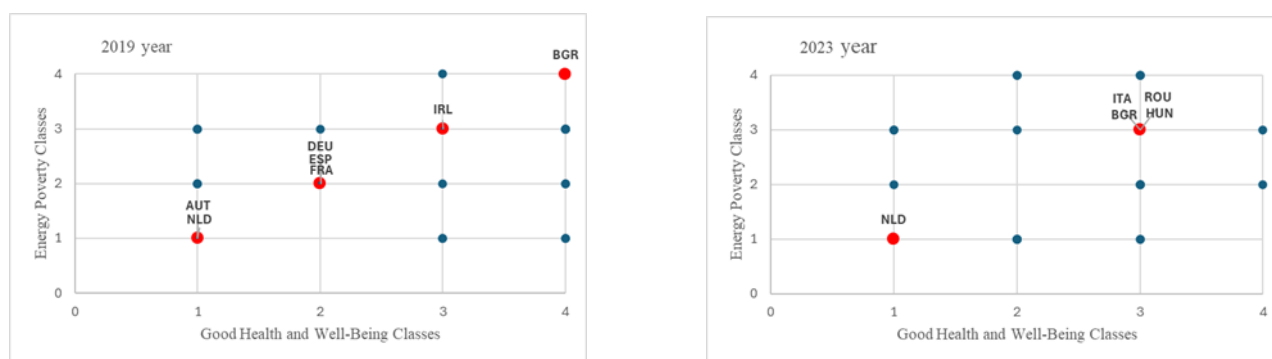


Figure 6. EU countries with consistent classification by H&W and EP levels, 2019–2023. ISO country codes: AUT–Austria, NLD–Netherlands, DEU–Germany, ESP–Spain, FRA–France, IRL–Ireland, BGR–Bulgaria, ITA–Italy, ROU–Romania, HUN–Hungary. Red dots indicate countries with consistent classification in both dimensions. Blue dots represent countries assigned to different classes in terms of H&W and EP.

The analysis of EU country classifications in the dimensions of energy poverty (EP) and health and well-being (H&W) revealed significant discrepancies in the positions of several countries across the two domains. In 2019, Belgium, Finland, and Sweden were classified in the most favorable category for H&W (Class 1), while simultaneously being placed in a lower class for EP (Class 3). This mismatch indicates a lack of alignment between health-social and energy conditions. For Belgium and Finland, this pattern persisted in 2023. A different configuration was observed in 2019 in Slovakia, Slovenia, Poland, and Croatia, where a less favorable or unfavorable position in H&W (Class 3 or 4) coincided with a favorable energy situation (Class 1). A similar discrepancy was noted in

Czechia and Estonia, where in both years these countries were assigned to the lowest H&W class (Class 4), yet classified at a moderate level for EP (Class 2). In 2023, compared to 2019, Poland and Croatia improved their H&W classification—moving from Class 4 to Class 3—while maintaining a favorable EP position (Class 1). An opposite trend was observed in Greece: despite maintaining a moderate standing in H&W (Class 2), the country remained in the lowest EP category (Class 4), pointing to persistent structural challenges in the energy domain.

4.3. Classification of EU Countries According to EP and H&W Using SOM

In the subsequent stage of the analysis, the classification of EU countries was carried out using self-organizing maps (SOM), which belong to the group of artificial intelligence methods. For the classification, a two-dimensional Kohonen grid with dimensions of 2×2 was applied, trained over 1000 epochs with gradually decreasing values of the learning coefficient and neighborhood radius. The weights were randomly initialized based on a Gaussian distribution with a fixed initial value, which ensured the reproducibility of the computations. The resulting clusters of countries served as the basis for further comparisons with the classification obtained using traditional methods, represented by QGIS.

4.3.1. Classification of EU Countries According to EP in 2019 and 2023 Using SOM

The classification of EU countries using SOM made it possible to distinguish four classes for EP and H&W in 2019 and 2023. Group 1 included the countries with the most favorable situation, while Class 4 comprised those with the most unfavorable values of the analyzed indicators. The distribution of countries across the respective classes is presented in Figure 7.

