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Digital Performance in EU Member States in the Context of the Transition to a Climate Neutral Economy

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Abstract: The climate-neutral economy is today, more than ever, the priority issue for all governmental and non-governmental bodies, directly and indirectly involved in the ambitious and responsible process of society's transition to the green economy. To be or not to be sustainable today is no longer an option, but an urgent necessity. Based on these considerations, our research aims to add to the knowledge on the digital performance of the Member States in the context of the transition to a climate neutral economy, by analyzing the mutations that have occurred in the digital performance of the EU countries in the period 2015–2020, as well as forecasting developments for the year 2025. In order to obtain a relevant result, we used the components of the DESI index, published by the European Commission, and the variables were processed through hierarchical cluster analysis. The results demonstrate that, around the core formed in 2015 by four high digitally performing countries from the North of Europe in 2015, other countries have gradually clustered, so that in 2025 we estimate that a number of eight Member States will be part of the group of the most digitally performing countries. These countries are decisively committed to the transition towards a climate-neutral economy, their initiatives and examples of good practice can be taken up by all European and non-European countries pursuing the same objectives of sustainable development.

Keywords: climate neutrality; European Green Deal; DESI index; sustainable development

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1. Introduction

Climate change, and all its negative consequences, is now a major concern for all countries in the world, regardless of their level of development. In this context, we identify clearly defined targets; for example, for Europe, reducing greenhouse gas emissions by at least 55% by 2030 and climate independence by 2050.

Therefore, alongside the above targets, at the European level we identify complex plans, such as the European Green Pact, which includes measures aimed primarily at reducing greenhouse gas emissions, as well as plans for investment in research and innovation to preserve Europe's natural environment [1].

It is also important to highlight that the current climate action initiatives are measures that all European countries must include in their sustainable development programmes. These are all underpinned by specific legislation, plans, and strategies, including: the European 2050 Climate Neutrality Act, the European Pact to involve citizens and all parts of society in climate action, the 2030 Target Plan to reduce net gas emissions, and the EU Climate Change Adaptation Strategy to make Europe a climate resilient society by 2050, fully adapted to the unavoidable impacts of climate change.

Europe's concern about climate change is also evident in terms of legislative initiatives, such as the moment on 14 July 2021, when European Commission adopted a series of legislative proposals setting out how climate neutrality will be achieved in the EU by 2050. This reviewed a number of elements of EU climate legislation, transport and resource use legislation, as well as the actual terms under which the EU's targets in the European Green Pact will be achieved.

Equally important, the new initiatives and legislation also set out how each country will adapt to the inevitable effects of climate change so that they become truly resilient through smarter, faster, and more systemic adaptation to climate change by 2050.

We can therefore highlight that the EU is acting in a rapid, sustainable way to transition to a climate-neutral economy and eliminate the negative consequences of climate change. The previous measures identified at the European level are also justified by the way society and the economy have evolved in 2021, which has been defined as the year of "radical climate change" characterized by devastating heat waves and droughts, decimated forests, and coastlines eroded by rising sea levels, evident not only in Europe but worldwide.

Not to be overlooked is the fact that all of these extreme situations in recent years have had direct consequences in the form of major economic losses in the EU, exceeding EUR 12 billion per year. Equally important, global warming of just 3 °C above current levels could generate an annual loss of at least EUR 170 billion. The current global problems, also accentuated by the COVID-19 pandemic, have intensified EU action for change, which is why one third of the EUR 1.8 trillion investment in the Next Generation EU Recovery Plan and the EU's seven-year budget will fund the European Green Deal [1].

As research published to date indicates, digital transformation is a priority for European firms, with advanced digital technologies fostering higher business productivity, which can generate higher investment volumes and at the same time facilitate increased innovation activity. Thanks to the availability of the money generated by increased productivity, in parallel with increasing stakeholder recognition of the importance of green investments, digital firms can invest more in measures to improve energy efficiency. This means that digital firms are more likely to make investments to tackle the impact of climate change [2]. In fact, the results of several studies published on the subject indicate that digital technology itself has the potential to significantly reduce global emissions [3].

The path to a climate-neutral economy is certainly an ambitious one, currently found in many forms and ways of action, from global/international cooperation to regional, national, and local partnerships. This is also why the circular and sustainable economy is one of the fundamental instruments of the Green Deal targeted as a priority for the post-COVID-19 period. In this context, at the EU level for the 2030s and 2050s, the focus is on the successful implementation of a sustainable and circular bio economy, with a focus on biomaterials and ecosystem services that will directly contribute to the EU's strength through increased competitiveness and job creation [4,5].

All these changes bring into perspective the change in EU climate policy, and the analyses carried out reflect the fact that climate change is not the same for all societies/states. Therefore, the existence of certain inequalities is reflected in the impact of climate change as well as in the capacity of states to respond to it. Thus, the introduction of climate change mitigation measures or the adaptation of states to climate change have relatively different effects on people, depending on their gender, social category, ethnicity, physical abilities, income level, etc. There are also differences in the attitude of authorities towards climate change and in the decision-making process on climate change [6,7].

