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COMPARATIVE SUSTAINABILITY AND RESILIENCE ASSESSMENT IN THE EU27 COUNTRIES

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Abstract

Building stable, adaptable and prosperous regions in the long term are objectives expressed by complementary concepts, such as regional resilience, sustainability and competitiveness. The need to achieve these objectives has been accentuated as a result of the Covid-19 pandemic, which has multiplied the efforts of EU countries to find new ways to promote sustainable, resilient economies; thus, it is worth mentioning the EU programmes and the temporary financial instruments launched by the European Commission. In this context, the authors of this paper propose a methodology for analysing the links between a series of economic indicators, the Sustainable Development Goals and the pillars of the Recovery and Resilience Facility (RRF), which represents the most important component of The Recovery Plan for Europe. The main research method is the cluster analysis,

employed in order to identify the grouping of the EU countries according to their similar characteristics with regard to the 12 analyzed indicators (e.g., the multidimensional poverty indicator, expenditures for the research and development sector, the share of energy from renewable sources and the rate of use of circular materials, etc.). In addition to this main objective there is also a secondary objective, that of comparing the results obtained by applying cluster analysis with those determined by means of the Regional Competitiveness Index 2.0. This study has highlighted the poor scores of Romania and Bulgaria regarding social services, besides the best outcomes both for these indicators and for renewable energy sources recorded by the Nordic countries. The results obtained in this research may contribute to formulating policy recommendations in the case of EU countries with low performance in terms of sustainability and resilience indicators.
Keywords: sustainable growth, Next Generation EU, renewable energy, K-means
JEL Classification: C38, I15, I32, Q2, Q56

1. Introduction

The Covid-19 pandemic was a turning point in the progress made by the Sustainable Development Goals (SDGs), as it was the first time a downward trend in the Sustainable Development Index was recorded. New problems also require new solutions, so that the EU had to create a plan to combat the adverse results of the pandemic: The Recovery Plan for Europe (European Commission, 2020), called NextGenerationEU, is a temporary instrument that is part of the European Union budget for the period 2021-2027, intended to complement the EU measures taken to support health, unemployment and credit for the private sector.

A central pillar of NextGenerationEU is the Recovery and Resilience Facility (RRF); this is built on six pillars, namely: (1) green transition, (2) digital transformation, (3) smart, sustainable and inclusive growth, (4) social & territorial cohesion, (5) health, and economic, social and institutional resilience, (6) policies for the next generation (European Commission, 2025). In the context of the RRF, each Member State develops and implements a National Recovery and Resilience Plan (NRRP) to benefit from the available funds.

To finance the other measures (i.e. to support health, unemployment and credit for the private sector), complementary European programmes are provided within NextGenerationEU, such as REACT-EU (Recovery Assistance for Cohesion and Territories of Europe). Additional funds are also brought to other programmes or funds such as Horizon Europe, InvestEU, EAFRD (European Agricultural Fund for Rural Development) and JTF (Just Transition Fund).

In this context, the main objective of the current research is to identify differences and similarities between EU Member States regarding their resilience and sustainability by employing a cluster analysis carried out via the K-means algorithm. The reason for using the K-means method is its popularity among researchers and the applicability of a recurrent and easy-to-follow algorithm (Jin & Han, 2011). The research is a sequel of the study conducted by Păuna et al. (2023), in which, based

on 12 indicators, a Principal Component Analysis was implemented: starting from these components, the cluster analysis was applied, which represents the core of this paper. The 12 indicators represent targets of several Sustainable Development Goals and, at the same time, are related to the six pillars of the Recovery and Resilience Facility (RRF).

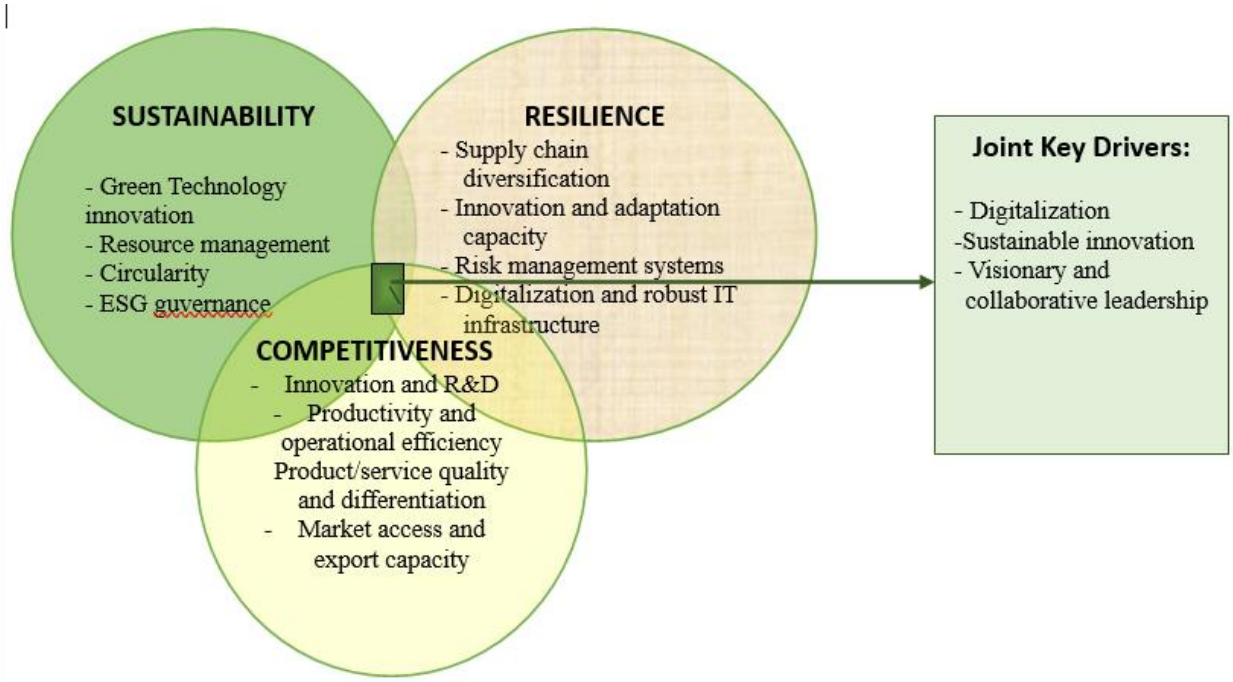
A secondary objective of this work is to compare the results obtained with the Regional Competitiveness Index (RCI 2.0). Although at first glance there may not seem to be a connection between RCI 2.0 and the other two concepts discussed, the indicators that make up this index are closely related to them. Moreover, the developers of this index define sustainability as the ability of regions to provide an attractive environment not only in the short term, but also in the long term (Dijkstra et al., 2023). Although this index defines the NUTS 2 performance, with some exceptions, there are no significant differences between regions within countries, so that the performance can be commented on at national level. This connection between RCI 2.0 and the resilience and sustainability of countries is also confirmed in current research by identifying similarities in the geographical results of the obtained clusters and the index values. Subsequently, for each cluster, a country (the country containing the most competitive region in that group) was chosen to compare the average of that class and the chosen region.

The added value of this study results from the combination of three important concepts: sustainability, resilience and competitiveness.