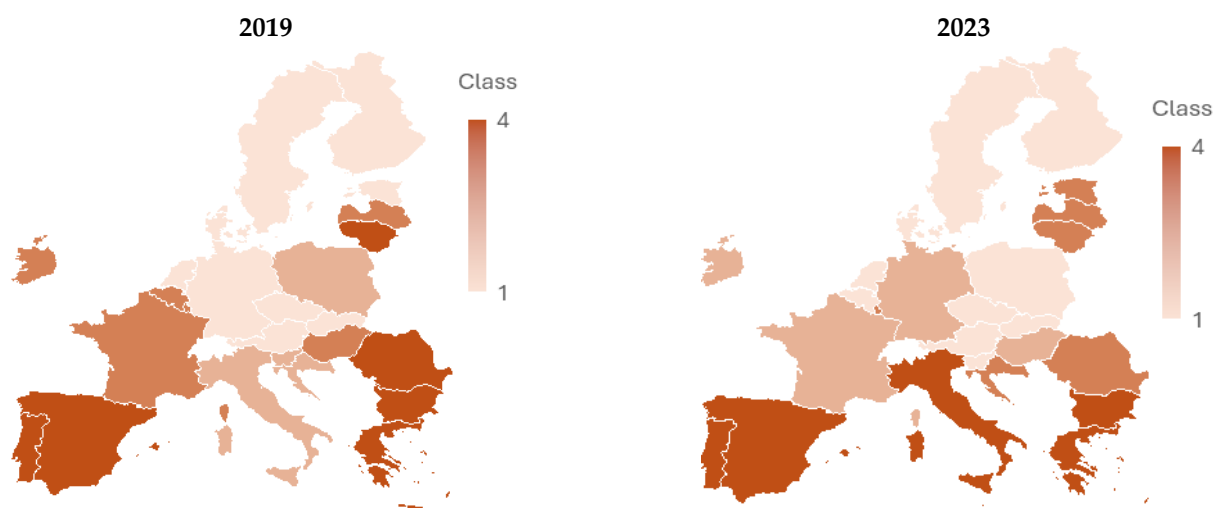


Figure 7. Spatial differentiation of EU countries according to EP in 2019 and 2023 using SOM.

Appendix C (Table A4) presents the mean values of ten diagnostic features calculated for each of the identified classes of EU countries. Relating them to the EU averages made it possible to distinguish characteristic profiles of the individual classes, differentiated in terms of the scale and determinants of EP.

The analysis of the classification results for 2019 and 2023, based on the mean values of the diagnostic features of individual classes relative to the EU average, revealed a clear differentiation of the energy-housing profiles of the Member States. Class 1 comprised countries with the most favorable profile, characterized by a low level of energy deprivation, relatively limited expenditure burden on energy, and stable housing conditions. Class 2 was distinguished by a moderate level of EP and above-average energy

consumption, which may be associated with a higher standard of living and greater availability of resources. Class 3 included countries where increasing difficulties were observed in terms of energy costs and the quality of housing infrastructure, as well as a growing share of households experiencing problems in maintaining adequate thermal comfort. Class 4 encompassed countries with the lowest energy consumption, high financial burdens, and intensified housing deficits, which indicates the persistent and structural nature of energy poverty within this group.

The classification of EU countries conducted using the SOM method showed that in the years 2019–2023, most states (16 out of 27) remained in the same class, which indicates the relative stability of the EP level. This applied both to countries with a favorable profile (e.g., Austria, Czechia, Denmark, Finland, Sweden) as well as those persistently belonging to less favorable classes (e.g., Bulgaria, Cyprus, Greece, Spain). However, clear changes were observed in 11 countries. The greatest improvement was recorded in Belgium, which moved from Class 3 to Class 1. An improvement in classification position was also observed in Poland, Slovenia, France, and Romania, which shifted to more favorable classes, indicating a relative mitigation of EP. A different direction of change was observed in Estonia, which dropped from Class 1 to Class 3, and in Italy, which moved from Class 2 to Class 4. A deterioration of the situation, albeit on a smaller scale, also occurred in Germany and Croatia.

The observed changes in the classification positions of EU countries in terms of EP can be linked to the varying pace of energy price increases, the different levels of household budget burden related to housing costs, and the uneven improvement or deterioration of housing conditions. Stability in most countries reflects persistent trends, while the shifts observed in selected states highlight specific economic and social circumstances that determined the scale of EP during the analyzed period.

4.3.2. Classification of EU Countries in 2019 and 2023 According to H&W Using SOM

Based on the values of the indicators describing the level of H&W in 2019 and 2023, the classification of EU countries was carried out using SOM. The analysis made it possible to distinguish four classes, with Class 1 comprising countries with the highest level of H&W, and Class 4 including those with the lowest values of the analyzed indicators. The distribution of countries across the respective classes is presented in Figure 8.