Based on these considerations, our research aims to provide additional knowledge on the digital performance of Member States in the context of the transition to a climate-neutral economy, by analyzing the changes that have occurred in the digital performance of the countries analyzed in the period 2015–2020, as well as forecasting developments for 2025.

In order to obtain a relevant result, we used the components of the DESI index, published by the European Commission, and the variables were processed by means of hierarchical cluster analysis to determine how European countries are grouped according to their level of digital performance, with a view to determining groups of countries with high performance and those with performance that should be improved.

The use of cluster analysis as an exploratory tool allows us to identify hidden structures and existing anomalies, but also to identify cluster data connectivity properties. This is why our research does not start from a series of hypotheses to be validated or invalidated but aims at revealing how EU countries evolve according to the analyzed digital performance, as well as at opening new research directions on a topical subject.

The results obtained demonstrate that, around the core formed in 2015 by four high digital performers from Northern Europe in 2015, other countries have gradually joined the group, so that in 2025 we estimate that eight Member States will be part of the group of the best digital performers, being countries decisively committed to the transition towards a climate neutral economy, whose initiatives and examples of good practice can be taken up by all European and non-European countries pursuing the same objectives of sustainable development.

This paper is divided into six sections. Following the introduction, Section 2 discusses the literature review, Section 3 presents the materials and methods used for research, Section 4 presents the main findings, Section 5 contextualizes the research results, and Section 6 aggregates the conclusions of the research.

2. Literature Review

The transition to a sustainable society and economy cannot be achieved without an awareness of human performance, especially in the current context of profound changes in society accentuated by the COVID-19 pandemic, focusing primarily on technologies and digital skills, some of the few assets that have allowed certain activities to continue, such as monitoring the spread of the virus or accelerating research to identify a vaccine. The level of digital performance can influence the ease and speed with which EU Member States will make the transition to a climate neutral economy, with the recent pandemic demonstrating the importance of digitalization in preventing and mitigating the effects of extreme events. In fact, according to the latest research, the COVID-19 pandemic has become the perfect accelerator for increasing digital performance, with positive effects on increasing the speed of adaptation to new economic and social conditions [8–10].

Neither can the latest political developments at the eastern border of the European Union be lost sight of, which will definitely generate significant consequences on economic and social developments among Member States, which will be confronted with the need to accelerate further towards an economy based on renewable resources, especially given the vulnerability generated by energy dependency. In this context, it becomes all the more important to objectively evaluate the digital performance of the EU countries, together with the assessment of their potential evolution.

The European Commission is thus increasingly concerned about the digital performance of Member States, which is now seen as a key element in the transition to a sustainable economy and society. In this respect, the actions initiated are primarily tracking the progress of EU Member States in terms of their digital competitiveness through the "Digital Economy and Society Index—DESI" [11].

We also note that the effects of DESI (connectivity, human capital/digital skills, use of internet service by citizens, integration of digital technology, and digital public services) on labor market indicators (labor market insecurity, long-term unemployment rate, employment rate, and income) reflect an increase in the employment rate but also in personal earnings, lowering the long-term unemployment rate as well as labor market insecurity, directly contributing to the improvement of labor market indicators [12,13].

Not to be overlooked is the fact that although most scientific studies identify a positive impact of information and communication technologies (ICT) on economic growth, there is also research that suggests that this impact is in some cases limited or even non-existent. This is because progress in ICT implementation and use leads to economic growth where we identify countries with developed economies [14–16].

On the other hand, even though the world has changed significantly in recent decades, along with globalization, new technologies have facilitated new business models, but they have put pressure on existing international tax rules. As a result, current global economic conditions have led many companies to migrate to Internet-based systems to increase efficiency, reduce their operating costs, and to be able to operate in real time across different platforms. In fact, new technologies, digitization, and the implementation of sustainable strategies are generating often-radical changes in the business environment and implicitly in the foundation and development of business strategies [17].

On the other hand, a number of researchers argue in their published studies that digitization, digital transformation, and the green economy have become the most commonly used words in the last decade, especially in recent years; this is because, for a business to remain competitive in the market, it needs to provide green products and services, which require a different approach to management practices [18–21].

For this reason, many companies have redesigned their business processes by investing in technologies, IT systems for economic analysis and decision support as well as social networks; thus, there is a direct correlation between the digital economy and the effects of digitization, as reflected in the Digital Economy and Society Index (DESI) [22].

Based on the published literature, we can identify a number of strong links between the DESI technology indicator variables and Gross Domestic Product (GDP) per capita, which are directly related to the use of certain Internet services by citizens but also to the integration of technology into all business processes and operations [23–25]. This is because digital transformation refers to a broad concept encompassing all the changes brought about by the availability and use of digital technologies in almost all areas of human activity. Consequently, we identify changes in business models, products and services, production and delivery methods, and the skills needed to remain competitive in an environment of constant change. In this context, countries are identifying permanent solutions in order to adapt their economies to the new conditions, exploiting new opportunities, and conducting research to assess their progress in terms of digitalization, both nationally and globally [26,27].