These concepts have certain dimensions which may overlap, but each of them is determined by specific essential factors. Sustainability refers to the ability of an organization or community to function in the long term without exhausting natural, social or economic resources. Resilience involves the ability to anticipate, respond and adapt to shocks (economic, climatic, health, etc.) and to quickly return to normal functioning. As a complement to this triad, competitiveness expresses the ability to perform better than the competition in the market in a sustainable way. To understand sustainability, resilience and competitiveness, it is important to identify their key drivers - the essential factors that determine success in these three directions. Figure 1 presents a synthetic scheme of the key drivers of the three concepts and the possible meeting points in the economy of a region.

Although combinations of competitiveness with sustainability (Bilbao-Terol et al., 2019) or with resilience (Borsekova et al., 2022) have been identified in the literature, to the best of our knowledge, few studies have been acknowledged to encompass all notions in a single paper.

Figure 1. Sustainability-Resilience-Competitiveness: Joint Key Drivers



Source: Own representation

Legend: ESG governance (Environmental, Social, Governance) = ESG governance;
IT = Information Technology; R&D = Research & Development

2. Literature exploration

Resilience and sustainability are concepts of global interest, with increasing attention to resilience triggered by the COVID-19 pandemic.

Regarding the European context, regional sustainability is debated by numerous authors. Thus, the impact of sustainability has been discussed since the Millennium Goals (United Nations, 2023), Dilly and Hüttl (2009) aiming to determine, through different methods, including cluster analysis, regions facing similar problems in terms of their sustainability; among them is the promotion of bioenergy. Also, through a cluster analysis, by using hierarchical algorithms, Popescu et al. (2017) aim to determine the sustainable competitiveness of European countries. The authors use four indicators to determine competitiveness: Human Development Index, Global Competitiveness Index, Environmental Performance Index and GDP per capita, forming different clusters for each of these indicators, studying the years 2008, 2010, 2012 and 2014. Among the results obtained, they note that Norway and Switzerland are the leading countries, with the highest performances for the indicators described, at EU level. The country that ranked most often in the leading cluster was Sweden, and Romania and Bulgaria were at the opposite pole.

On the role of clusters in the development of the sustainable economy, Derlukiewicz et al. (2020) note that they facilitate the sustainable growth of small and medium-sized businesses by encouraging stakeholder participation in the process of increasing sustainability in the business environment. The cohesion and sustainability of the EU is determined by analysing 14 indicators in the period 2006-2020 for NUTS2 regions. The results obtained describe, among others, the need to reduce disparities between EU regions (Ionescu et al., 2021). Another way to support regional economic development is related to the transition to green energy. Thus, for the period 2010-2020, EU Member States can be classified into three clusters where Germany, France, Italy, Spain, the Netherlands, and Bulgaria have values above the EU average. The second cluster contains countries such as Austria, Slovakia, Sweden, Finland, Sweden, Romania, Portugal, and Denmark for which values are average or slightly higher than the Union average. The Baltic States together with Cyprus, Malta, Luxembourg, and Slovenia form a third cluster with vulnerabilities in terms of sustainable energy development, with values below the EU average (Ionescu et al., 2022).

Studies addressing regional and local sustainability and resilience have been also carried out for other EU Member States such as Latvia, Poland, or Slovakia. In the case of Latvia (Judrupa, 2021), the main objective of the study was to identify through the Regional Competitiveness Index (RCI) those sustainable development strategies specific to each region by adjusting the sub-indexes presented in the RCI methodology (Dijkstra et al., 2023). For Poland, local resilience is to be achieved by switching fuels to renewable energy sources. A "Low Carbon Economy Plans" analysis is presented for the 10 largest cities (Verma et al., 2023). Slovakia's regional sustainability is described in terms of traditional local products produced by small farmers. What was noted after applying a questionnaire was that in more developed areas there was an affinity of respondents towards locally produced products, while in less developed areas (where income is lower), people were inclined to buy those products at the lower price (Jaďuďová et al., 2018).

Demertzis and Domínguez-Jiménez (2020) emphasize the need to adopt common fiscal measures at EU level to increase economic resilience and mitigate the disproportionate impact on different regions. Moreover, Steurer and Hametner (2013) discuss the gaps in the implementation and monitoring of sustainable strategies, suggesting that there is an urgent need for a harmonized framework at EU level. Furthermore, Martin and Sunley (2020) demonstrate that European regions with a diversified economic base and with constant investments in education and innovation have been better able to manage economic shocks and recessions. Evenhuis (2020) point out that adaptability and economic development are more pronounced in regions that prioritize innovation and interregional cooperation. Crescenzi et al. (2007) show that, in a context of crisis such as a

recession or global structural changes, economic competitiveness proves to be an essential factor for increasing resilience and reducing economic vulnerabilities.

Since experts who have dealt with the concepts of resilience and sustainability have a diverse approach, therefore, a systematization of several relevant titles from literature was proposed according to the following main themes: resilience in the context of the pandemic, regional sustainability frameworks, and correlation of resilience with economic competitiveness.

The comparison of the results obtained by the mentioned authors highlights diverse perspectives and confirms the correlation between economic resilience, regional sustainability and economic competitiveness, but also highlights differences in methodologies and approaches.

Studies on the resilience of EU states in the context of the Covid-19 pandemic, such as the one written by Incaltarau et al. (2024), contribute to the analysis of the economic resilience of European regions, emphasizing that European cohesion funds played a crucial role in mitigating the economic effects of the pandemic, especially in weaker regions in Eastern Europe. Also, within the same topic, Pickner et al. (2023) argue that post-pandemic economic recovery policies, such as Next Generation EU, not only ensured a faster economic recovery, but also contributed to reducing disparities between regions in the EU. On the other hand, Dilly and Hüttl (2009) provide a pre-pandemic perspective on economic shocks, discussing how financial crises affect regional systems unevenly. This prefigures observations in recent articles, such as those by Demertzis et al. (2020), which highlight that the lack of economic diversification in less developed regions makes them more vulnerable to shocks.

One of the papers that has researched the regional sustainability framework in the EU is the article published by Popescu et al. (2017) in which the authors explore the interaction between economic competitiveness and sustainability in the EU, arguing that investments in the green transition directly contribute to long-term economic growth. Similarly, Derlukiewicz et al. (2020) studies the circular economy in the European context, identifying a positive dynamic between regions implementing sustainable models and their long-term economic growth. This analysis confirms the conclusions of Gomonov et al. (2020), which focuses on solid economies based on recycling and resource efficiency.

Regarding resilience and economic competitiveness, recent studies, such as that of Ionescu et al. (2022), examine the relationship between competitiveness and adaptability, focusing on digital innovation as a driver for economic growth and resilience in EU regions. This theme is in line with Martin and Sunley (2020) and Evenhuis (2020) who emphasize the importance of economic diversification and research in increasing economic and regional resilience. The article by Pickner et al. (2023) introduces the perspective of digitalization as a fundamental factor of economic resilience

and competitiveness, an idea also supported by Zaharia and Bălăcescu (2020), who highlight digital divides as a key obstacle to the development of poorer regions within the EU. On the other hand, Dilly and Hüttl (2009) draw attention to the risks of economic centralization, arguing that these dynamics can limit long-term resilience, a conclusion that recent articles, which are more optimistic about interregional cooperation, do not reach.