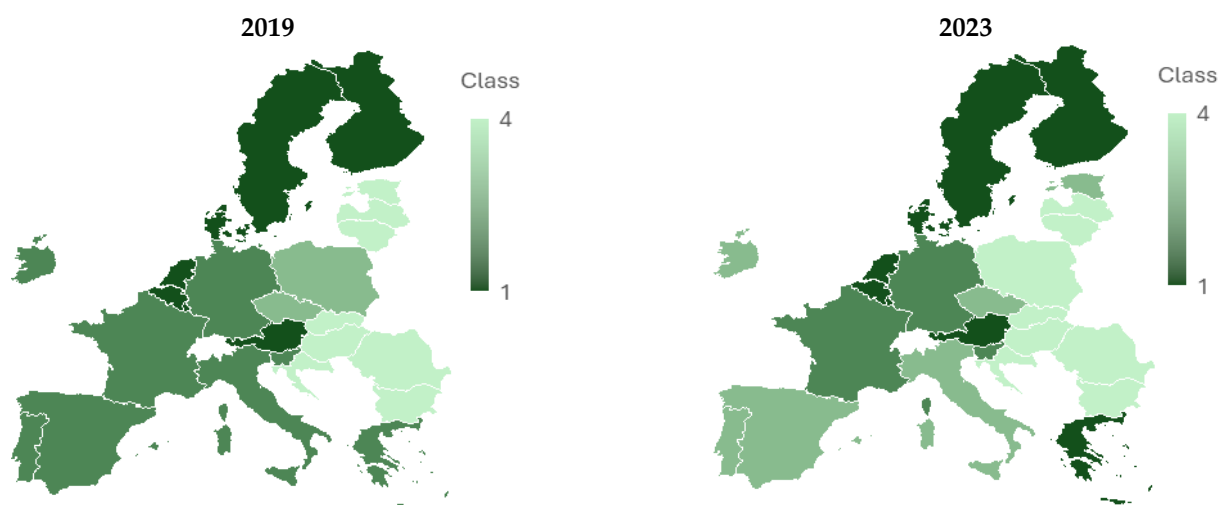


Figure 8. Spatial differentiation of EU countries according to H&W in 2019 and 2023 using SOM.

For a more comprehensive interpretation of the classification results, Appendix C (Table A5) presents the mean values of five diagnostic features calculated for each of the

identified classes of EU countries. Relating them to the EU averages made it possible to determine the characteristic profiles of the individual classes, differentiated in terms of the scale and determinants of H&W.

The analysis of the classification results for 2019 and 2023, based on the mean values of diagnostic features in individual classes relative to the EU average, revealed significant differences in the level of H&W among the Member States. Class 1 included countries with the highest level of well-being, characterized by favorable self-assessed health, a low share of unmet medical needs, low avoidable mortality, and a high level of life satisfaction as measured by the Happiness Index. Class 2 comprised countries with a moderate level of H&W, close to the EU average, indicating a relatively stable level of health and well-being in this group. Class 3 included countries where growing difficulties in healthcare provision and deteriorating well-being indicators were observed, including lower Happy Index values. The least favorable profile was observed in Class 4, comprising countries with low self-assessed health, high unmet medical needs, and elevated avoidable mortality, indicating substantial deficits in H&W.

The classification of EU countries according to H&W obtained using the SOM method showed that in the years 2019–2023, most states (19 out of 27) remained in the same class, which indicates the relative stability of the H&W level. Stability was recorded both among the countries with the highest H&W values (e.g., Austria, Belgium, Denmark, Finland, Luxembourg, Netherlands, Sweden) and among those with the lowest results (Bulgaria, Croatia, Hungary, Latvia, Lithuania, Romania, Slovakia). An improvement in classification position was observed in three countries: Cyprus (from Class 2 to 1), Greece (from Class 2 to 1), and Estonia (from Class 4 to 3). These changes indicate a relative improvement in health and well-being in these countries. Conversely, in five states a deterioration in position was recorded. Ireland, Italy, Portugal, Poland, and Spain were classified in a lower category, reflecting a weakening of H&W indicators in the analyzed period.

The observed stability of positions for most EU countries in 2019 and 2023 should be linked to persistent trends in self-assessed health, medical needs, or perceived well-being. The improvement in classification position for Cyprus, Greece, and Estonia may have resulted from favorable changes in access to healthcare as well as improvements in the subjective assessment of health and quality of life. Conversely, the deterioration in the positions of Ireland, Italy, Portugal, Poland, and Spain indicates a weakening of H&W indicators, which can be associated, among other factors, with a higher share of unmet medical needs and less favorable trends in avoidable mortality.

4.3.3. Alignment Between EP and H&W in EU Countries Using SOM

The assessment of the relationship between EP and H&W in EU countries conducted using the SOM method made it possible to determine the degree of consistency between the classifications obtained for both dimensions in 2019 and 2023. Into four classes, from the most favorable (Class 1) to the least favorable (Class 4), highlighted cases of clear consistency as well as significant discrepancies in the positions of individual countries. The distribution of states in the charts (Figure 9) showed which countries were characterized by a parallel level of EP and H&W, and which displayed an imbalance between EP and H&W.

