

ASSESSING OPEN DATA MATURITY ACROSS EUROPE: EVIDENCE FROM A CLUSTER ANALYSIS

Iwona ZDONEK^{1*}, Anna SOŁTYSIK-PIORUNKIEWICZ²

¹ Silesian University of Technology; iwona.zdonek@polsl.pl, ORCID: 0000-0002-3377-0904

² University of Economics in Katowice; anna.soltysik-piorunkiewicz@ue.katowice.pl,

ORCID: 0000-0002-7935-1377

* Correspondence author

Purpose: The aim of this article is to determine the state of open data maturity in European countries. Two research questions were addressed: RQ1: What are the distributions of the main dimensions describing open data maturity in European countries? RQ2: What is the stratification of European countries in terms of open data maturity?

Design/methodology/approach: To achieve the aim of the article, an analysis of the open data maturity dimensions for 34 European countries was carried out based on data from 2024. The distributions of these dimensions were analyzed, and a cluster analysis was performed on the collective open data maturity indicators and for each dimension individually.

Findings: The results indicate that open data maturity among European countries is high, and these countries can be divided into two clusters. The cluster of countries with high open data maturity is more numerous.

Research limitations/implications: Due to the small number of observations, cluster analyses were conducted on a limited number of grouping variables. The study covered only European countries. Future research could include studies comparing the open data maturity of European countries with other countries.

Practical implications: Our research has revealed which European countries are leading the way in open data maturity. Observing the solutions implemented in these countries can help other countries improve their open data maturity.

Social implications: Because comparing open data enables countries to learn from each other, the societal implications of our research are related to strengthening the European data community. This builds cohesion among EU member states in terms of openness, interoperability, and digital transformation.

Originality/value: The novelty of our research is that we present clusters of European countries not only in terms of overall open data maturity, but also in terms of individual dimension indicators. This provides broader insight into which European countries are leaders in open data maturity and identifies them as countries worth emulating.

Keywords: open data, open data maturity, cluster analysis.

Category of the paper: Research paper.

1. Introduction

Public sector open data is data collected by public bodies that is made available free of charge for reuse for any purpose (Lnenicka et al., 2024; Cunha et al., 2024). Public sector data is therefore shared on a non-personal and non-commercial basis. This way, citizens' rights to protect personal data are not violated, nor are commercial entities' trade secrets violated. Open data becomes a source of innovation, not only digital but also environmentally friendly. It is a raw material for businesses and startups, enabling the creation of new data-driven services, applications, and products (Mohamad, 2025). Additionally, opening public data strengthens the transparency and accountability of institutions towards citizens, which contributes to building social trust.

Open data maturity reports indicate that development across the four dimensions of open data maturity (Policy, Portal, Impact, and Quality) is uneven. For example, in the 2019 report, the Impact dimension was the weakest among EU countries (Blank, 2020). In the 2023 report, the average maturity increased, and the increase in Impact and Quality was the most significant (Page et al., 2023). This suggests that while countries are making progress overall, there are still significant differences in the pace of development across dimensions. Therefore, although open data maturity reports present aggregated data, the literature lacks in-depth analysis based on statistical modeling that describes how countries differ not only in their overall maturity but also in their profiles across dimensions. Therefore, there is an urgent need to fill this research gap. Therefore, this paper addresses two research questions:

RQ1: What are the distributions of the main dimensions describing open data maturity in European countries?

RQ2: What is the stratification of European countries in terms of open data maturity?

The authors of this article aimed to answer the research questions posed. This goal was achieved through a literature review and analysis of variables measuring open data maturity in 2024 in European countries. The analysis was conducted by examining the distributions of variables describing the dimensions and performing cluster analysis on each of the open data maturity dimensions.

The novelty of our research is that we present clusters of European countries not only in terms of overall open data maturity, but also in terms of individual dimension indicators. This provides broader insight into which European countries are leaders in open data maturity and identifies them as countries worth emulating.

The structure of the article is guided by the stated goal. First, a literature review is presented, focusing on the potential of open data in digital and green transformations and presenting the dimensions of open data maturity. This is followed by a presentation of the analytical methodology, followed by the analytical results, and finally, a discussion of the obtained results.

2. Literature background

2.1. The potential of open data

In the digital era, open public data (ODG) has become a key element in the transformation of governance towards data-driven models. In this way, they represent an important initiative for the development of the digital economy. An analysis of the literature on public open data revealed that public data is disclosed to unlock its intrinsic value and foster innovation and digital transformation (Lan et al., 2025; Sun et al., 2025; Wang, Zhou, et al., 2025; Chen, Zhang, 2024). It was found that OGD has a positive impact on the innovativeness of enterprises, and this is achieved mainly by reducing information asymmetry of enterprises, increasing the scale of acquiring enterprise resources and improving the operational efficiency of enterprises (Sun et al., 2025). The use of open data is currently a rapidly growing area of research in academia, and businesses are the main actors encouraged to use public data to generate value (Chen, Zhang, 2024). This is due to the fact that the digital transformation of enterprises is necessary to obtain new strategic advantages in the future and support high-quality development.

Public data exhibits the characteristics of public goods. This means that many businesses can access public data resources without increasing costs, or even for free. In this way, public data provides businesses with a competitive advantage in terms of cost. Moreover, public data has strong integration capabilities and can be incorporated into management, production, and sales processes in various ways. This enables data integration and the digitization of products, services, and processes. This is how digital transformation and organizational change are fueled, stimulating the development of new products, processes, and technologies (Chen, Zhang, 2024). Additionally, open data supports the green transformation by enhancing environmental performance (Zhou, Huan, 2024; Ling et al., 2025; Luo et al., 2025; Xing et al., 2024; Xu, Mu, 2025; Wu, Xie, 2024; Wu, 2024; Wang, Chen et al., 2025; Peng, Xiao, 2024). For example, open meteorological, hydrological, geographic, and energy data allow companies to optimize energy consumption, plan logistics, and manage environmental risks. Furthermore, publicly available emissions data helps companies monitor their own environmental indicators and benchmark themselves against the industry. Open data enables the creation of new products, applications, and business models that help reduce environmental impact. Examples include smart grid systems, carbon footprint tracking tools, and circular economy platforms. When businesses and public institutions share data (e.g., on waste, energy, logistics), data ecosystems are created that support the circular economy. This facilitates, among other things, recycling, the exchange of secondary raw materials, and the planning of low-emission supply chains (Dwivedi et al., 2023). This confirms that green innovations are one of the most important paths to reducing the impact of climate change and achieving global environmental sustainability (Guo et al., 2025).