Comparing these studies demonstrates a general consistency in identifying key drivers of economic resilience, regional sustainability and competitiveness in the EU. More recent studies, such as Incaltarau (2024) and Pickner (2023), place greater emphasis on digitalization, cohesion policies and integrated EU-wide responses, reflecting lessons learned during the pandemic. Older research, such as Dilly and Hüttl (2009) and Popescu et al. (2017), provides a solid theoretical basis on the impact of globalization and sustainable strategies, which is expanded and detailed by recent articles. Overall, all studies highlight the need to reduce regional disparities and to strategically invest in sustainability, innovation and economic diversification to ensure long-term prosperity within the EU.

3. Method

In this section, the cluster analysis will be described, as well as the calculation method of the EU Regional Competitiveness Index 2.0. First, the indicators employed as well as the data sources are presented (Table 1).

Table 1. Indicators

Indicator	Label	Measure	Source	SDG
Individuals using the Internet	I	% of population	World Bank	SDG4
GDP per capita	pib_cap	US$	World Bank	SDG8
People using safely managed drinking water services	safety_drw	% of population	World Bank	SDG6
People using at least basic sanitation services	bss	% of population	World Bank	SDG6
Multidimensional poverty headcount ratio	i_sm	% of total population	World Bank	SGD1
Immunization, measles	mm_vacc	% of children ages 12-23 months	World Bank	SDG3
Gross domestic expenditure on R&D	RD	% of GDP	Eurostat	SDG9
Forest area	PP	% of land area	World Bank	SDG15
Renewable energy sources in electricity	Ren_el	%	Eurostat	SDG13

Renewable energy sources	Ren_e_s	%	Eurostat	SDG13
People using safely managed sanitation services	safety_ss	% of population	World Bank	SDG6
Circular material use rate	CIRCULAR	%	Eurostat	SDG12

Source: Own representation

Furthermore, it is necessary to mention that the data were collected for 2022, which was the latest year available at the time this study was conducted. The indicators are targets of the Sustainable Development Goals, from which we have selected SDG1 - No poverty, SDG3 - Good health and well-being, SDG4 - Quality education, SDG6 - Clean water and sanitation and SDG8 - Decent work and economic growth, SDG9 - Industry, innovation and infrastructure, SDG12 - Responsible consumption and production, SDG13 - Climate action, and SDG15 - Life on land. In addition to their association with the SDGs, the indicators are closely linked to the six pillars that compose the Recovery and Resilience Facility. These pillars define transition to green economy (renewable energy sources, circular material utilization rate), digital transformation (percentage of people using the Internet), economic cohesion, productivity and competitiveness (GDP/capita), social and territorial cohesion (percentage of forest area, people using safely managed drinking water services, multidimensional poverty rate), economic resilience, social, medical and institutional (percentage of children aged 12-23 months immunized for measles) and policies for future generations (gross domestic expenditure on research and development).

The main objective was to reveal the similarities and dissimilarities between the EU Member States. To this end, a cluster analysis was carried out through Principal Component Analysis (PCA), applied to the 12 indicators above. The reduction of dimensionality by applying PCA was previously performed in a study conducted by Păuna et al. (2023), with the first four components taking over 73% of the variance of the initial data. The purpose of applying PCA is to take over as much of the variance of the initial data as possible, while maintaining the uncorrelation between the components, which are orthogonal. In this sense, most of the information is preserved, reducing information redundancy (Frades & Matthiesen, 2010). The application of PCA before implementing cluster analysis has been carried out in various studies such as Lu et al (2011) and Penkova (2017), the latter applying the K-means algorithm, which was also explored in our research. Haryati and Sugiyarto (2021), argued that PCA application before cluster analysis leads to better results compared to clustering performed on the initial data set.

Cluster analysis involves grouping objects according to their similarities and differences (Jain & Dubes, 1988). Among the most well-known methods for grouping entities into classes are K-means and hierarchical methods (Dalmaijer et al., 2022). The K-means algorithm involves granting a priori number of clusters chosen by the researcher (Ezugwu et al., 2021) with methods to identify the

optimal number of classes, including silhouette width and gap statistics (Sinaga & Yang, 2020). Among the application areas of this algorithm are facial detection, load pattern, wireless sensor networks, social tags (Ahmed et al., 2020). The reasons for choosing the K-means algorithm include efficiency and ease of use (Ikotun et al., 2023).

Our secondary objective was to compare the clusters' characteristics with those of the Regional Competitiveness Index 2.0. To this end, after applying the cluster analysis, a country was chosen from each of the four classes, accompanied by the most competitive region among those belonging to the countries that compose the four clusters. RCI 2.0 is a composite index of which 68 indicators are part. This index is calculated for each of the NUTS 2 regions that assemble the EU countries (Dijkstra et al., 2023). These indicators are grouped according to 11 pillars, which in turn belong to a number of three sub-indexes: Basic sub-index (consisting of Institutions, Macroeconomic Stability, Infrastructure, Health and Basic education), Efficiency sub-index (described by the indicators Higher education, Labor Market efficiency and Market size) and Innovation sub-index (composed of Technological readiness, Business sophistication and Innovation).

4. Results and discussion

This section is dedicated to the cluster analysis and the comparison of the results obtained with the Regional Competitiveness Index.

4.1. Cluster analysis: K-means algorithm

For the main objective, the starting point is represented by the PCA results obtained by Păuna et al.(2023). Subsequently, the results of the cluster analysis carried out in the current research were provided and, through the grouping of classes and principal components, the similarities and differences between the member countries of the EU were revealed.

Thus, Table 2 shows the correlations between the main components and the analyzed indicators.

Table 2. PCA

	Comp.1	Comp.2	Comp.3	Comp.4
I	0.70	0.02	0.47	0.23
pib_cap	0.60	0.14	0.61	-0.01
safety_drw	0.64	0.19	-0.17	0.39
bss	0.76	0.16	-0.37	0.05
i_sm	-0.65	-0.19	0.36	-0.22
mm_vacc	0.52	-0.13	0.32	0.36
RD	0.77	-0.29	-0.24	-0.25
PP	0.17	-0.76	-0.25	0.16

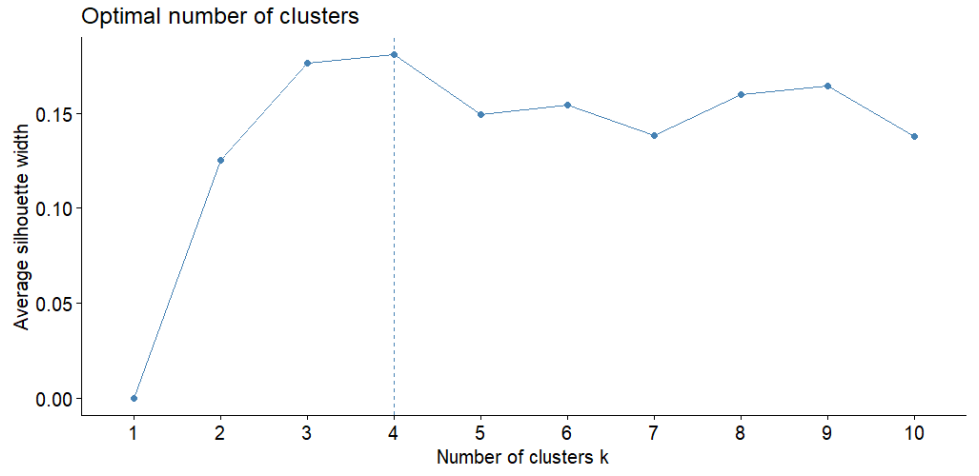
Ren_el	0.24	-0.81	0.12	-0.26
Ren_e_s	0.16	-0.95	-0.05	0.00
safety_ss	0.54	0.12	0.27	-0.62
CIRCULAR	0.54	0.44	-0.31	-0.40

Source: own representation

According to Păuna, et al. (2023) four components have been identified:

- Comp.1: Social services and development (this being positively correlated with the indicators People using safely managed drinking water services, People using at least basic sanitation services, Immunization, measles, Gross domestic expenditure on R&D, and negatively with Multidimensional poverty headcount ratio);
- Comp.2: Environmental protection (correlates negatively with Forest area, Renewable energy sources in electricity, Renewable energy sources);
- Comp.3: Digital Economy (correlates positively with Individuals using the Internet and GDP per capita);
- Comp.4: Environmental development through production and sanitary safety (which correlates negatively with the indicators People using safely managed sanitation services and Circular material use rate).