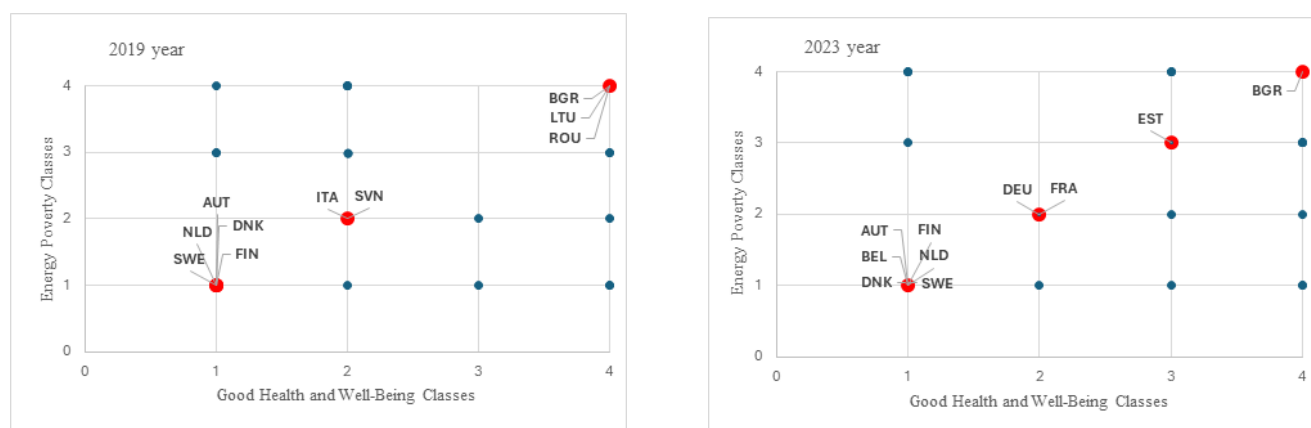


Figure 9. EU countries with consistent SOM-based classification in terms of H&W and EP in 2019 and 2023. ISO country codes: AUT—Austria, BEL—Belgium, BGR—Bulgaria, DEU—Germany, DNK—Denmark, EST—Estonia, FIN—Finland, FRA—France, ITA—Italy, LTU—Lithuania, NLD—Netherlands, ROU—Romania, SVN—Slovenia, SWE—Sweden. Red dots indicate countries with consistent classification in both dimensions. Blue dots represent countries assigned to different classes in terms of H&W and EP.

The comparison of the classification of EU countries according to EP and H&W revealed a high degree of consistency between these dimensions. The points located along the diagonal of the charts indicated countries with convergent positions in both classifications—in 2019 and 2023, these included Austria, Denmark, Finland, the Netherlands, and Sweden in the most favorable classes, as well as Bulgaria, Lithuania, and Romania in the least favorable ones. Despite individual shifts (e.g., Germany, France, Estonia), the overall arrangement remained stable, confirming the persistent, structural relationship between EP and H&W.

The analysis of the classification revealed the presence of countries located outside the line of concordance, i.e., lacking consistency between the results for EP and H&W. In 2019, this group included, among others, Belgium, Luxembourg, and Malta, which were characterized by high H&W indicator values while being classified into lower EP classes. A different pattern was observed in Czechia, Estonia, and Slovakia, where low H&W values contrasted with assignment to higher EP classes. In 2023, the discrepancies persisted, with particularly strong disparities recorded for Cyprus and Malta (high H&W combined with classification into the lowest EP class) as well as Czechia, Poland, and Slovakia (low H&W combined with high EP scores).

The comparison of the classification of EU countries according to EP and H&W obtained using QGIS and SOM shows that both methods lead to consistent conclusions at the general level, although they differ in their sensitivity to changes in individual countries. In both approaches, the stable advantage of Northern and Western European countries (e.g., Austria, Denmark, the Netherlands, Sweden) was confirmed, as they consistently appeared in the most favorable classes in terms of EP and H&W. Similarly, countries with persistently unfavorable profiles, such as Bulgaria and Romania, were identified in both methods.

The comparison of classifications obtained using QGIS and SOM indicated consistency in the overall assessment of the situation, while highlighting differences for individual countries. In the area of EP, QGIS recorded, among others, a marked decline in Spain's position and an improvement in Bulgaria and Sweden. In contrast, SOM pointed to an improvement in the positions of Belgium, Poland, and Slovenia, as well as a deterioration in Estonia and Italy. With respect to H&W, QGIS emphasized improvements in several Central and Southern European countries and a decline in Spain's position, while

SOM additionally highlighted an improvement in Cyprus and Estonia but also a deterioration in Ireland, Italy, Portugal, and Poland.