2.2. Open data maturity

Open Data Maturity (ODM) is an annual assessment of European countries regarding the extent to which public sector data is open, the extent to which its reusability is supported, and the structures and mechanisms in place for this process. Data is collected via a survey. Participation in ODM is voluntary. It covers the EU-27, EFTA countries, EU candidate countries, and other European countries.

Open Data Maturity is a framework for assessing countries' progress in implementing and managing open data policies (EU, 2024a). It encompasses four key dimensions: Policy, Portal, Quality, and Impact. Together, they provide a comprehensive picture of the development and effectiveness of national open data ecosystems. Each dimension has its own indicators, which serve as survey questions, allowing a country to receive points.

The Policy dimension refers to the strategic and institutional framework supporting the implementation of open data initiatives. It encompasses the existence of national legal frameworks or open data strategies, as well as mechanisms for governance and coordination between different levels of government: national, regional, and local. Furthermore, the degree of policy implementation is analyzed, including data publication plans, monitoring mechanisms, and actions promoting and supporting data reuse. This dimension is measured by indicators such as the policy framework, governance of open data, and open data implementation (EU, 2024a). A mature policy in this area means that open data is an integral part of the country's broader digital strategy, and its implementation is systematic and long-term.

The Portal dimension addresses the features and functionality of national open data portals. The assessment assesses the availability of user-centric features and advanced tools, such as search engines, opinion and feedback mechanisms, and discussion forums. The availability of usage statistics, the portal's durability and stability, and the thematic and administrative scope of published data are also considered. This dimension is measured by indicators such as: portal features, portal usage, data provision, and portal sustainability (EU, 2024a). A well-developed data portal provides a central point of access to public sector information, supporting transparency in government activities and user engagement.

The Quality dimension refers to the completeness, accuracy, and timeliness of published data and metadata. Metadata compliance with international standards, such as DCAT-AP, as well as the degree of automation of metadata acquisition and integration processes from various sources, are assessed. High data quality is crucial for effective reuse, ensuring interoperability, and building trust among users. This dimension is measured by metrics such as: metadata currency and completeness; monitoring and measures; DCAT-AP compliance; and deployment quality and linked data (EU, 2024a). The dimension therefore reflects the technical and organizational maturity of open data management processes in each country.

The Impact dimension focuses on measurable outcomes and benefits resulting from open data reuse. It includes assessing strategic awareness and the existence of mechanisms to monitor, promote, and support data reuse. It also examines evidence of specific cases of use and their tangible impacts. This dimension encompasses various types of impact, including economic, social, environmental, and political. It demonstrates the contribution of open data to innovation, public policymaking, and societal development. Measuring impact, however, is one of the greatest challenges in assessing open data maturity, as it requires both qualitative and quantitative evidence of actual effects. This dimension is measured by indicators such as: strategic awareness; measuring reuse; and created impact (EU, 2024a).

In recent years, many countries have made significant progress in disclosing public data (Sołtysik-Piorunkiewicz, Zdonek, 2021; Zdonek, Sołtysik-Piorunkiewicz, 2021; Zdonek, 2021; Luo et al., 2025; EU, 2024a). However, differences persist in the diversity and quality of data shared by these countries. These differences should be monitored and addressed. According to what we could find, there are no studies addressing and reporting on differences between European countries in specific dimensions of open data maturity. That's why we decided to conduct our own research to fill this research gap.

3. Methods

Data on open data maturity in individual European countries is for 2024. It was taken from the official European Union website dedicated to open data (EU, 2024b). This data is collected annually to measure European countries' progress in promoting and facilitating the accessibility and reuse of public sector information. The data is collected through a survey that measures open data maturity across four dimensions, each measured by separate indicators. This method collected data for 34 countries, measuring 23 variables. The data included variables related to the dimensions of open data maturity and indicators describing these dimensions. The data also included the overall open data maturity for each country. This variable was called Composite Maturity and was calculated from four main dimensions.

To answer the first research question, we examined the distributions of the four dimensions of open data maturity and the overall maturity variable Composite Maturity. Boxplots were constructed for these five variables, allowing for the observation of score concentration, outliers, and skewness. Additionally, basic descriptive statistics were calculated: mean, standard deviation, and IQR. Visualization and calculations allowed us to identify the most and least problematic dimensions describing open data maturity. Furthermore, a correlation analysis of the five variables studied was conducted to determine the degree of correlation between the dimensions. Pearson's linear correlation coefficient was used to calculate the correlation.

To answer the second research question, five cluster analyses were conducted using the k-means method. Because data were available for only 34 countries, it was decided not to use all variables simultaneously in the analysis. Such many variables with a relatively small number of observations could have produced unreliable results. Therefore, the first cluster analysis used five variables. Four of them addressed dimensions of open data maturity and were generalized indicators measuring these dimensions. The fifth measured open data maturity at the most general level (composite maturity). In this way, the following variables were selected for analysis: `policy_dimension`, `portal_dimension`, `quality_dimension`, `impact_dimension`, and `composite_maturity`. This stage of the research provided insight into the division of European countries in terms of the overall level of open data maturity.

Next, clustering was performed within each dimension using the indicators of each dimension as grouping variables. This stage of the research provided insight into the clustering of European countries within each of the four dimensions of open data maturity. In each case, the cluster analysis results were visualized in a two-dimensional space. To this end, two principal components were calculated using the Principal Component Analysis (PCA) method, using the grouping variables used in the given cluster analysis. This method created a two-dimensional space within which points representing each of the European countries studied were presented, divided into clusters. Furthermore, based on the calculated principal components, an additional variable was created summing the two principal components. The results were then sorted in descending order, and the countries with the top ten scores were filtered out. These countries were considered countries worth emulating.