Figure 2. Silhouette coefficients



Source: own processing

To determine the number of clusters, silhouette coefficients were calculated for grouping countries into one to 10 classes. According to Figure 2, the highest average silhouette coefficient was calculated for four classes. Thus, by applying the K-means algorithm, the four clusters were illustrated in Table 3.

Table 3. Clusters

Cluster	Countries
1	Romania, Bulgaria
2	Sweden, Finland, Austria
3	Ireland, Denmark, Germany, Netherlands, Belgium, Luxemburg, Malta and Spain
4	Estonia, Latvia, Lithuania, Poland, Czechia, Slovakia, Slovenia, Hungary, Croatia, Greece, Cyprus, Italy, France and Portugal

Source: own representation

Table 4 presents the means of the four clusters for the four main components. In the case of the component intended to describe social services and development, the lowest mean was assigned to cluster 1, a sign that it faces the worst performance for this index, with cluster 2 at the opposite pole. From the point of view of environmental protection (Comp.2), cluster 2 also presents the best performance, together with cluster 1; in a diametrically opposite situation is cluster 3, which is characterized by the lowest values of forested area and renewable energy sources. The third component was positively correlated with the percentage of people who used the internet, but also with GDP per capita, in this situation cluster 3 excelling with the highest average of scores, while cluster 4 displays the lowest values. For component 4 the lowest average score was noted for cluster 1, while the highest average score was observed for cluster 4.

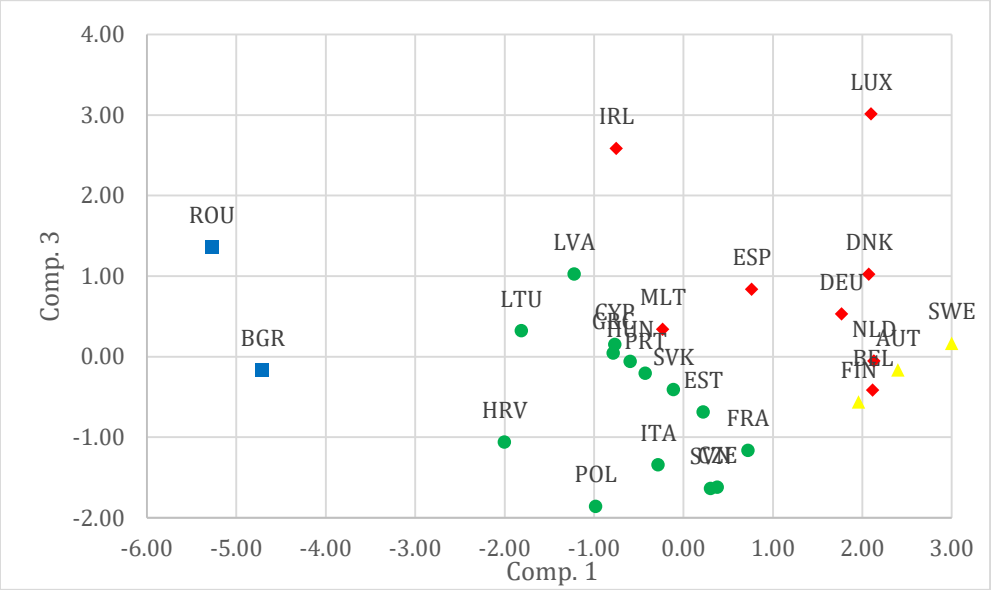
Table 4. Cluster means

Cluster	Comp.1	Comp.2	Comp.3	Comp.4
1	-4.99	-0.82	0.60	-0.87
2	2.46	-2.83	-0.19	-0.13
3	1.25	1.10	0.98	-0.20
4	-0.53	0.10	-0.61	0.27

Source: own representation

For a clearer illustration of the performances of each cluster and each country, Figures 3 and 4 present the results obtained by country for the four main components.

Figure 3. Cluster analysis – Components 1 and 3

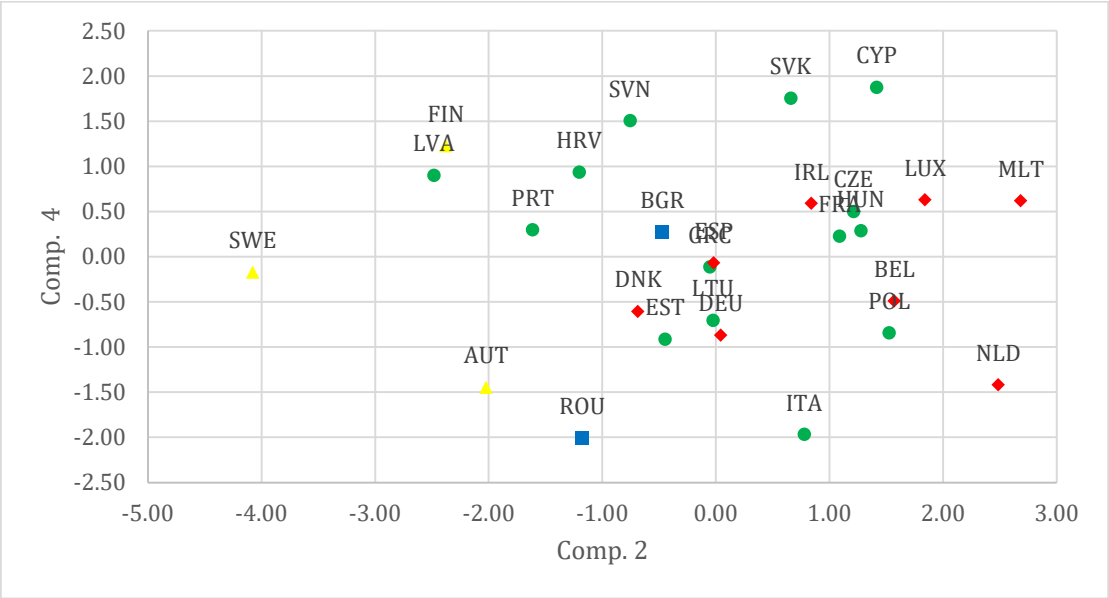


Source: own processing

Figure 3 displays the grouping of countries into clusters according to the oX (Comp.1) and oY (Comp.3) axes. It can be noted that Romania and Bulgaria form a cluster (cluster 1), being defined by the lowest values recorded for Social Services and Development and average values for Digital Economy. Cluster 2, composed of Sweden, Austria and Finland, is characterized by the highest values of Social Services and Development, but low to medium values for Digital Economy. Luxembourg, Denmark, the Netherlands, Belgium, Germany, Spain, Malta and Ireland form the third cluster, which has high values for Social Services and Development and medium to high values for Digital Economy. The remaining countries form the fourth cluster described by medium to high values for the first principal component, but small to medium values for the third.