5. Discussion and Conclusions

Due to the phenomena analyzed, i.e., EP and H&W, this study fits into the trend of research on sustainable development. The adoption of 17 SDGs by the UN in 2015 set the direction for actions aimed at balancing social, economic, and environmental aspects at the global and local levels. Poverty was included as the first SDG because it has a direct impact on the achievement of other SDGs, e.g., it limits access to education, healthcare, decent housing, and work. It therefore hinders the achievement of other SDGs, such as improving health (SDG 3), quality education (SDG 4), and reducing inequalities (SDG 10). As early as the beginning of the 1990s, the impact of energy poverty on the functioning of households was highlighted, including the problem of adequate heating of dwellings [147]. Bouzarovski [148] points out in many publications that EP is the main aspect of material poverty that exacerbates social exclusion and inequality. The literature review in this manuscript emphasizes that EP is an important element of poverty and is linked to many other aspects of people's lives. Many researchers address the issue of EP in relation to, for example, social inequalities [149], quality of housing conditions [150], climate change [151], unemployment [152], education and gender [153], and mental well-being [154], pointing to the relationship between EP and these phenomena.

The aim of this study is, among other things, to assess the links between EP and H&W. The approach used in our article takes a broader view of EP, as it refers not only to health but also to factors determining health, including causes of death and healthcare in the context of the well-being of EU residents.

In order to achieve the objective of the study, both objective and subjective indicators were used in relation to both phenomena, i.e., EP and H&W. We also emphasize that subjective indicators are particularly important in the assessment of H&W. Based on a review of the literature and to our knowledge, the phenomena indicated have not yet been analyzed in the context presented in this article—this approach fills a research gap in the assessment of these phenomena. The indicators used in our study to analyze EP and H&W were taken from the Eurostat database and are characterized by high quality and reliability, as they are collected and processed in accordance with established standards. This ensures their reliability and the comparability of countries that are included in this database.

The literature on the subject contains many studies conducted for a specific country [16,155–158] or part of it, e.g., in cities [159], municipalities [160], or rural areas [161–163]. In our study, we analyze all 27 EU countries in two years: 2019 and 2023, i.e., before and after the COVID-19 pandemic. Such research is particularly important when comparative analyses are carried out between countries belonging to larger organizations, such as the EU, and these countries should, in accordance with the recommendations of the European Commission [164,165], should implement measures aimed at eliminating poverty in all its forms (SDG1) and ensuring healthy lives and promoting well-being for all at all ages (SDG3) [166].

The use of QGIS (a GIS tool for spatial visualization) provides a traditional, well-established basis for assessing EU countries in terms of EP and H&W. On the other hand, the use of an artificial intelligence-based approach allows for the discovery of hidden patterns and non-linear relationships that classical methods might not reveal. This combination of classic and modern methods gives a new quality to comparative analysis. The classic method (QGIS) allows for the creation of classification and visualization of spatial diversity between countries. SOM enables grouping and non-linear segmentation of countries in terms of similarities, which is a broader issue compared to the linear ordering of countries. This creates a more complete, multidimensional picture of the objects being

analyzed. The SOM method is rarely used in socio-economic analyses at the EU level, especially in the context of EP and H&W. A review of the literature reveals few studies in which authors use SOM to identify homogeneous groups of objects, particularly EU countries. In their work, Lucchini and Assi [167] use SOM to identify homogeneous groups of people in Switzerland based on 44 indicators of deprivation and well-being. Another study [129] shows that SOM can be effectively used to classify EU countries in the context of energy indicators used to assess the level of energy security. Although some studies have addressed the use of SOM to ensure sustainable energy development in countries and their location on a 2D map, these studies do not directly relate to EP and H&W. Therefore, a review of the available literature shows that no research has been conducted to date on the use of SOM to assess EU countries, taking into account both EP and H&W simultaneously. This proposal, a classification of countries, represents a new approach to the study of the complex phenomena of EP and H&W.

On the basis of the results of the classification of EU countries, the classic QGIS method found the occurrence of:

1. Consistency among certain Member States in terms of EP and H&W. In 2019, Austria and the Netherlands were in the most favorable class in terms of both H&W and EP. In contrast, in 2023, only the Netherlands maintained a high, consistent position in the most favorable class in terms of the phenomena studied. Ireland and Bulgaria ranked in classes indicating an unfavorable situation in terms of both EP and H&W.
2. Discrepancies in some EU countries including EP and H&W. In 2019, Belgium, Finland, and Sweden achieved very good results in terms of H&W, but at the same time were classified in the group with a higher EP level. In Slovakia, Slovenia, Poland, and Croatia, with lower H&W scores, these countries were characterized by a favorable situation in terms of EP. Finland improved its EP situation but maintained an unsatisfactory H&W level.