Researchers also point out that the digital transformation of the economy offers new insights into innovative processes, creates new opportunities in the labor market, and has the potential to contribute to a 20% reduction in global CO_2 emissions by 2030. Moreover, in parallel with the intensification of the digitalization processes of the economy, the carbon footprint of the ICT industry is continuously improving/decreasing; a consequence of the use of alternative green fuel sources, mainly in energy-intensive data centers [28–30].

In addition to the decarbonization process, digitalization will create solutions that can contribute to the transition towards a sustainable, circular economy, thus enabling the European manufacturing sector to strengthen its leadership position. There is also support for the idea that financing innovations in green technology and digital solutions contribute to reducing the carbon footprint, reducing the use of natural resources and materials, improving sustainability of the life cycle of production and distribution, and extending the life cycle of products and services [31–33].

There are a number of published researches on the decarbonization aspects of the economy and the impact that digitalization has on these processes; the results indicate that society is deeply concerned about these issues. The research results indicate that, on the one hand, the processes of decarbonization have a fundamental influence on the transformation of the energy sector and, on the other hand, the transition of the energy market to low-carbon technology is a real political challenge [34,35].

In the same context of concerns about the decarbonization of the economy in the European Union and beyond, given that policy processes will require engagement amongst a wide range of stakeholders who have very different visions for the physical implementation of deep decarbonization, the Deep Decarbonization Pathways Project (DDPP) initiative should also be mentioned. Based on the application of the principles underlying the development of this methodology, the aim is to reduce carbon emissions while maintaining development aspirations [36].

All these arguments reinforce the idea that digitalization is the fourth industrial revolution, the main aim of which is to create and develop a low-carbon circular economy. The promotion and implementation at the EU Member State level of the sustainable digital sector is also supported by various pieces of legislation, which aim to establish mandatory requirements to incentivize companies to move towards sustainability and a climate neutral economy [37].

Thus, as a benchmark at the European Commission level, the Digital Economy and Society Index (DESI) is calculated and published through DG Connect (Directorate-General for Communications Networks, Content, and Technology). DG Connect is the department responsible for the development of a digital single market at the EU level, aiming at smart, sustainable, and inclusive growth among Member States.

Gortazar [25] and Ibarra et al. [38] mainly argue for the existence of correlations between technological indicators and social development, especially in economically developed countries. Therefore, between the DESI technology indicator variables and GDP per capita, there are strong, direct relationships, which are also influenced by the use of certain internet services by citizens but also by the integration of information and communication technology into production processes by companies.

We also identify a number of arguments that support the fact that a country's level of digitalization also influences the reduction of the risks of poverty and social exclusion and therefore the sustainable development of society. Thus, the analysis of the correlations between the DESI indicator and the indicator "People at risk of poverty or social exclusion" indicates that EU Member States with higher levels of digitalization have a lower percentage of their population at risk of poverty and social exclusion. However, the likelihood of positive changes in this area is higher for countries with lower levels of digitalization [39,40].

Not to be overlooked is the fact that current legislation, government reports, and current global policy are all focused on climate change. This is why we reiterate the idea that the current context can be turned into business opportunities but also into a means to ensure sustainable economic growth. We therefore identify a number of connections between climate change and the current political and economic context, connections that can be materialized in changes in production processes, technology, and digitalization [41,42].

Published studies on the effects of ICT implementation and digital performance growth in any country's economy also highlight that, at least from the perspective of EU Member States, the levels of DESI indicators and the dynamics of their changes vary from one country to another, even if all decision makers are pro-growth, including in the less performing countries, in this respect [43].

Increasing convergence across EU Member States in terms of the level of development of the digital economy and society is the only way to rapidly achieve sustainable long-term performance. In other words, society is in the process of transition from a market to a digital economy, and this process inevitably requires resolving the contradictions between the needs of the economy, the state, the labor market, and the expectations of employers [44,45].

3. Materials and Methods

Based on the relevance and importance of the topic under investigation, in order to analyze the digital performance in the EU Member States in the context of the transition to a climate neutral economy, we decided to use the main components of the DESI index as the variables underlying the proposed analysis. Given that very little research has been conducted to date to address this approach, and because there are no published methodologies to address this topic of interest, we decided to use cluster analysis. Cluster analysis is an inductive exploratory technique in that it uncovers structures without explaining the reasons for their existence. In other words, it is a hypothesis-generating technique rather than a hypothesis-testing technique. This is also the reason why we have not suggested research hypotheses but propose a different point of view from the existing literature, precisely to open new research directions.

The DESI index is calculated every year, since 2014, and its main components are connectivity, human capital, internet use, digital technology integration, and general public services. The connectivity component looks at fixed broadband services, mobile broadband services, speed, and broadband prices. Human capital, an important element of the DESI, refers to internet usage, alongside basic and advanced digital skills. The internet usage component considers the extent to which EU citizens use online content, communications, and transactions. The integration of digital technology has been considered precisely because it analyses and reflects the evolution of digitalization of enterprises and the evolution of e-commerce. The fifth component of the DESI, general public services, tracks the implementation, evolution, and efficiency of e-government services provided to citizens of European countries. Each of these components has a calculated score in the range of 0–100 [11].