Regarding the determination of the characteristics of the clusters according to the main components two (Environmental protection) and four (Environmental development through production and sanitary safety), it is noted that the countries composing the second cluster have the lowest values recorded for Environmental protection (having the highest percentages of renewable energy, but also of forested areas). Cluster 1 is described by average values in terms of Environmental protection, cluster 4 presents small to medium values, while cluster 3 is defined by the presence of the highest recorded values, a sign that it faces the smallest forested areas, as well as the lowest percentages of renewable energy sources. For the placement of the countries according to the fourth component, Environmental development through production and sanitary safety, the countries that make up the clusters cover values from the entire oY axis, only cluster 3 being defined by average values (Figure 4).

Figure 4. Cluster analysis – Components 2 and 4



Source: own processing

Table 5 shows the decomposition of data variability for this grouping of countries into clusters.

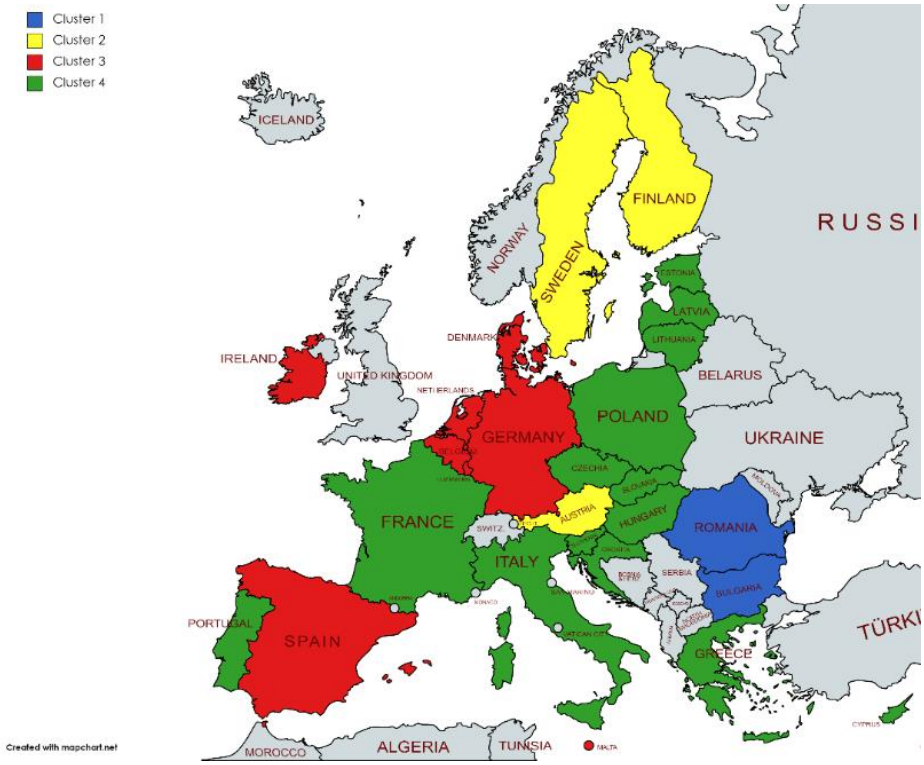
Table 5: Variability decomposition

Total	Within	Between	Between/Within
236.46	100.70	135.76	1.35

Source: Own representation

It can be noted that the total variance is 236.46, being divided into variability within (100.70) clusters and variability between (135.76) them. A grouping of countries into clusters is good when the variability between clusters is as high as possible, and the ratio of between-class and within-class variability is above unity (1.35>1).

Figure 5: Cluster map



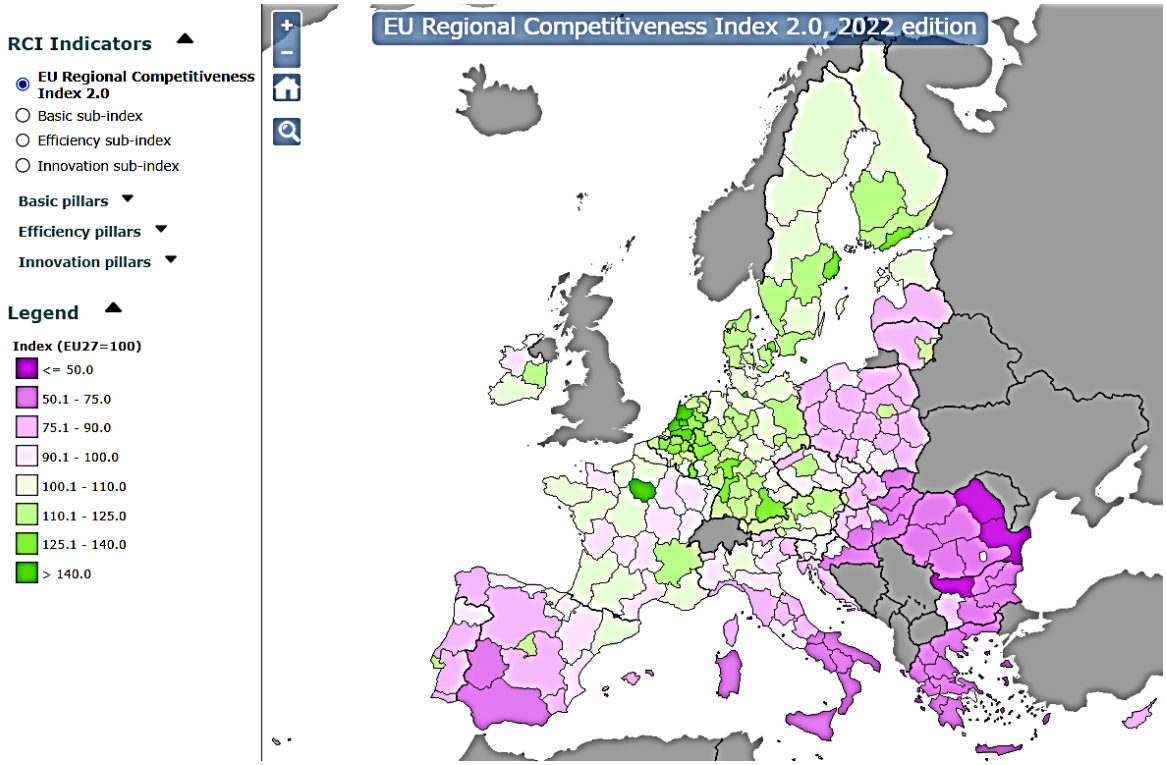
Source: own processing using mapchart.net

According to the visualization of the geographical location of the clusters (Figure 5), it is noted that the countries of the north of the EU (Sweden and Finland), together with Austria, are described by the highest values recorded for Social Services and Development and Environmental protection, while the southeast (Romania and Bulgaria) is described by the lowest values for Social Services and Development, but with average values for the other main components analyzed.

4.2. Comparison with the Regional Competitiveness Index

To achieve the secondary objective of the paper, in this subsection the Regional Competitiveness Indicator (RC1 2.0) for the 27 EU member states is brought into discussion, subsequently analysing the performance of some regions belonging to the four clusters mentioned in the previous subsection.