The use of SOM allowed for the identification of the following patterns:

1. A comparison of EU country classifications according to EP and H&W revealed a high degree of consistency between these dimensions. Countries with similar positions in both classifications in 2019 and 2023 were: Austria, Denmark, Finland, the Netherlands, and Sweden in the most favorable classes, and Bulgaria, Lithuania, and Romania in the least favorable ones.
2. Inconsistency between EP and H&W results in 2019 in a group of countries comprising Belgium, Luxembourg, and Malta, which had high H&W values while being classified in lower EP classes. A different pattern was observed in the Czech Republic, Estonia, and Slovakia, where low H&W values contrasted with higher EP grades. In 2023, the discrepancies persisted, with particularly strong disparities observed in Cyprus and Malta (high H&W values while being classified in the lowest EP class) and the Czech Republic, Poland, and Slovakia (low H&W values while receiving high EP ratings).

Based on the study conducted and the results obtained, the authors provided affirmative answers to all research questions posed in the introduction. The results of this study are particularly significant in the context of the COVID-19 pandemic, which has highlighted the importance of both the EP problem and the H&W issue, especially during such a challenging time as the period of isolation as well as conflict in Ukraine, causing an increase in energy prices.

The results presented in this study indicate that countries with the highest EP levels are located in two distinct regions: Eastern and Southern Europe. Countries with the lowest EP levels are located in Northern and Central Europe. In the case of H&W, higher levels of H&W were observed in northern and western European countries, while lower levels were observed in eastern and central European countries.

Many of the indicators characterizing EP relate to the housing conditions of households. In countries where high levels of this phenomenon have been recorded, measures should be taken to reduce it. Regarding households, these measures should contribute to increasing energy efficiency through thermal modernization of buildings (insulation, replacement of windows, smart heating systems), support for energy-efficient appliances, and the development of subsidy programs for households [168].

However, in the case of low H&W levels, which are reported by residents of some EU countries and are mainly related to indicators reflecting health status, measures should be taken to improve the accessibility and quality of healthcare, strengthen disease prevention, promote healthy lifestyles, and social and educational programs [68,169]. Our research confirms that QGIS emphasizes changes related to crossing class boundaries, while SOM captures more subtle shifts in country profiles. In practice, this means that classical approaches and artificial intelligence tools are complementary—their combined use allows for a more complete and reliable recognition of phenomena in the EP and H&W areas.

In conducting this study, the authors encountered several limitations. The most common limitations include gaps in the data and a lack of information about the phenomenon being analyzed. A particularly important limitation is the unavailability of information in the Eurostat database on the satisfaction of EU residents with various aspects of life in individual member states. These data are usually aggregated and insufficient for comparative analysis.

Our study on EP and H&W reveals important implications for policymakers, researchers, entrepreneurs, and citizens in terms of making informed decisions about the phenomena under investigation. First, the authors present and apply new tools for measuring EP and H&W, which allow for a more accurate assessment and visualization of its scope. Second, they present several recommendations for energy and social policies aimed at reducing EP and strengthening H&W.

Research on EP and H&W is extremely important because it helps us understand how inappropriate EP levels affect H&W and, more generally, quality of life. It enables us to identify ways to combat social inequalities, develop effective public policies, and support the energy transition in a fair and sustainable manner.

The authors plan to expand the scope of their research beyond the EU and include additional indicators characterizing EP and H&W, as well as consider other phenomena related to poverty and quality of life. Future research will also include an assessment of poverty, including energy poverty in households, based on a questionnaire developed at the regional and local levels. The authors also plan to focus on assessing the quality of classifications generated by both traditional methods and those based on artificial intelligence. Research is also planned to examine the differences between euro area and non-euro area economies in terms of counteracting EP and supporting H&W through lending activities.

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Appendix A

Table A1. Timeline of main EU regulations addressing EP.

Year	Regulation	Legal Reference Document	Main Focus
2018	Renewable Energy Directive (RED II) [170]	(Directive (EU) 2018/2001)	Promoting renewable energy adoption and addressing energy poverty through access to clean energy.
	Energy Efficiency Directive (EED) [171]	(Directive (EU) 2018/2002)	Improving energy efficiency and prioritizing vulnerable groups in energy-saving measures.
2019	Clean Energy for All Europeans Package [164]		Establishing a fair energy market, with provisions to protect vulnerable consumers and define energy poverty.
	European Green Deal [172]	(COM/2019/640 final)	Achieving climate neutrality by 2050, with measures to tackle energy poverty through investments in clean energy.
2020	Just Transition Mechanism Just Transition Fund [173]	(COM/2020/22 final) (Regulation (EU) 2021/1056)	Supporting regions and communities most affected by the transition to a low-carbon economy.
2021	Recovery and Resilience Facility (RRF) [174]	(Regulation (EU) 2021/241)	Facilitating post-COVID recovery, with a focus on green transitions and addressing energy poverty.
	European Pillar of Social Rights Action Plan [175]	(COM/2021/102 final)	Promoting social fairness, equal access to essential services, and energy poverty reduction.
2022	REPowerEU Plan [176]	(COM/2022/230 final)	Reducing dependency on Russian fossil fuels and addressing energy poverty through energy diversification and safety.
2023	Commission Recommendation (EU) 2023/2407 of 20 October 2023 on energy poverty [177]	(EU) 2023/2407	Guidelines for EU member states to enhance the identification, monitoring, and mitigation of energy poverty, emphasizing the need for targeted measures to protect vulnerable consumers and promote energy efficiency.