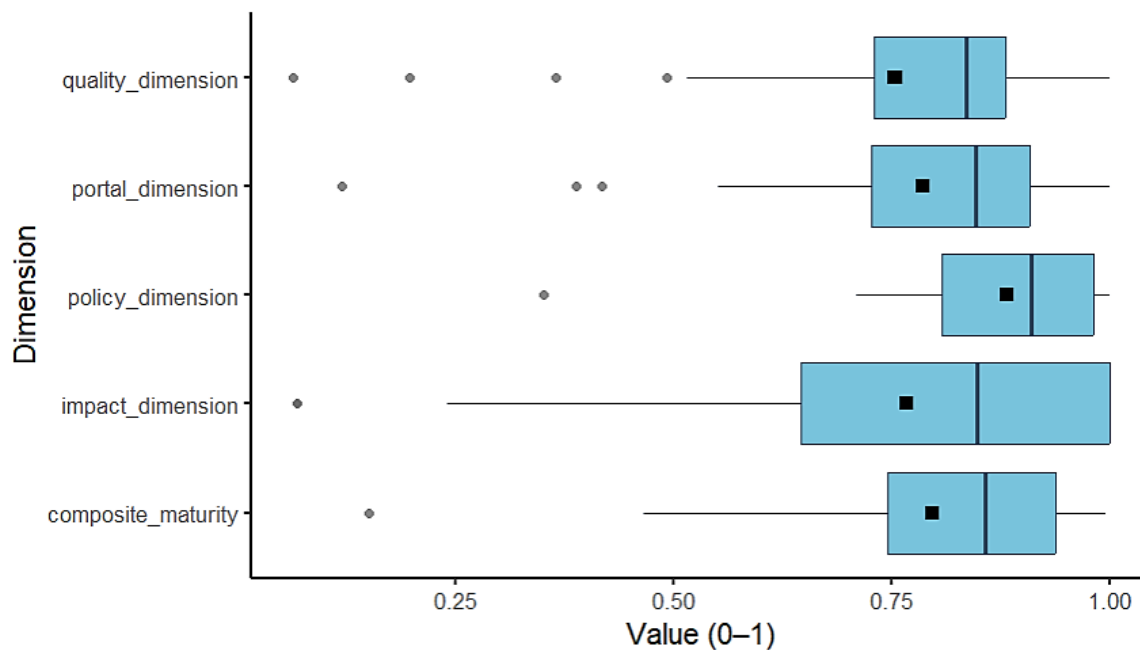
Three criteria were used to determine the number of clusters, using variables from the most general cluster analysis. The number of clusters determined there was used in all other analyses. This decision was made to facilitate comparison of clusters obtained using different grouping variables.

All calculations were performed in the R environment using both core and dedicated packages. Packages particularly important for the analyses include `tidyverse`, `psych`, and `ggplot2`.

4. Results

4.1. Distribution of open data maturity dimensions

To answer the initial research questions, distribution graphs of the studied indicators were created. The results are presented in Figure 1.



Note: the square indicates the average, the circles indicate outliers.

Figure 1. Distribution of open data maturity dimensions.

Source: own study.

Analysis of this figure indicates that all dimensions are characterized by a relatively high mean (above 0.75), left skewness, indicating a concentration of results at high values, and the presence of outliers with low values. The best results belong to the Policy dimension. This dimension is characterized by the highest mean (mean = 0.882) and moderate dispersion (sd = 0.130, IQR = 0.174). This means that meeting the requirements in this dimension is relatively easiest for the countries surveyed. Lower averages are found for the Portal (mean = 0.786), Quality (mean = 0.754), and Impact (mean = 0.768) dimensions. The Portal and Quality dimensions have relatively low dispersion. In turn, the Impact dimension has a large scatter of results (sd = 0.269, IQR = 0.353). This means that for the countries surveyed, meeting the requirements in these three dimensions is relatively the most difficult. Furthermore, countries differ significantly in terms of Impact.

To determine how the discussed dimensions are correlated, a correlation matrix was created and visualized. The results are presented in Figure 2.

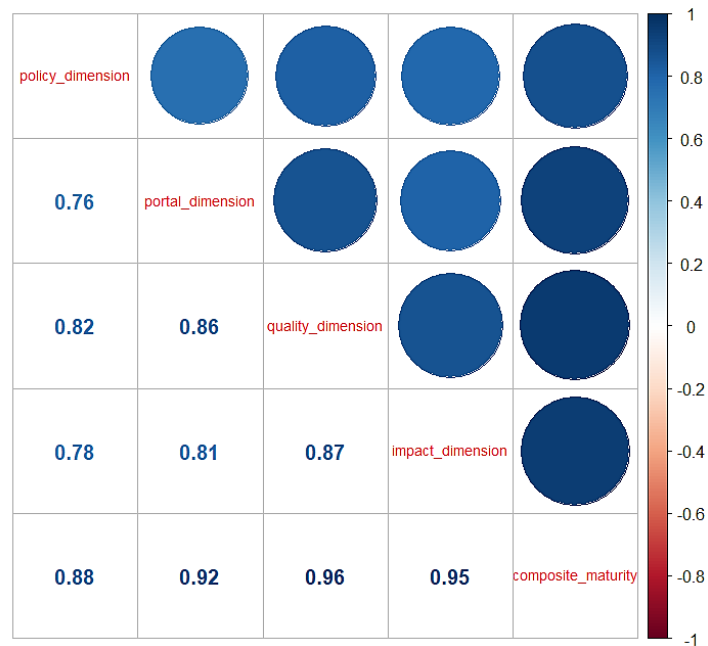


Figure 2. Correlation matrix of variables selected for cluster analysis.

Source: own study.

It shows very high correlations between variables. The Quality dimension correlates particularly highly with the Policy, Portal, and Impact dimensions. The highest correlations are found for Composite Maturity. However, this is due to the fact that this dimension is calculated from the other four dimensions.

4.2. Cluster analysis - selection of the number of clusters

To answer the second research question regarding the stratification of countries in terms of open data maturity, a k-means cluster analysis was conducted.

To determine the number of clusters, the WCSS, Caliński-Harabasz, and average silhouette criteria were used. The results are presented in Figures 3-5.

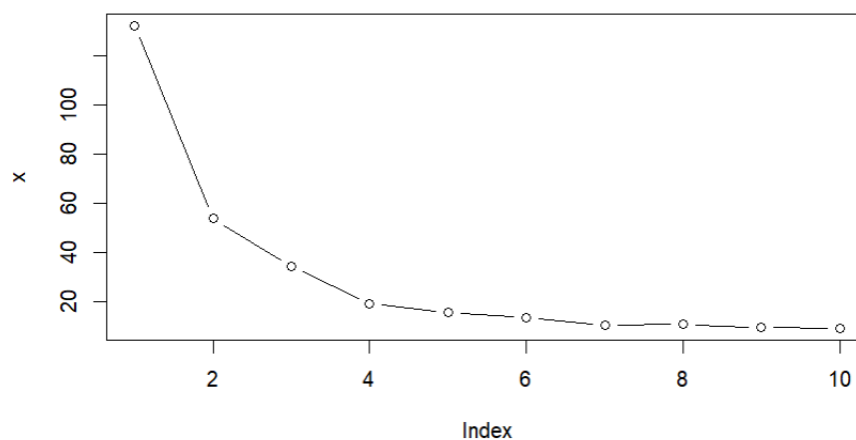


Figure 3. Scree plot illustrating the identification of the optimal number of clusters using the elbow method.