Figure 6. EU Regional Competitiveness Index 2022



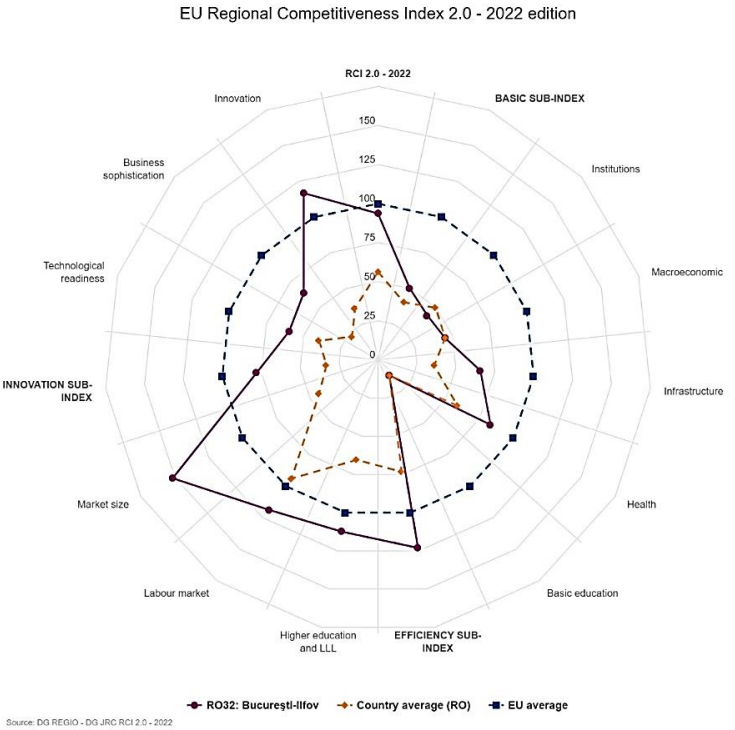
Source: https://ec.europa.eu/regional_policy/assets/regional-competitiveness/index.html#/

Figure 6 shows the values recorded by the EU regions for the 2022 edition of the Regional Competitiveness Index. Compared to the results in Figure 3, it is noted that cluster 1 coincides with the lowest values recorded by RCI 2.0, and cluster 2 overlaps the regions with the highest values of this index.

The region with the highest RCI 2.0 registered in cluster 1 is Bucharest-Ilfov (Figure 7). The comparison between the values recorded by this region and the average of the country to which this region belongs (Romania), shows that it exceeds by far almost all the indicators presented, with the exception of Institutions (where the average of Romania exceeds the average of the region) and Basic education (where the values overlap).

Regarding the comparison with the EU average, it is noticed that for all the indicators making up the Basic Sub-Index, the region registers lower values than the EU average.

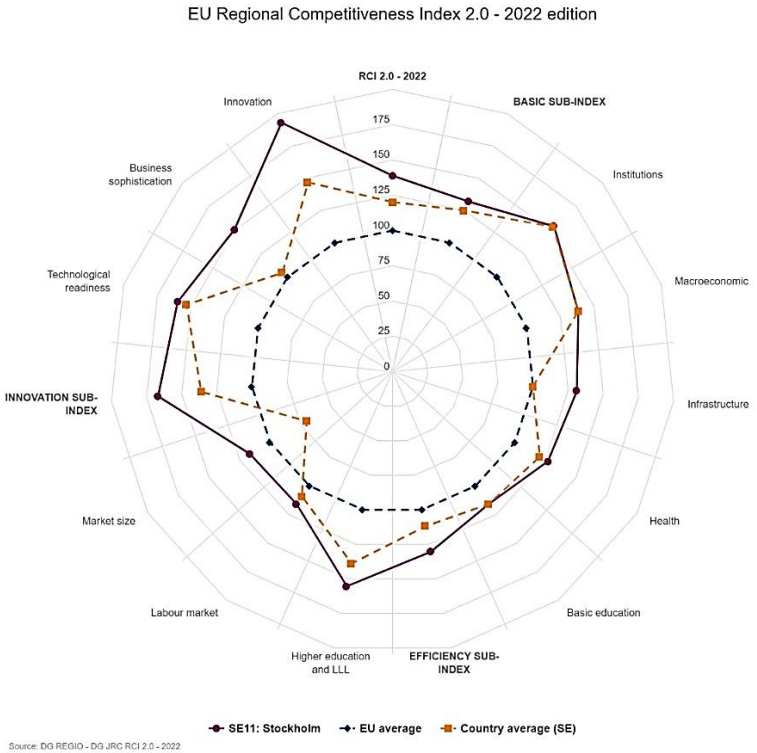
Figure 7. RCI 2.0 RO32



Source: own processing

The same can be said about the indicators in the Innovation Sub-Index, with the exception of Innovation; and for the indicators that make up the Efficiency Sub-Index, the region outperforms the EU27 average.

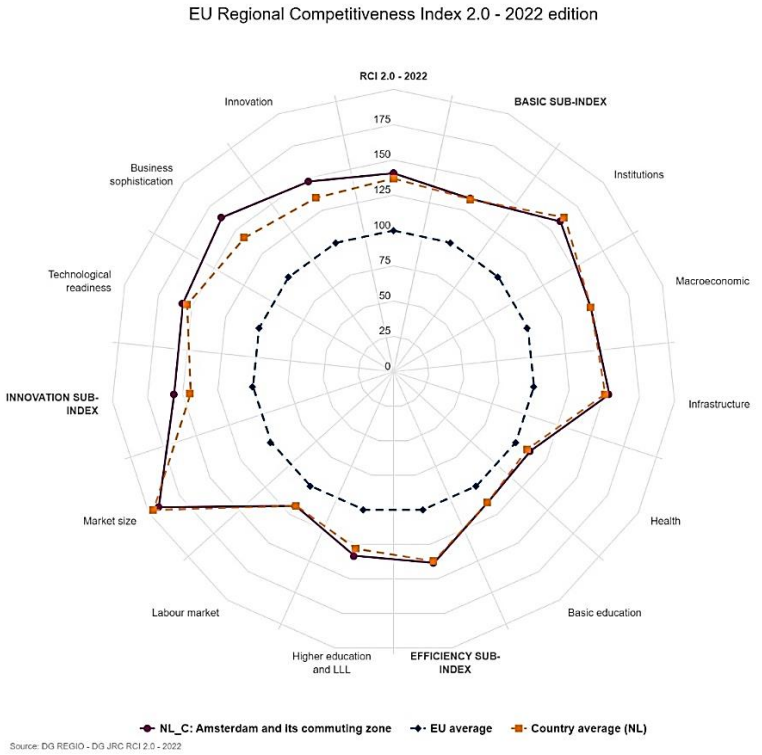
Figure 8. RCI 2.0 SE11



Source: own processing

On behalf of the second cluster, the region with the highest RCI 2.0 is Stockholm (Figure 8). Comparing the region with the country's average, it is noted that in most cases, the region's values exceed the average, and there are also situations where they overlap (Institutions, Macroeconomic, Basic education). Analysing this indicator by comparing it with the EU average, it is highlighted that all the recorded values exceed this mean.