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Appendix B

Table A2. Characteristics of EU country classes based on average values of diagnostic variables for EP, relative to the EU average (2019 and 2023)—QGIS classification.

No.	Diagnostic Variable	Year	EU Average	Class 1	S	Class 2	S	Class 3	S	Class 4	S
1	Population unable to keep home adequately warm by poverty status	2019	8.2	4.3	↓↓	5.1	↓	10.2	↑	24.0	↑↑
		2023	9.5	5.4	↓	5.5	↓	11.6	↑	20.0	↑↑
2	Expenditure on electricity, gas, and other fuels as a proportion of the total household expenditure	2019	21.6	21.5	≈	22.5	↑	21.2	≈	20.3	↓
		2023	22.3	19.4	↓	23.9	↑	22.2	≈	22.5	≈
3	Average annual electricity prices for household consumers (with consumption from 2500 kWh to 4999 kWh)	2019	0.1364	0.1345	≈	0.1247	↓	0.1443	↑	0.1548	↑↑
		2023	0.1362	0.1438	↑	0.1219	↓	0.1414	≈	0.1444	↑
4	At-risk-of-poverty rate	2019	21.0	16.7	↓↓	20.5	↓	22.1	↑	31.1	↑↑
		2023	16.2	14.8	↓	15.6	↓	16.5	≈	19.6	↑

5	Heating degree days	2019	2639	2720	↑	2412	↓	2961	↑↑	1801	↓↓
		2023	2560	2435	↓	3030	↑	2484	≈	1429	↓↓
6	Cooling degree days	2019	140	76	↓↓	172	↑	125	↓	268	↑↑
		2023	65	53	↓	45	↓	67	↑	154	↑↑
7	Total population considering their dwelling as too dark	2019	5.2	3.9	↓	5.2	≈	6.1	↑	5.2	≈
		2023	5.6	3.7	↓	4.7	↓	6.4	↑	7.3	↑
8	Total population living in a dwelling with a leaking roof, damp walls, floors, or foundation, or rot in window frames or floor	2019	13.6	11.9	↓	12.4	↓	16.1	↑	12.1	↓
		2023	13.8	11.3	↓	10.0	↓	16.3	↑	18.3	↑
9	Housing cost overburden rate	2019	8.3	6.2	↓	8.5	≈	5.8	↓	26.1	↑↑
		2023	8.3	5.7	↓	9.1	↑	7.1	↓	18.4	↑↑
10	Final energy consumption in households per capita	2019	559	569	↑	577	↑	579	↑	355	↓↓
		2023	522	510	↓	588	↑	516	≈	325	↓↓

Trend symbols relative to the EU average (S): ↑↑—significantly above average, ↑—slightly above average, ≈—close to average, ↓—slightly below average, ↓↓—significantly below average.

Table A3. Characteristics of EU country classes based on average H&W diagnostic variables, relative to the EU average (2019 and 2023)—QGIS classification.

No.	Diagnostic Variable	Year	EU Average	Class 1	S	Class 2	S	Class 3	S	Class 4	S
1.	Self-perceived health (from 16 to 64 years)	2019	67.16	74.64	↑	65.33	↓	59.62	↓	65.68	↓
		2023	66.95	72.39	↑	63.63	↓	65.60	↓	64.40	↓
2.	Self-reported unmet need for medical examination and care	2019	2.47	0.91	↓↓	1.88	↓	2.62	↑	3.89	↑↑
		2023	2.56	1.09	↓↓	2.47	↓	2.84	↑	4.58	↑↑
3.	Share of people with good or very good perceived health	2019	66.84	72.78	↑	71.18	↑	73.18	↑	57.19	↓
		2023	66.97	70.74	↑	71.83	↑	67.78	↑	35.80	↓↓
4.	Standardized preventable and treatable mortality	2019	289.92	210.4	↓↓	197.69	↓↓	253.16	↓	408.83	↑↑
		2023	296.17	205.24	↓↓	224.53	↓↓	382.09	↑↑	390.16	↑↑
5.	Happy Index	2019	6.44	7.27	↑	6.50	↑	6.17	↓	5.90	↓
		2023	6.63	7.21	↑	6.53	↓	6.23	↓	6.45	↓

Trend symbols relative to the EU average (S): ↑↑—significantly above average, ↑—slightly above average, ↓—slightly below average, ↓↓—significantly below average.