Source: own study.

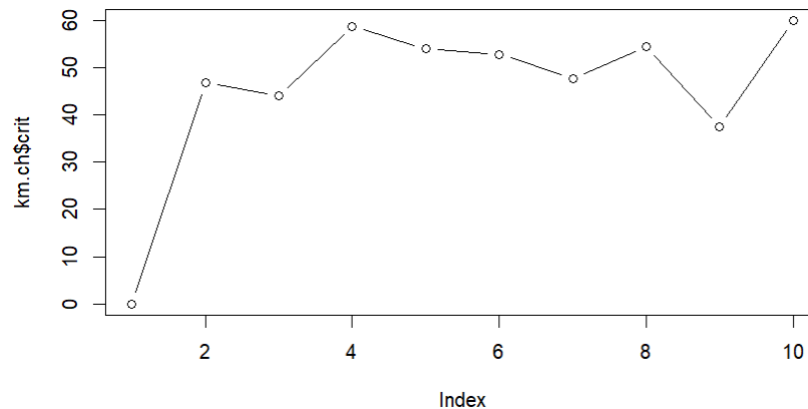


Figure 4. Determination of the optimal number of clusters based on the Calinski-Harabasz criterion.

Source: own study.

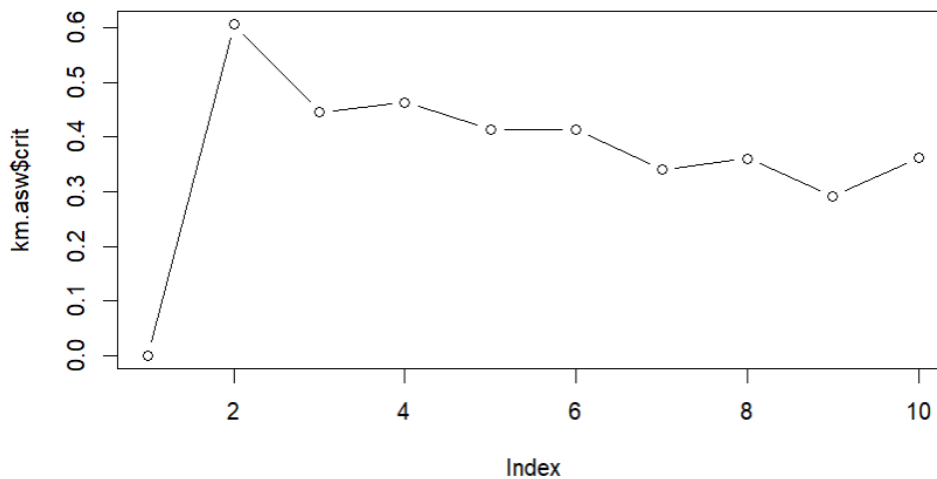


Figure 5. Determination of the optimal number of clusters based on the average silhouette criterion.

Source: own study.

The WCSS and average silhouette criteria indicated that two clusters were the optimal number. The Caliński-Harabasz criterion indicated 10 clusters as optimal. Ultimately, however, the decision was made to divide the studied countries into two clusters.

Cluster analysis based on general dimensions

After determining the optimal number of clusters, the analysis began. A k-means cluster analysis was performed, and a cluster number was assigned to each country in the data frame. The results were presented in a 2D graph, with the axes representing the principal components obtained using Principal Component Analysis (PCA). Therefore, this analysis was performed using varimax rotation. The results are presented in Figure 6.

	RC1	RC2
policy_dimension	0.450	0.888
portal_dimension	0.873	0.376
quality_dimension	0.799	0.530
impact_dimension	0.796	0.500
composite_maturity	0.814	0.580
	RC1	RC2
SS loadings	2.90	1.797
Proportion Var	0.58	0.359
Cumulative Var	0.58	0.939

Figure 6. Principal Component Analysis results.

Source: own study.

This figure shows that reducing the five variables studied to two principal components explains 94% of the data variability. Four of the studied variables are correlated with the first component: portal dimension, quality dimension, impact dimension, and composite maturity. The policy dimension is correlated with the second component.

The obtained results were considered acceptable as 2D graph axes, and the cluster analysis results are presented in their arrangement (Figure 7). Analysis of Figure 7 indicates that most of the 34 countries studied demonstrate high open data maturity. These countries are classified as “cluster blue”. This cluster is characterized by high values on the RC1 and RC2 axes, representing the principal components obtained from the PCA results. Cluster named “red bluster” includes six examined countries characterized by lower scores on the RC1 and RC2 axes. There is one outlier in this cluster: Bosnia and Herzegovina, which is characterized by exceptionally low indicators in the field of open data maturity.