Figure 9. RCI 2.0 NL_C

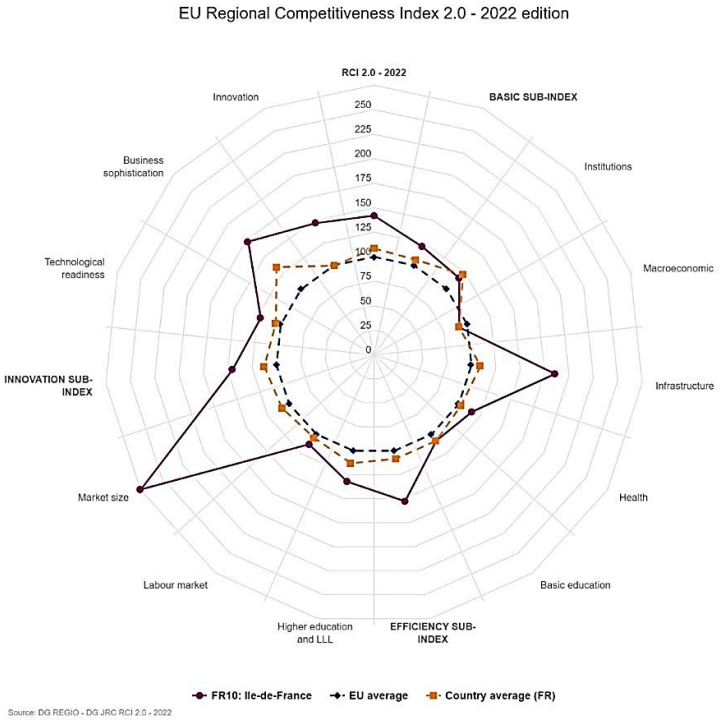


Source: own processing

Considering the third cluster, the region with the highest RCI 2.0 is Amsterdam and its commuting zone. From Figure 9 it can be noted that both the region and the country average exceed the EU average for all the indicators analyzed by this index. For the comparison between the analyzed region and the average of the country to which it belongs, areas where the region exceeds or overlaps with the average are noted, with the exception of Institutions and Market size, where the values of the region are very slightly lower than those of the country.

For the last cluster presented, the region with the highest RCI 2.0 is Ile de France, and, according to Figure 10, the only indicator for which the EU average exceeds the region's values is Macroeconomic.

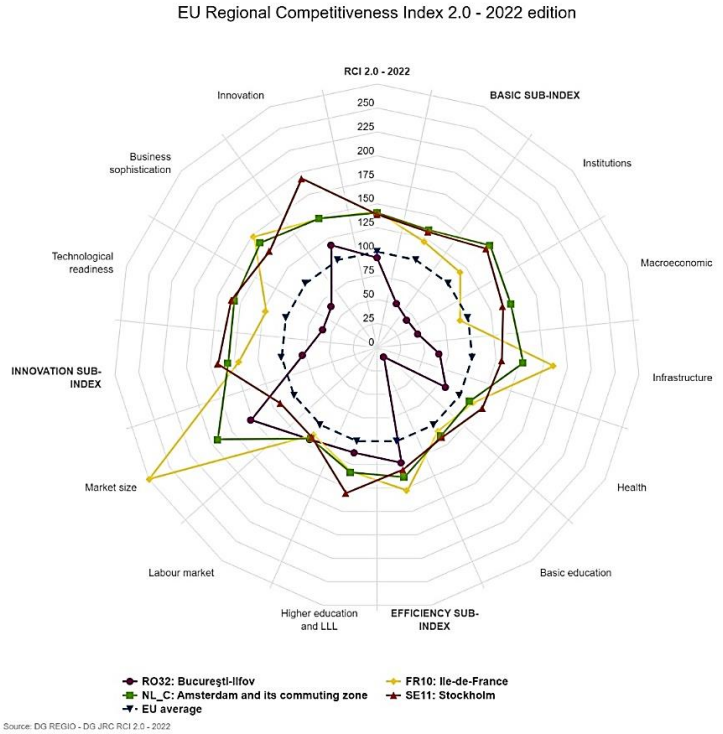
Figure 10. RCI 2.0 FR10



Source: own processing

Viewing the comparison with the average of France, it is pointed out that for Macroeconomic and Basic education the values overlap, and for Institution its value exceeds that of the region.

Figure 11. RCI 2.0 four regions



Source: own processing

Regarding the year 2022, it is noted that the values for the Ile de France (FR10), Amsterdam and its commuting zone (NL_C) and Stockholm (SE11) regions are very close, whereas the Bucharest-Ilfov region (RO32) has a much lower value (Figure 11). From the Basic Sub-Index point of view, it is observed that the values for the NL_C and SE11 regions are very close, followed by the FR10 region, and a lower value is recorded for the RO32 region (being the only one with a value below the EU average). For the Efficiency Sub-Index, the values of the four regions are much closer, all exceeding the EU average; the FR10 region records the highest value, followed by NL_C, SE11, and the last ranked region is, again, the RO32 region. For the Innovation Sub-Index, the RO32 region is the only one below the EU27 average, all other regions having close values in descending order being SE11, NL_C and FR10.

Looking at the evolution of the European ranking for RCI 2.0 (Table 6), it is noted that although in 2016 and 2019 Stockholm managed to rank in the top three countries, in 2022 it fell to the sixth position. Although the Ile de France region ranks fifth in 2016, it advances to the podium of the first three regions in the next two analysed periods, and with regard to the Amsterdam region and its commuting zone, there is an increase from one analysed period to another. Although the other three analyzed regions were always in the top 10 countries in terms of the values recorded for RCI 2.0, for the Bucharest-Ilfov region the highest position reached is 124 in 2019. Although it managed to increase from 150 recorded in 2016, for the year 2022 it dropped five positions reaching 129.

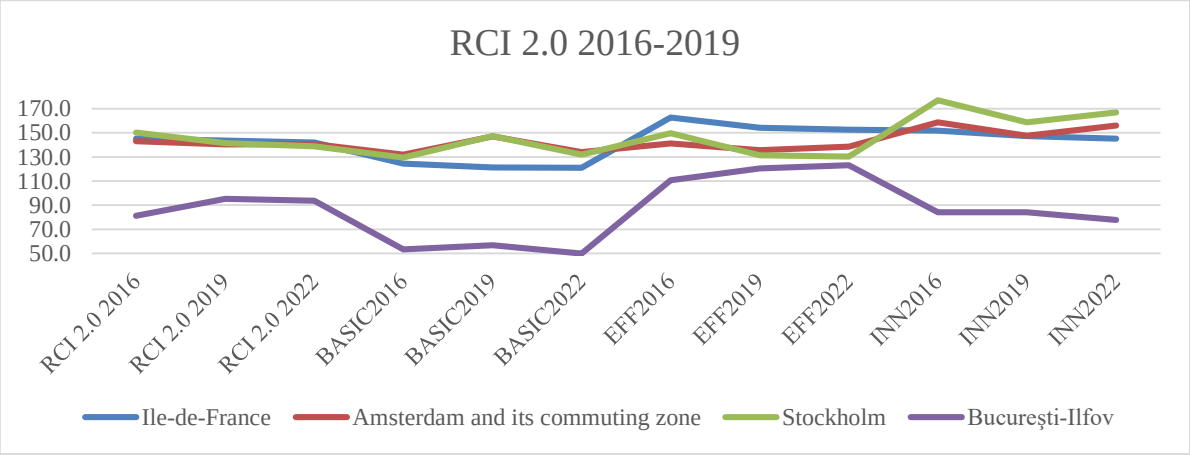
Table 6. RCI 2.0 ranking

Region	Label	RANK2016	RANK2019	RANK2022
Ile-de-France	FR10	5	2	3
Amsterdam and its commuting zone	NL_C	9	5	4
Stockholm	SE11	2	3	6
Bucureşti-Ilfov	RO32	150	124	129

Source: Own representation

For the evolution over time of RCI 2.0, but also of the three main sub-indices, it can be noted from Figure 12 that the first regions of Ile-de-France, Amsterdam and its commuting and zone and Stockholm have close values, the Bucharest-Ilfov region presenting values far below those of the others, the only area in which it seems to come close to their performances being Efficiency.