In our research, we aimed to analyze the evolution of the EU Member States in terms of the variables analyzed, between 2015–2020, with a forecast of the evolution for 2025, based on hierarchical cluster analysis. Given that the data provided by the European Commission have been available since 2015, we decided to extrapolate the dynamic evolution of the variables until 2025, in order to obtain a potential picture of the foreseeable mutations among EU countries for the whole 2015–2020–2025 interval. Even though main EU-wide targets are proposed for the year 2030, given the short period of time for which data are published, the extrapolation had to be limited to the year 2025 in order not to jeopardize the validity of the models by accumulating forecast errors.

For forecasting the data series specific to each of the DESI components, the variables were processed using SPSS software [46], based on the ARIMA methodology, due to its predictive power and flexibility. The methodology was originally developed by Box and Jenkins [47–49], based on a combination of an autoregressive process (AR) and moving average (MA) model. An autoregressive process takes the form of a linear regression of the current value of the series against one or more previous values of the series, generating an AR process of order p, according to Equation (1):

$$X_t = \delta + \theta_1 X_{t-1} + \theta_2 X_{t-2} + \cdots + \theta_p X_{t-p} + \varepsilon_t \quad (1)$$

where X_t is the time series, ε_t is white noise, and $\delta = (1 - \sum_{i=1}^{p} \theta_i)\mu$, with μ denoting the process mean.

Another often-used approach for univariate time series is to model the series evolution based on moving averages (MA). Such a model is based on linear regression of the current value of the series against white noise or random shocks to one or more previous values of the series. The random shocks for each point in time are assumed to come from the same data distribution, most likely following a normal distribution, taking the form of Equation (2):

$$X_t = \mu + A_t - \theta_1 A_{t-1} - \theta_2 A_{t-2} - \cdots - \theta_q A_{t-q} \quad (2)$$

where X_t is the time series, μ is the mean of the series, A_{t-i} are white noise terms, $\theta_1, \ldots, \theta_q$ are the parameters of the model, and the value of q is the order of the MA model.

SPSS software allows for the estimation of exponential smoothing models, or univariate or multivariate models, based on the identification of the best-fitting Autoregressive Integrated Moving Average (ARIMA) model for one or more dependent variable series, in the form ARIMA (p,d,q), where p is the lag of the autoregressive process, d is the degree of differencing, and q is the lag of the moving average model.

3.1. Sample Selection and Variables

The main characteristics of the variables analyzed for the years 2015, 2020, and 2025 are presented in Table 1.

Table 1. Descriptive statistics of the variables analyzed for the years 2015, 2020, and 2025.

Variable	2015				2020				2025			
	Min	Max	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.
Connectivity	4.36	11.38	8.16	1.9374	8.34	16.46	13.10	2.1544	11.30	38.87	18.44	4.9941
Human capital	6.87	18.05	10.99	2.8120	8.11	19.61	12.32	3.1831	7.46	26.09	13.50	4.6089
Use of Internet services	3.26	9.80	6.74	1.6549	5.38	11.45	8.57	1.6079	6.74	23.71	11.26	3.3655
Integration of digital technology	3.06	9.59	6.02	1.9770	3.57	14.86	8.66	3.0502	4.10	20.04	11.11	4.1702
Digital public services	3.09	11.59	7.65	2.4387	7.26	13.40	10.83	1.7649	9.86	28.39	14.69	3.2404

Source: own calculations, based on DESI Index data.

Once the values of the variables for the year 2025 were estimated, we applied the specific methodology of hierarchical cluster analysis to identify how the EU Member States are clustered in terms of the selected variables in the years 2015, 2020, and 2025. This clustering approach gives us the possibility to obtain a clear picture of the clusters of performing countries alongside the countries with more modest performance. In addition, by analyzing and comparing the composition of the identified clusters for the three years considered, we can track the dynamics of each country's adaptation to the demands of the current and future European context in terms of digital performance and the transition to a climate neutral economy.

3.2. Model and Method

Cluster analysis aims to group similar variables so that the degree of association between two variables is as high as possible if they belong to the same group, and as low as possible if they belong to different groups. Cluster analysis is mainly used to identify hidden structures in the available data, without providing detailed explanations or causal interpretations but offering an alternative way of approaching and interpreting selected variables [50].

In order to identify clusters in a manner suitable for the proposed purpose we used the squared Euclidean distance [51,52] to determine the proximity matrix (3):

$$W = \|w_{ij}\|_{i=\overline{1,n},j=\overline{1,n}}, \quad w_{ij} = \sqrt{\sum_{i=1}^{n}\left(z_{ik} - z_{ij}\right)^2}, \quad j = \overline{1,m}, \quad k = \overline{1,m} \quad j \neq i, \quad k \neq i, \quad w_{ii} = 0 \tag{3}$$

To determine the distance between formed clusters we used Ward's Method [51–54], which minimizes the increase in the total within-cluster sum of squared error, calculated according to Equation (4):

$$\Delta(A,B) = \sum_{i \in A \cup B} \|x_i - m_{A\cup B}\|^2 - \sum_{i \in A} \|x_i - m_A\|^2 - \sum_{i \in B} \|x_i - m_B\|^2 - \frac{n_{A\cap B}}{n_{A\cup B}} \|m_A - m_B\|^2 \tag{4}$$

To check the validity of the assumptions, the first step is to examine available data for normal distribution. The results are summarized in Table 2 (Kolmogorov-Smirnov test) and Table 3 (Shapiro-Wilk test).