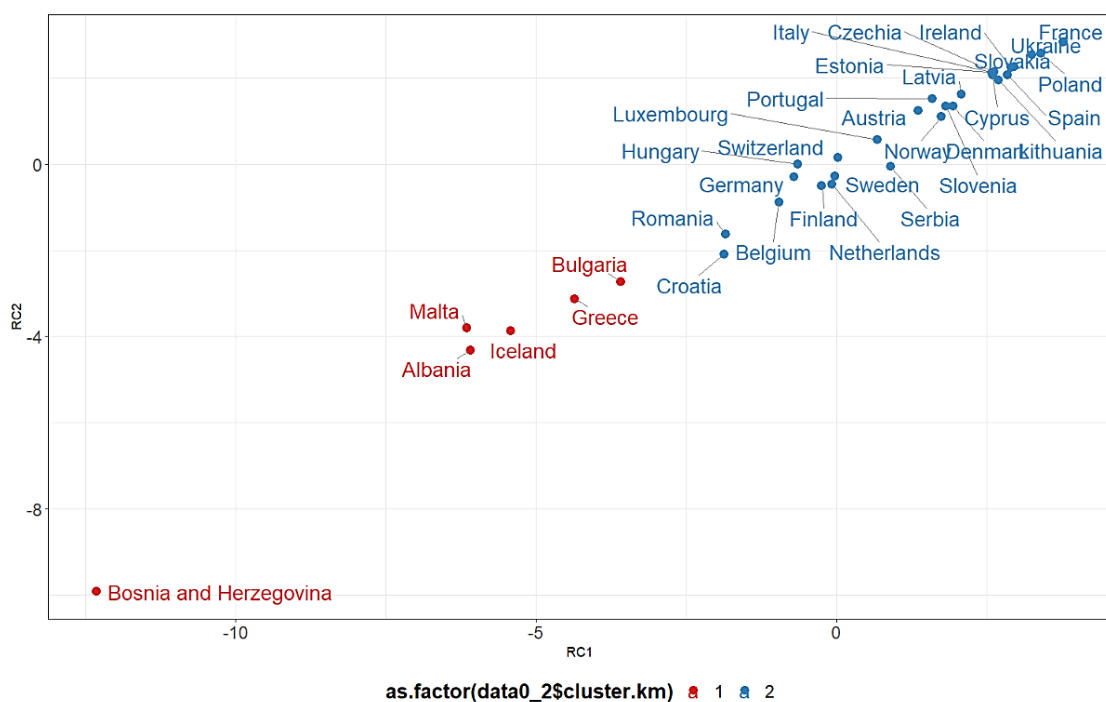


Figure 7. Cluster analysis results based on dimensions of policy, portal, quality, impact and composite maturity.

Source: own study.

To further explore both clusters, boxplots were created for each of the five variables, broken down by cluster (Figure 8). This confirms the high scores for the individual dimensions of “blue cluster”. Furthermore, it indicates that for “red cluster”, the most problematic dimensions are Impact and Quality. “Red cluster” is characterized not only by low mean values but also by a large dispersion of scores across these two dimensions. The least problematic dimension is Police. These conclusions are consistent with the previously presented analysis of the distributions of these dimensions.

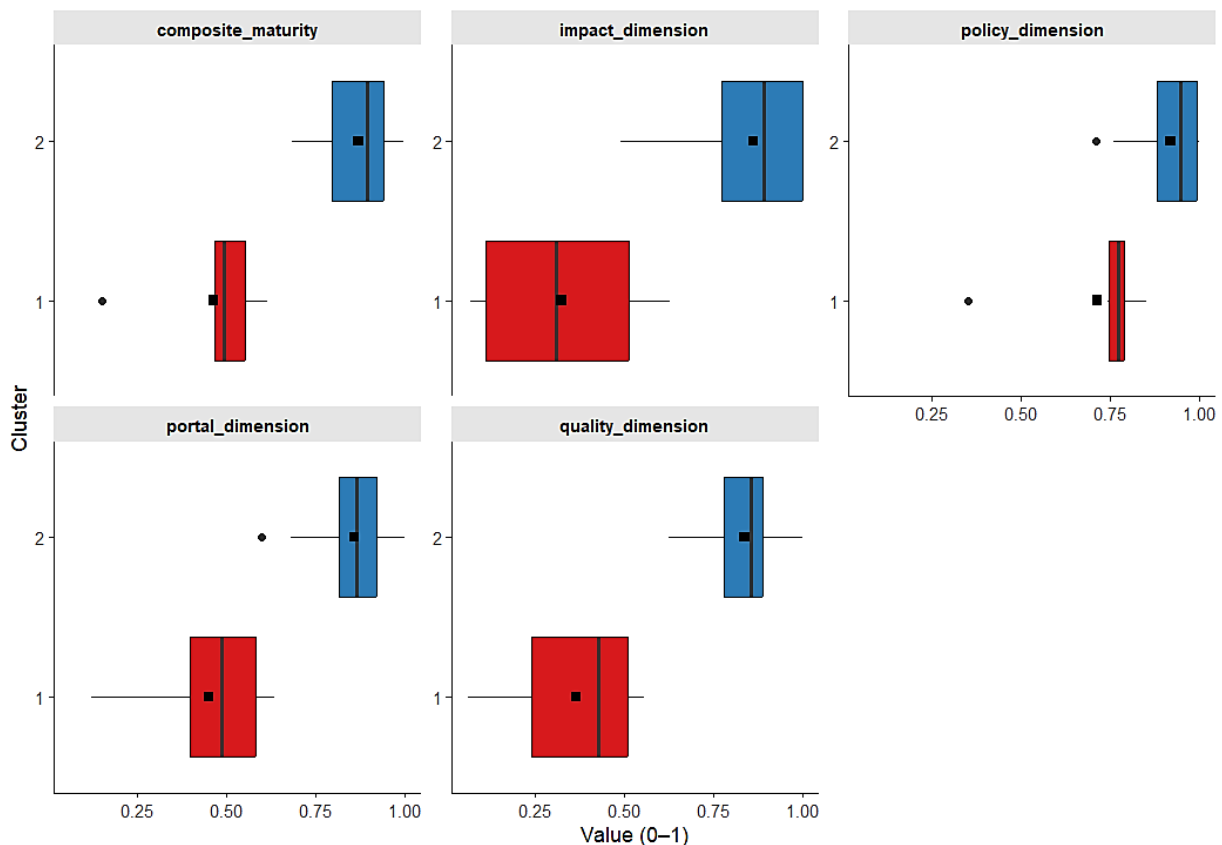


Figure 8. Comparison of open data maturity by two clusters.

Source: own study.

Cluster analysis in individual dimensions

Using the methodology applied for cluster analysis on the general dimensions of open data maturity, four additional cluster analyses were performed, each based on indicators describing a given dimension. This method utilized four indicators in the Policy dimension, five indicators in the Portal dimension, four indicators in the Quality dimension, and eight indicators in the Impact dimension. The results of these analyses are presented in Figures 9-12.