Figure 12. RCI 2.0 2016-2019



Source: Own representation

A bird's eye view shows that the results of our research can be placed in the same register as those of the studies mentioned in the section dedicated to specialized literature.

Thus, according to Incaltarau et al. (2024) and Pickner et al. (2023), countries with more robust economic systems such as Germany and France have directly benefited from efficient national mechanisms, compared to vulnerable regions in Eastern Europe.

An unprecedented acceleration of digitalization in response to the pandemic is also highlighted. Countries that are already digitally advanced (e.g. Denmark, Sweden) have demonstrated faster adaptability. Zaharia and Bălăcescu (2020) support the need for increased investments in digitalization to raise resilience in regions lagging behind.

Steurer and Hametner (2013) identify Nordic and Western European countries (Sweden, Netherlands, Germany) as leaders in integrating economic, social and environmental sustainability into their regional policies. They use advanced indicators to monitor progress and implement strategies aligned with the European Green Deal agenda. On the other hand, studies by Kacperska and Łukasiewicz (2020) and Popescu et al. (2017) show that Central and Eastern European (Visegrád) regions face difficulties in the transition to a sustainable framework due to fossil fuel dependence, insufficient investment and poor coordination between national and regional policies.

Gomonov et al. (2021) suggest that integrating the circular economy can accelerate the sustainable transition. Countries such as the Netherlands and Belgium perform excellently due to advanced recycling systems, while Eastern Europe still relies on traditional waste management practices.

Studies by Martin and Sunley (2020) and Ionescu et al. (2022) indicate a close link between competitiveness and innovation capacity. Countries that invest heavily in R&D, such as Finland and Germany, strengthen their resilience in the long term.

Evenhuis (2020) underlines that regions dependent on a single economic sector are more vulnerable to crises. In this regard, policies should include support for diversification of economic sectors, especially in Eastern Europe.

Yuniarta et al. (2023) show that well-developed social protection systems, typical of Northern Europe, support not only economic resilience but also innovative performance, providing a stable basis for competitive growth.

Popescu et al. (2017) and Derlukiewicz et al. (2020) conclude that the energy transition, through the adoption of green energy, has a positive impact on economic resilience and competitiveness, indicating a critical need to accelerate the transition in less performing regions.

The overall results indicate the disparities between EU regions, but also the common opportunities in areas such as digitalization, the green transition and the circular economy. Nordic and Western European countries dominate most indicators of resilience, sustainability and competitiveness, while less developed regions in Eastern Europe require greater investment and coordinated policies at European level to reduce the gaps. Overall, sustainable development, innovation and interregional cooperation are essential for building a more balanced and better performing European Union.

5. Conclusion

According to the main objective, this paper has aimed to determine the degree of sustainability and resilience registered by the EU member states. The first step to achieve this objective was to perform a cluster analysis to determine the similarities between countries based on four main components made up of 12 initial indicators. Following this analysis, it has been found that Romania and Bulgaria recorded the lowest values regarding Social services and development (this component, describing the percentage of people who use safely managed drinking water services, but also at least basic sanitation services, is also composed of the percentage of children immunized for measles, but also of the indicator of multiple poverty, as well as of Gross domestic expenditure on R&D). For the other three main components presented, this cluster was characterized by average values. The second identified cluster (composed of Austria, Finland and Sweden) was characterized by the highest values recorded for the Social services and development component, but also for Environmental protection (a sign that the percentage of forested areas as well as that of sources of renewable energy reach the highest EU values).

For the third cluster, the presence of medium to high values is found for the Social services and development component, but also for the Digital Economy (this also assumes the presence of medium to high values for the percentage of individuals using the Internet and GDP per capita). For Environmental protection, the values are high (a sign that the percentages of wooded areas, but also those of renewable energy sources are low), while for the fourth component, the values exposed are middling (average values for the percentage of people using safely managed sanitation services and circular material use rate). The fourth cluster includes half of the EU member states medium for Social services and development and small to medium for Digital Economy, also for Environmental protection the values are predominantly medium to high (thus having a small to medium percentage of forested areas and renewable energy sources).

Next, to achieve the secondary objective, the performance of NUTS 2 regions was illustrated through the lens of RCI 2.0 and an attempt was made to compare them with the results provided by using the cluster analysis. It has been found that the first group corresponds to the regions with the lowest index values, while the second cluster corresponds to some of the highest RCI 2.0 values for the year 2022. Also, for most of the countries belonging to cluster three, regions with medium to high values are identified, while the majority of the countries composing cluster four present regions with medium to low RCI 2.0 values. Regarding the analysis of the regions (containing the capitals) with the highest values recorded for the four clusters, it is noted that whereas in the case of the Ile-de-France, Amsterdam and its commuting zone and Stockholm regions the values are close to each other, the Bucharest-Ilfov region is far below them, the only sub-index with small differences compared to the other regions is Efficiency.

The results obtained suggest a series of policy recommendations to promote resilient economic development, regional sustainability and competitiveness in the European Union (EU). They indicate that there is a need to increase funding for poorer regions in Eastern Europe to boost economic diversification, digital infrastructure and education. EU policies should be tailored to the needs and characteristics of each region, including those through local strategies for diversifying economies dependent on a single sector. Moreover, policy measures should facilitate the transfer of knowledge and good practices between advanced (e.g. Nordic) and less developed (e.g. Eastern European) regions. It is essential that Member States invest in digital training to increase the skills of the population, especially in disadvantaged regions.

Marginalized regions need significant investment in high-speed internet and access to technology to mitigate the effects of digital exclusion. In addition, Member States should adopt policies that encourage recycling, waste reduction and the optimization of natural resources to support the circular economy. Furthermore, public and private funds should strongly support research and

development of innovative green energy solutions. Economic resilience can be strengthened through cooperation at EU level, as suggested by the pursuit of frameworks similar to Next Generation EU for future crises.

Most studies converge to the conclusions that European leaders in various areas are the Nordic and Western European countries, thanks to their advanced infrastructure, high innovation capacity and sustainable strategies. On the other hand, the Eastern European and Visegrád Group countries face structural challenges, investment deficits and competitiveness gaps. The results suggest an acute need for uniform policies and support at EU level in areas such as digitalization, green transition and combating social exclusion.

Policy recommendations based on these studies underline the need for an integrated and coordinated approach at EU level to ensure sustainable economic development, increase resilience and reduce regional disparities. Digitalization, the green transition, supporting innovation and increasing cohesion between Member States are recurring themes that require sustained action to meet the challenges of the future.

Nevertheless, our study has limitations. The first limitation refers to the number of indicators. Obviously, there is a larger number of indicators designed to study sustainability as well as resilience; however, by investigating both concepts, their number was narrowed down to encompass the two notions. Moreover, depending on the chosen clustering method, the results may differ; but, given the popularity of the method, as well as the application of PCA in the study that our research was connected with, this technique proves to be a useful one.

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