Table 2. Tests of Normality (Kolmogorov-Smirnov [a]).

Variable	2015			2020			2025		
	Statistic	df	Sig.	Statistic	df	Sig.	Statistic	df	Sig.
Connectivity	0.090	27	0.200 *	0.139	27	0.193	0.210	27	0.104
Human capital	0.103	27	0.200 *	0.114	27	0.200 *	0.130	27	0.200 *
Use of Internet services	0.146	27	0.146	0.102	27	0.200 *	0.200	27	0.097
Integration of digital technology	0.128	27	0.200 *	0.200	27	0.070	0.148	27	0.136
Digital public services	0.116	27	0.200 *	0.101	27	0.200 *	0.185	27	0.089

* This is a lower bound of the true significance. [a] Lilliefors Significance Correction. Source: own construction using SPSS.

Table 3. Tests of Normality (Shapiro-Wilk).

Variable	2015			2020			2025		
	Statistic	df	Sig.	Statistic	df	Sig.	Statistic	df	Sig.
Connectivity	0.970	27	0.593	0.962	27	0.416	0.753	27	0.091
Human capital	0.960	27	0.362	0.946	27	0.169	0.931	27	0.274
Use of Internet services	0.963	27	0.422	0.953	27	0.249	0.812	27	0.066
Integration of digital technology	0.944	27	0.149	0.936	27	0.096	0.938	27	0.110
Digital public services	0.961	27	0.396	0.953	27	0.248	0.715	27	0.122

Source: own construction using SPSS.

According to the existing literature [55–57], the results provided by the Kolmogorov–Smirnov test and Shapiro–Wilk test demonstrate that the available data follow a normal distribution, but that there is also a reasonable suspicion that the variables might indicate some deviations from the normal distribution. However, according to the literature, and considering the sample size and the reduced impact of the type of distribution on the proposed analysis [57,58], we can use the whole data set for hierarchical cluster analysis.

In the next step of the analysis, based on the agglomeration schedules and dendrograms of the clusters in the three periods analyzed, as well as considering the existing literature [51,59,60], we determined the optimal number of clusters for each of the three periods analyzed.

A three-cluster solution was determined to best fit the data by providing the most relevant clusters, minimizing differences within clusters while maximizing the differences between clusters at the same time. The selected solution is consistent with existing literature and the recommendations for cluster segmentation [49,59]. The results obtained could thus provide a broader and more accurate picture of the digital performance evolution in the EU countries, between 2015–2025 (Figures 1–3).