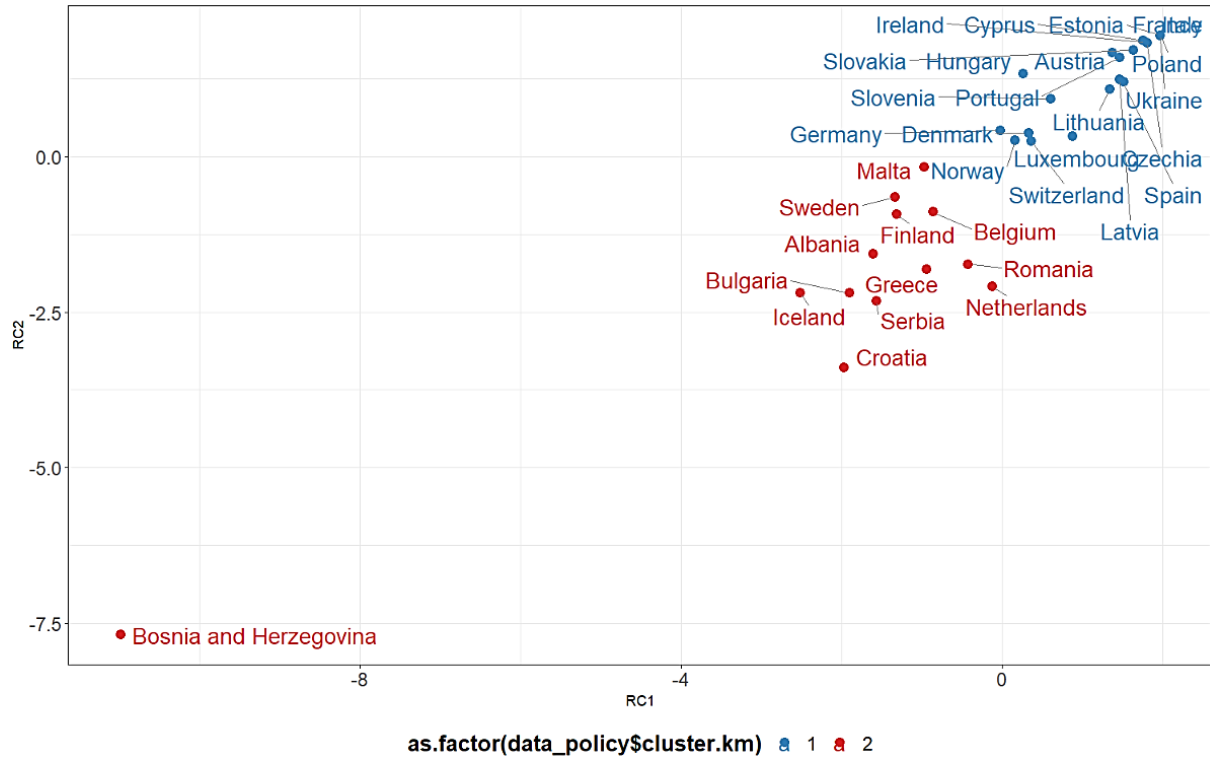


Figure 9. Clusters in Policy dimension of open data maturity.

Source: own study.

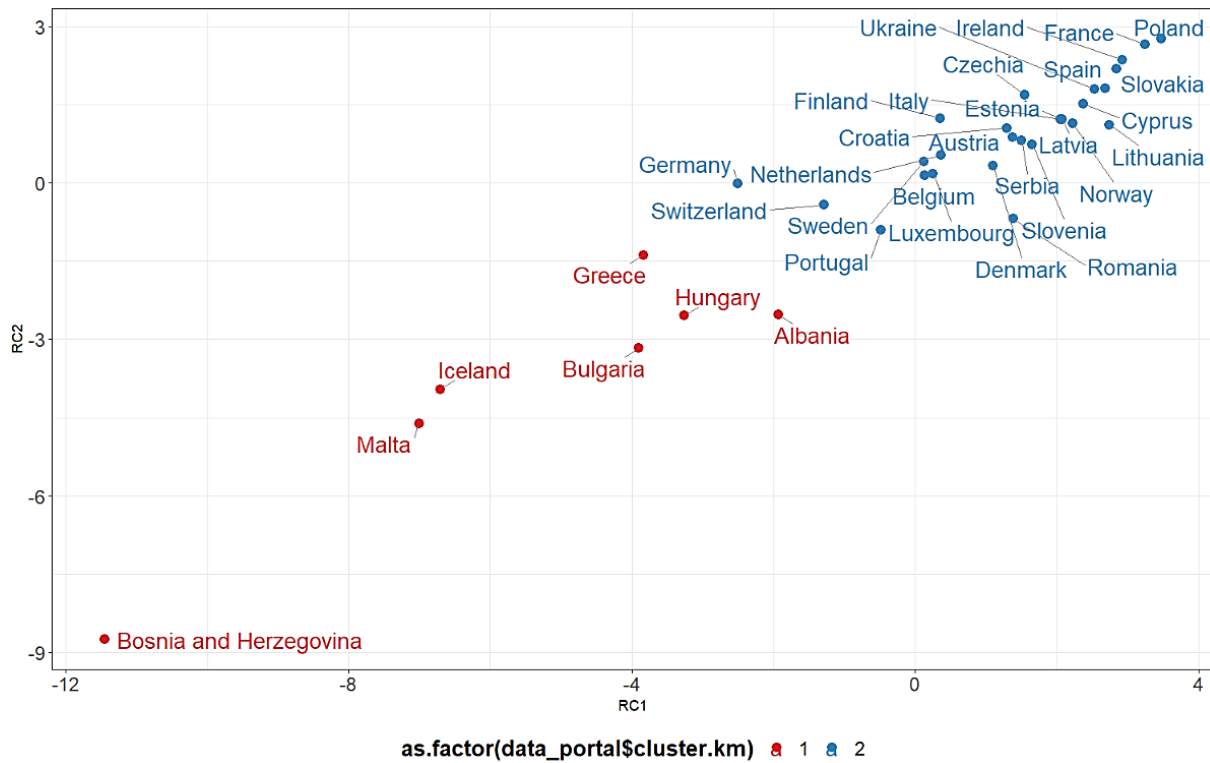


Figure 10. Clusters in Portal dimension of open data maturity.

Source: own study.