Appendix C

Table A4. Characteristics of EU country classes based on average values of diagnostic variables for EP, relative to the EU average (2019 and 2023)—SOM classification.

No.	Diagnostic Variable	Year	EU Average	Class 1	S	Class 2	S	Class 3	S	Class 4	S
1	Population unable to keep home adequately warm by poverty status	2019	8.2	3.0	↓↓	6.1	↓↓	5.2	↓↓	17.4	↑↑
		2023	9.5	5.5	↓↓	8.7	↓	8.6	↓	16.4	↑↑
2	Expenditure on electricity, gas, and other fuels as a proportion of the total household expenditure	2019	21.6	25.2	↑	19.1	↓	23.2	↑	17.6	↓
		2023	22.3	25.2	↑	25.0	↑	19.2	↓	19.3	↓

3	Average annual electricity prices for household consumers (with consumption from 2500 kWh to 4999 kWh)	2019	0.1364	0.1171	↓	0.1437	↑	0.1373	≈	0.1538	↑
		2023	0.1362	0.1278	↓	0.1392	≈	0.1444	↓	0.1396	≈
4	At-risk-of-poverty rate	2019	21.0	17.2	↓	19.3	↓	21.0	≈	26.3	↑↑
		2023	16.2	13.1	↓	13.7	↓	20.8	↑↑	18.0	↑
5	Heating degree days	2019	2639	3556	↑	2361	↓	2707	≈	1694	↓↓
		2023	2560	3271	↑↑	2357	↓	3066	↑	1228	↓↓
6	Cooling degree days	2019	140	26	↓↓	155	↑	57	↓↓	325	↑↑
		2023	65	18	↓↓	37	↓↓	38	↓↓	170	↑↑
7	Total population considering their dwelling as too dark	2019	5.2	4.0	↓↓	3.8	↓↓	7.1	↑↑	6.0	↑
		2023	5.6	4.2	↓↓	8.4	↑↑	4.6	↓	6.6	↑
8	Total population living in a dwelling with a leaking roof, damp walls, floors, or foundation, or rot in window frames or floor	2019	13.6	9.9	↓↓	13.9	≈	16.3	↑	15.7	↑
		2023	13.8	10.4	↓↓	17.7	↑↑	11.5	↓	18.5	↑↑
9	Housing cost overburden rate	2019	8.3	8.5	≈	5.9	↓↓	6.5	↓↓	10.6	↑↑
		2023	8.3	7.9	≈	8.2	≈	7.4	↓	9.6	↑
10	Final energy consumption in households per capita	2019	559	703	↑	539	≈	633	↑	352	↓↓
		2023	522	616	↓	551	≈	575	↑	325	↓↓

Trend symbols relative to the EU average (S): ↑↑—significantly above average, ↑—slightly above average, ≈—close to average, ↓—slightly below average, ↓↓—significantly below average.

Table A5. Characteristics of EU country classes based on average H&W diagnostic variables, relative to the EU average (2019 and 2023)—SOM classification.

No.	Diagnostic Variable	Year	EU		S	Class 2		S	Class 3		S	Class 4		S
			Average	Class 1		Class 2	S		Class 3	S		Class 4	S	
1.	Self-perceived health (from 16 to 64 years)	2019	67.16	74.64	↑	60.31	↓	58.25	↓	69.61	≈			
		2023	66.95	71.62	↑	64.83	↓	57.88	↓	68.71	≈			
2.	Self-reported unmet need for medical examination and care	2019	2.47	0.91	↓↓	2.16	↓	9.85	↑↑	2.55	≈			
		2023	2.56	1.08	↓↓	2.43	↓	5.97	↑↑	1.90	↓↓			
3.	Share of people with good or very good perceived health	2019	66.84	72.78	↑	70.36	↑	60.65	↓	58.50	↓			
		2023	66.97	72.12	↑	65.40	↓	66.23	≈	61.66	↓			
4.	Standardized preventable and treatable mortality	2019	289.92	210.40	↓↓	207.90	↓↓	337.16	↑	449.92	↑↑			
		2023	296.17	208.76	↓↓	232.91	↓↓	246.81	↓	466.18	↑↑			
5.	Happy Index	2019	6.44	7.27	↑	6.26	↓	6.52	≈	5.81	↓			
		2023	6.63	6.97	↑	6.73	↑	6.51	≈	6.24	↓			

Trend symbols relative to the EU average (S): ↑↑—significantly above average, ↑—slightly above average, ≈—close to average, ↓—slightly below average, ↓↓—significantly below average.

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