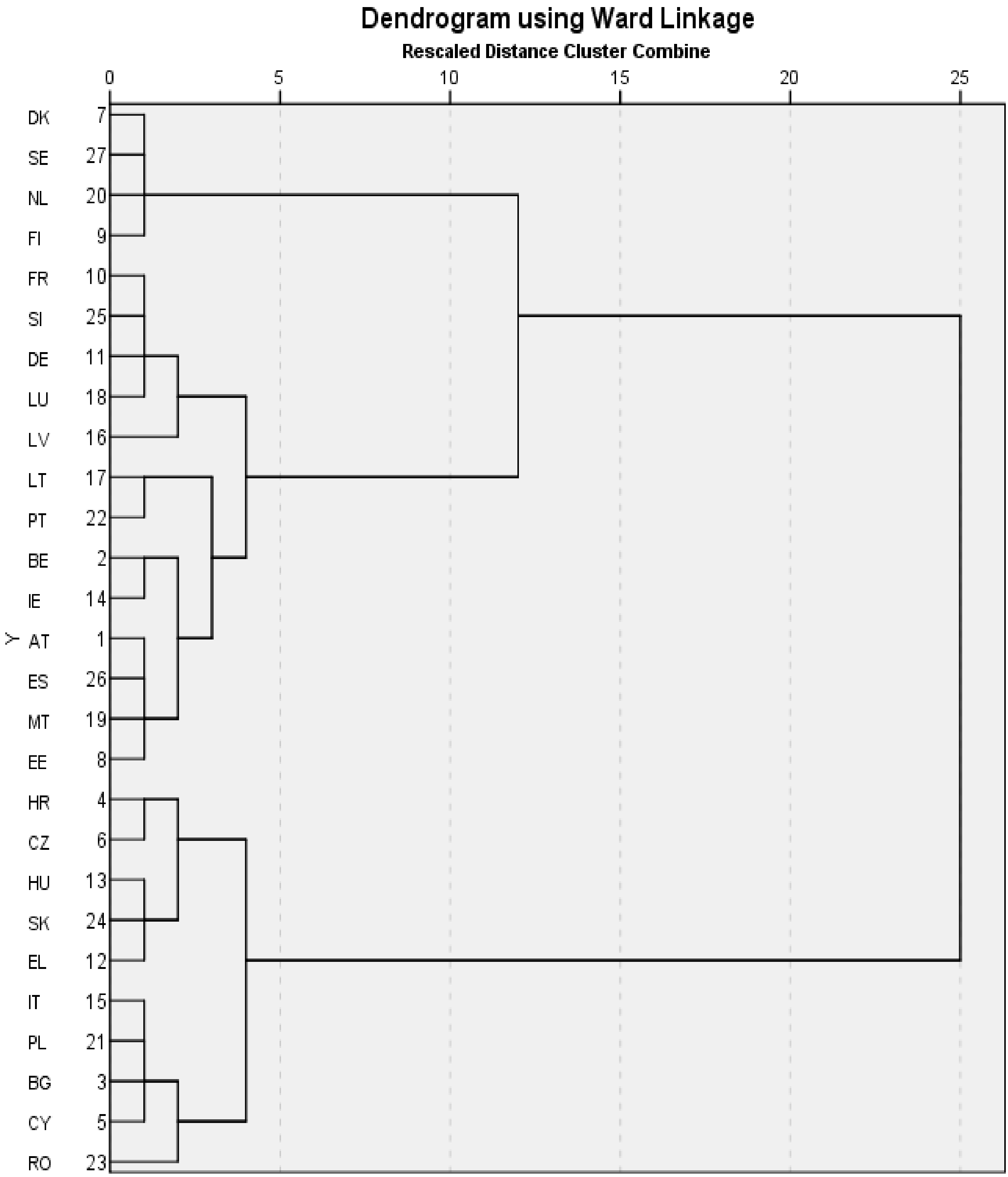

Figure 1. Dendogram of clusters, year 2015. Source: own construction using SPSS.

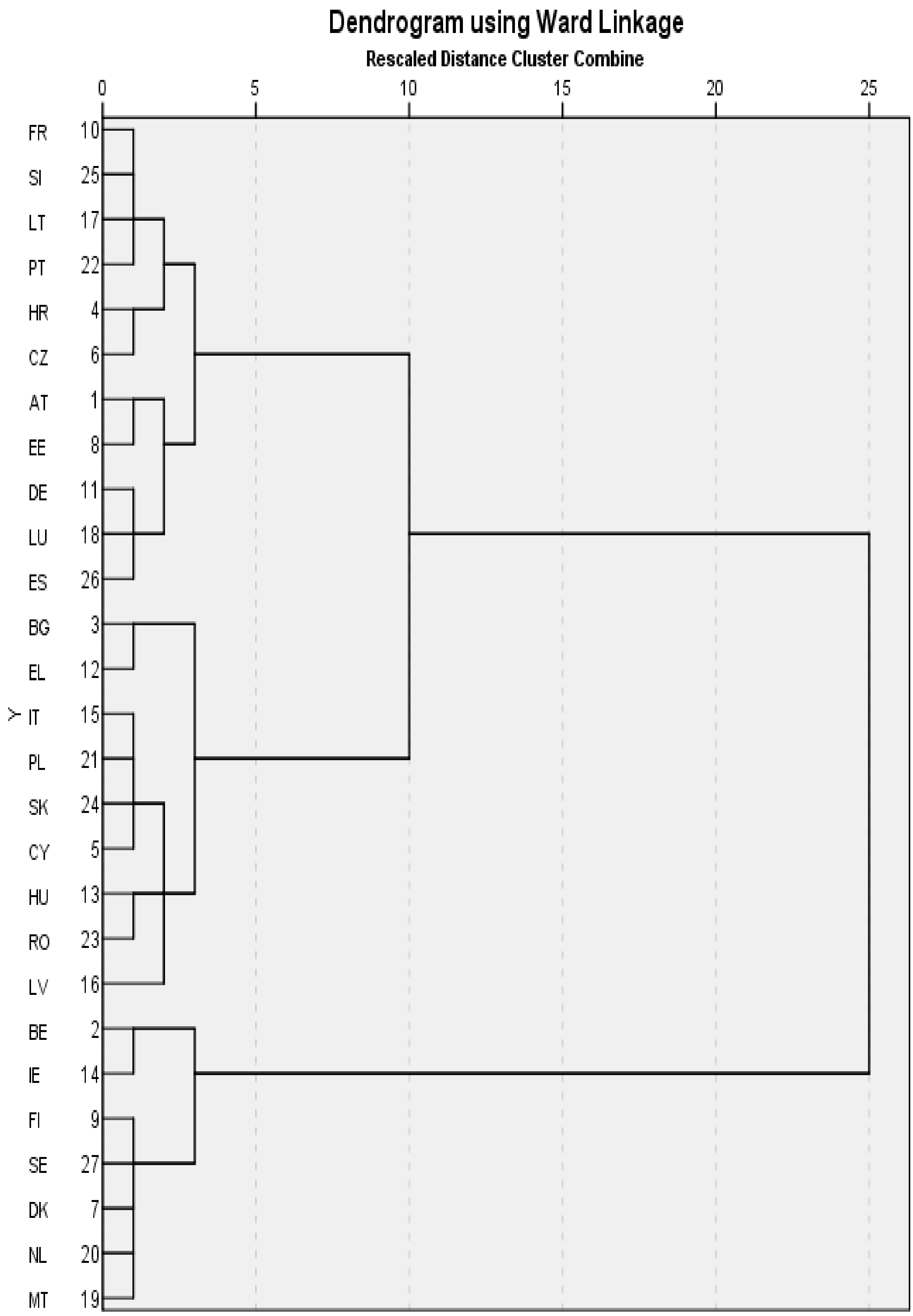

Figure 2. Dendogram of clusters, year 2020. Source: own construction using SPSS.