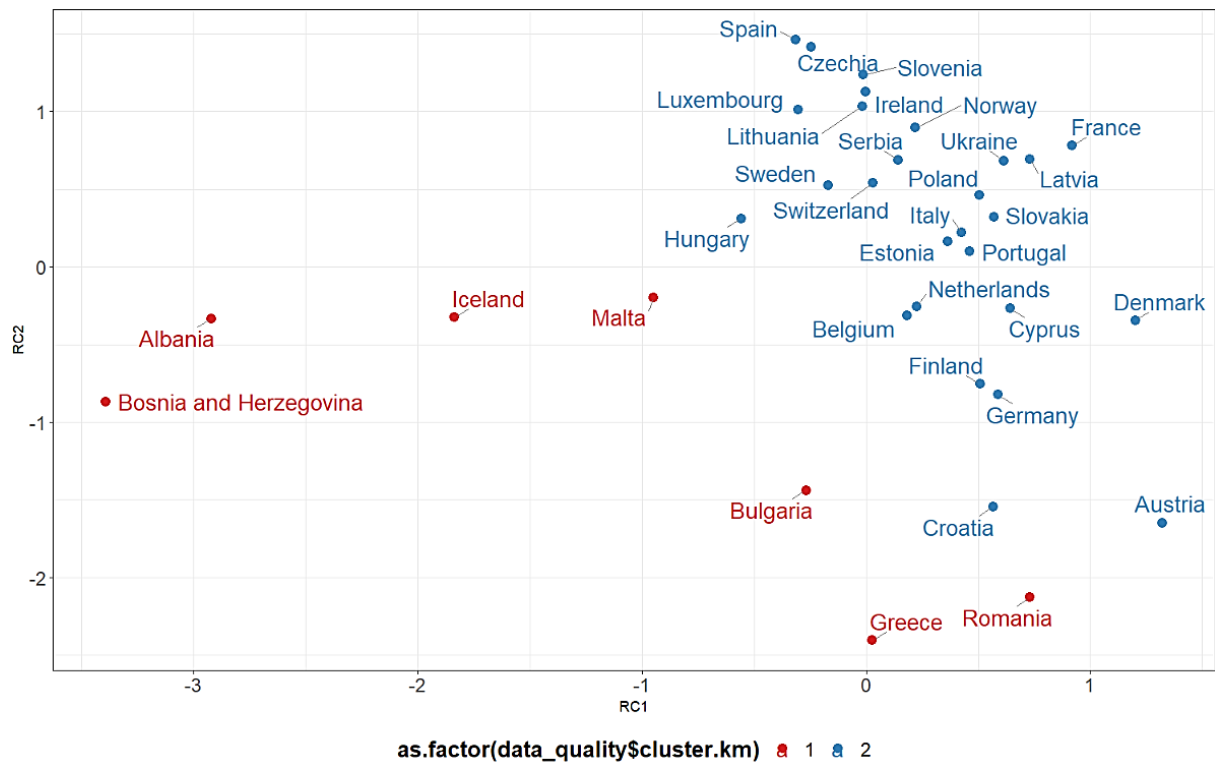


Figure 11. Clusters in Quality dimension of open data maturity.

Source: own study.

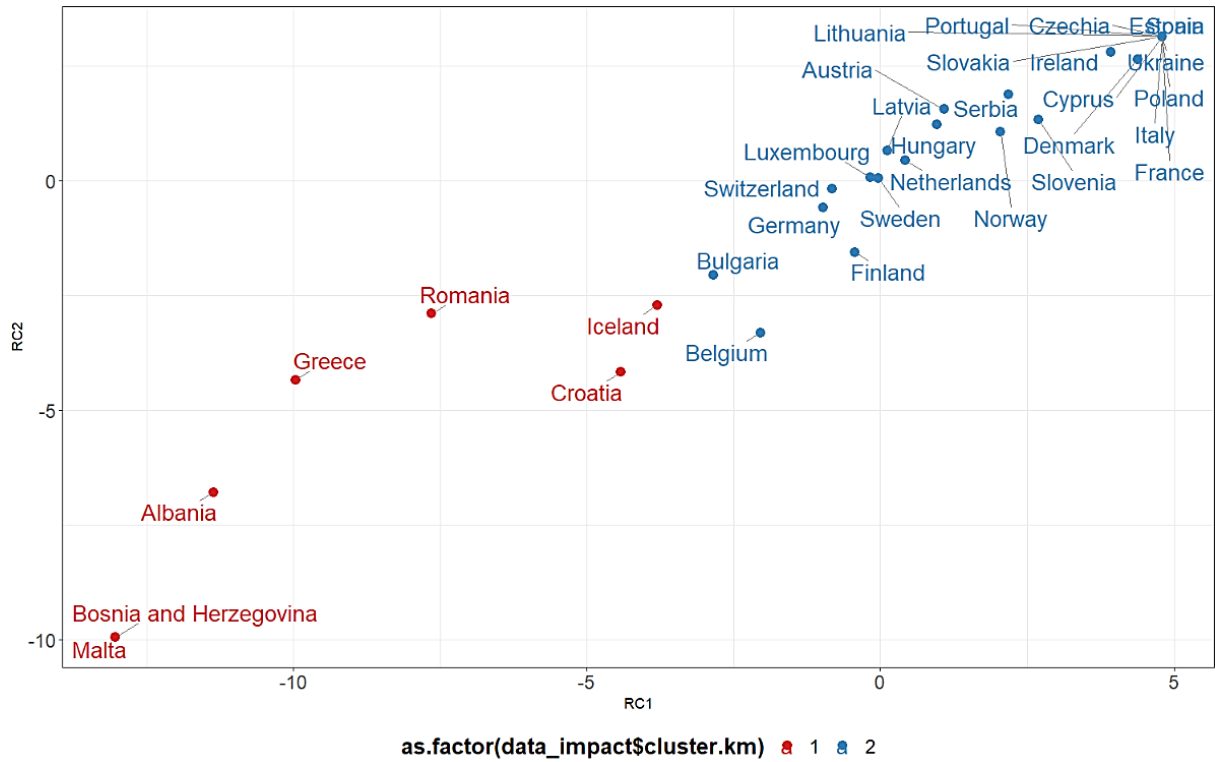


Figure 12. Clusters in Impact dimension of open data maturity.

Source: own study.

It was assumed that countries would be grouped into two clusters each time, as in the case of cluster analysis performed on four dimensions and the Composite Maturity variable. For the Policy dimension, the cluster associated with the lower maturity level encompassed 13 countries. For the remaining dimensions, the lower maturity cluster encompassed 7 countries.

Since we assumed we were looking for countries with the best results, we used the scores of two principal components (RC1 and RC2) calculated for each country in each dimension. After summing RC1 and RC2, we sorted the results in descending order and filtered out the 10 countries with the highest scores in each dimension. The top ten most advanced countries in each dimension are listed in Table 1. The most frequently occurring countries are: France, Poland, Spain, Cyprus, Ireland, Ukraine, Slovakia, Czechia, Estonia, and Lithuania (see. Figure 13).