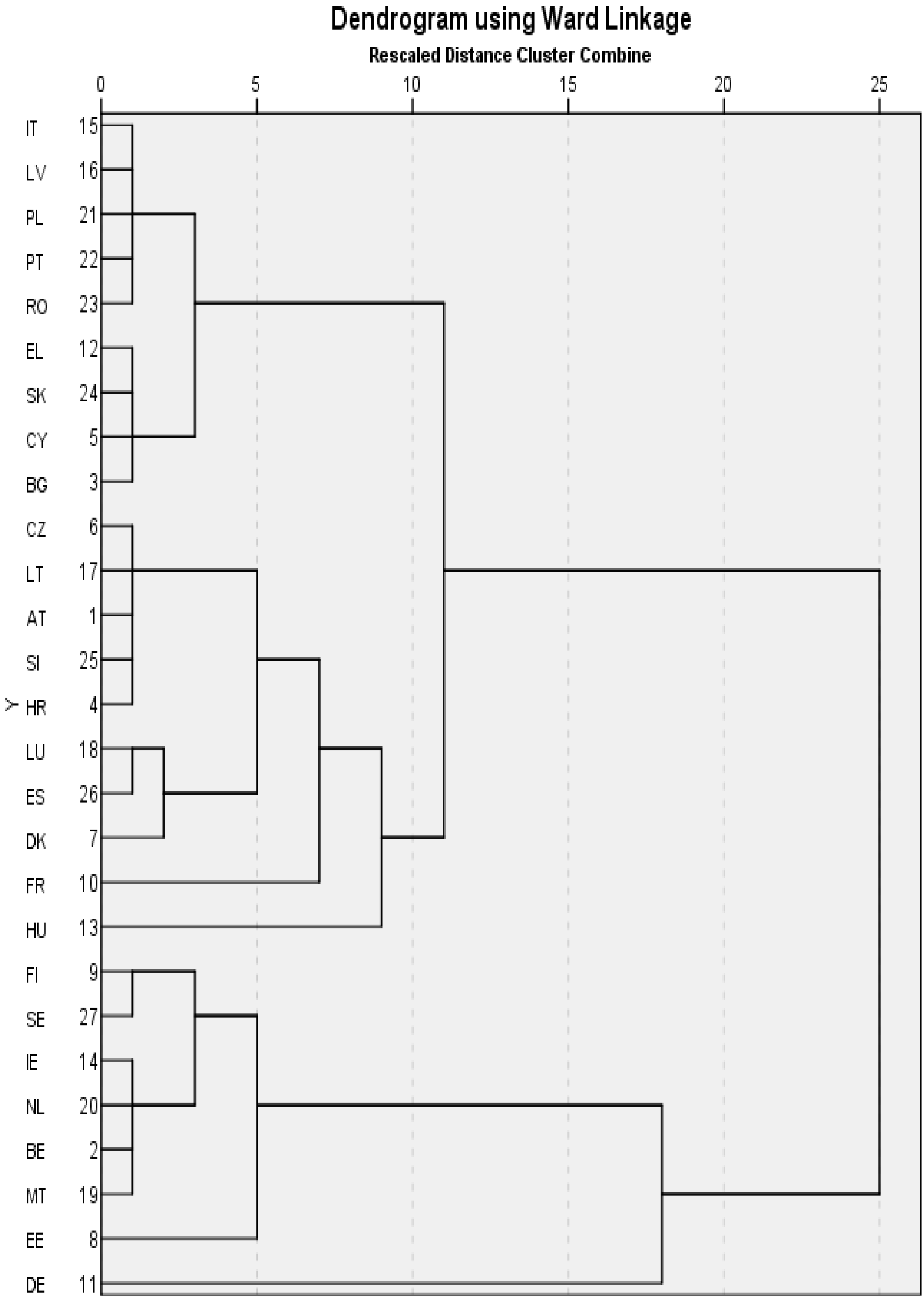

Figure 3. Dendogram of clusters, year 2025. Source: own construction using SPSS.

To check the validity of the clusters, making use of the existing literature and considering that unequal sized clusters were identified, we decided to use the Welch Test and the Brown–Forsythe Test (Null Hypothesis H_{0_1}: variable means do not differ significantly). The results of the tests for a significance threshold of $\alpha = 0.05$ are presented in Tables 4–6:

Table 4. Robust tests of equality of means, clusters for year 2015.