Table 1.

Ranking of the 10 countries with the highest scores in each dimension of open data maturity

Policy dimension	Portal dimension	Quality dimension	Impact dimension	5 main dimensions
Estonia	Poland	France	Czechia	France
France	France	Latvia	Estonia	Poland
Italy	Ireland	Ukraine	Spain	Ukraine
Poland	Spain	Slovenia	France	Slovakia
Ukraine	Slovakia	Czechia	Italy	Ireland
Czechia	Ukraine	Spain	Cyprus	Cyprus
Ireland	Cyprus	Ireland	Lithuania	Czechia
Cyprus	Lithuania	Norway	Poland	Italy
Slovakia	Norway	Lithuania	Portugal	Estonia
Portugal	Estonia	Poland	Slovakia	Cyprus

Source: own study.

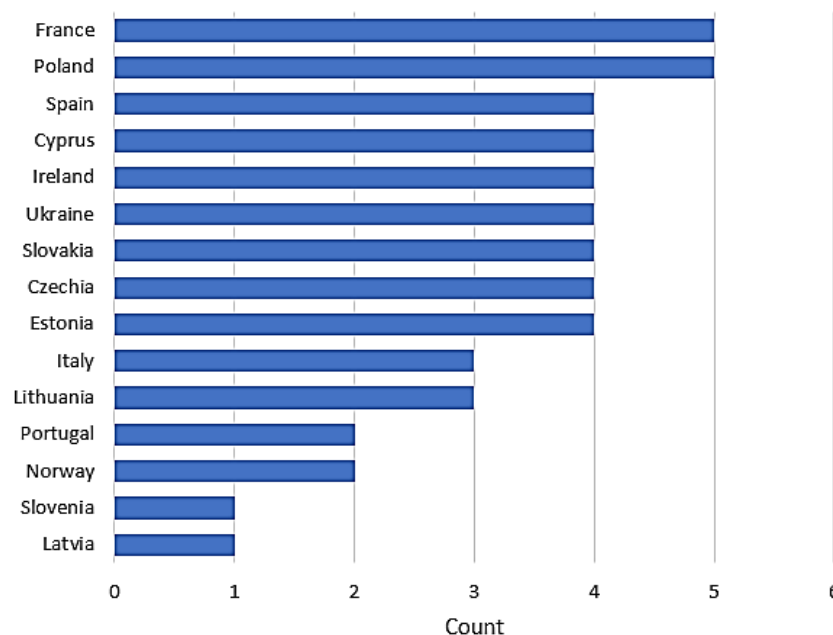


Figure 13. Frequency of a country's appearance in dimension rankings.

Source: own study.

5. Discussion

The presented research results indicate that the countries studied are characterized by relatively high open data maturity. However, this maturity varies across four dimensions. Achieving high maturity in the Policy dimension was the easiest for countries, while achieving it in the remaining three dimensions was more challenging. Additionally, the Impact dimension shows the greatest variation in open data maturity across countries. These results are consistent with the studies presented in (Blank, 2020) and (Page et al., 2023).

Cluster analysis revealed that, using the general dimensions, 11 countries with the highest scores on open data maturity dimensions can be identified. These are France, Poland, Spain, Cyprus, Ireland, Ukraine, Slovakia, Czechia, Estonia, and Lithuania. We recommend these countries as examples to follow. Our results are consistent with, but not identical to, those in this work (Page et al., 2023).

We also identified countries with lower open data maturity, including Albania, Bosnia and Herzegovina, Bulgaria, Greece, Iceland, and Malta. Using dimensions such as Portal, Quality, and Impact, we also include Croatia, Hungary, and Romania in these six countries. Our results are consistent with the work of (Page et al., 2023).

The most restrictive dimension in terms of grouping the surveyed countries in terms of open data maturity was the Policy dimension. This dimension yielded the best results and therefore identified as many as 13 countries with lower maturity. In our opinion, this dimension should be considered an outlier. This is indicated not only by the higher scores on this dimension but also by the results of the principal component analysis, which clearly showed that this dimension should be treated as a separate principal component.

While we identified 11 countries as clear leaders in open data maturity, it's worth emphasizing that the group of countries achieving a high level of data maturity was much broader across all analyzed dimensions. This demonstrates that European data ecosystems are gradually maturing not only in a few leading countries but across the entire region. This broad "high cluster" indicates that European Union countries are consistently developing a common infrastructure and data sharing culture, which is the foundation for building a European data community. The convergence of maturity levels across so many countries signifies the growing harmonization of standards, processes, and policies regarding public data. In practice, this translates into an increased willingness to leverage data as a strategic resource that supports both digital and green transformations. As a result, it's clear that the drive to open data is becoming a key element of European development policy, and a high level of data maturity is no longer the domain of a few leaders but is becoming a hallmark of an increasingly large part of Europe.

6. Conclusion

The results indicate that, overall, open data maturity in European countries is high. However, the countries analyzed can be divided into two groups with different levels of maturity. This division persists across all dimensions of open data maturity.

The group of countries with high open data maturity is larger. Additionally, our research identified eleven European countries leading the way in open data maturity. Dividing countries into two groups with different levels of maturity suggests that strategies and interventions should be tailored to their current level of development. The stable division into groups suggests that systematically monitoring open data maturity and benchmarking against leaders can help countries more effectively identify gaps and assess the effectiveness of implemented changes.

Countries with lower maturity require basic actions to strengthen data infrastructure and organization, while more advanced countries can focus on increasing data quality, interoperability, and reuse.

The countries identified in the study as leaders in open data maturity can serve as benchmarks for other countries. Analyzing the solutions these countries employ (in terms of data management, standards, sharing methods, and user support) can accelerate the development of open data systems in countries with lower maturity.

Research limitations and future directions

Because the dataset contained relatively few observations, the cluster analysis was performed using a reduced set of grouping variables. The study focused exclusively on European countries, so future research could expand by comparing the open data maturity of European nations with countries from other regions.

As directions for further research, we suggest that it would be worthwhile to examine the use of open data in individual countries indicated as open data maturity leaders. Such analyses would provide broad insight into how open data is used and what values it generates. Analyses in this context would be an interesting extension of the issue of open data maturity.

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