		Statistic [a]	df1	df2	Sig.
Connectivity	Welch	24.324	2	12.428	0.000
	Brown–Forsythe	19.136	2	22.944	0.000
Human capital	Welch	22.730	2	8.313	0.000
	Brown–Forsythe	22.940	2	10.676	0.000
Use of Internet services	Welch	62.067	2	13.719	0.000
	Brown–Forsythe	37.463	2	20.604	0.000
Integration of digital technology	Welch	34.727	2	15.157	0.000
	Brown–Forsythe	16.079	2	22.339	0.000
Digital public services	Welch	35.839	2	14.169	0.000
	Brown–Forsythe	28.268	2	23.368	0.000

[a] Asymptotically F distributed. Source: own construction using SPSS.

Table 5. Robust tests of equality of means, clusters for year 2020.

		Statistic [a]	df1	df2	Sig.
Connectivity	Welch	2.674	2	14.294	0.003
	Brown–Forsythe	2.715	2	20.089	0.090
Human capital	Welch	35.601	2	12.277	0.000
	Brown–Forsythe	27.110	2	14.338	0.000
Use of Internet services	Welch	18.529	2	13.181	0.000
	Brown–Forsythe	22.465	2	18.881	0.000
Integration of digital technology	Welch	88.299	2	13.050	0.000
	Brown–Forsythe	111.323	2	17.014	0.000
Digital public services	Welch	8.935	2	15.531	0.003
	Brown–Forsythe	8.338	2	20.962	0.002

[a] Asymptotically F distributed. Source: own construction using SPSS.

Table 6. Robust tests of equality of means, clusters for year 2025.

		Statistic [a]	df1	df2	Sig.
Connectivity	Welch	0.660	2	13.678	0.033
	Brown–Forsythe	1.104	2	12.084	0.036
Human capital	Welch	15.998	2	14.303	0.000
	Brown–Forsythe	19.411	2	14.414	0.000
Use of Internet services	Welch	7.891	2	14.091	0.005
	Brown–Forsythe	3.227	2	13.425	0.042
Integration of digital technology	Welch	8.827	2	14.188	0.003
	Brown–Forsythe	12.424	2	17.957	0.000
Digital public services	Welch	1.418	2	14.655	0.027
	Brown–Forsythe	2.089	2	12.123	0.016

[a] Asymptotically F distributed. Source: own construction using SPSS.

Subsequently, the results were tested by the ANOVA methodology ($p = 0.05$), for all three generated clusters. The results are summarized in Tables 7–9.

Table 7. The analysis of variance (ANOVA), clusters for year 2015.

		Sum of Squares	df	Mean Square	F	Sig.
Connectivity	Between Groups	53.051	2	26.525	14.293	0.000
	Within Groups	44.539	24	1.856		
	Total	97.590	26			
Human capital	Between Groups	136.209	2	68.105	23.563	0.000
	Within Groups	69.368	24	2.890		
	Total	205.578	26			
Use of Internet services	Between Groups	49.810	2	24.905	27.932	0.000
	Within Groups	21.399	24	0.892		
	Total	71.209	26			
Integration of digital technology	Between Groups	48.912	2	24.456	11.136	0.000
	Within Groups	52.708	24	2.196		
	Total	101.620	26			
Digital public services	Between Groups	96.403	2	48.201	19.866	0.000
	Within Groups	58.231	24	2.426		
	Total	154.634	26			

Source: own construction using SPSS.

Table 8. The analysis of variance (ANOVA), clusters for year 2020.

		Sum of Squares	df	Mean Square	F	Sig.
Connectivity	Between Groups	22.330	2	11.165	2.725	0.036
	Within Groups	98.349	24	4.098		
	Total	120.679	26			
Human capital	Between Groups	185.642	2	92.821	28.638	0.000
	Within Groups	77.789	24	3.241		
	Total	263.431	26			
Use of Internet services	Between Groups	44.785	2	22.392	23.959	0.000
	Within Groups	22.431	24	0.935		
	Total	67.215	26			
Integration of digital technology	Between Groups	220.427	2	110.214	123.214	0.000
	Within Groups	21.468	24	0.894		
	Total	241.895	26			
Digital public services	Between Groups	31.141	2	15.570	7.497	0.003
	Within Groups	49.843	24	2.077		
	Total	80.983	26			

Source: own construction using SPSS.

Table 9. The analysis of variance (ANOVA), clusters for year 2025.

		Sum of Squares	df	Mean Square	F	Sig.
Connectivity	Between Groups	59.763	2	29.881	1.218	0.031
	Within Groups	588.705	24	24.529		
	Total	648.468	26			
Human capital	Between Groups	351.994	2	175.997	21.088	0.000
	Within Groups	200.303	24	8.346		
	Total	552.298	26			

Table 9. *Cont.*

		Sum of Squares	df	Mean Square	F	Sig.
Use of Internet services	Between Groups	62.799	2	31.399	3.252	0.046
	Within Groups	231.700	24	9.654		
	Total	294.498	26			
Integration of digital technology	Between Groups	233.132	2	116.566	12.772	0.000
	Within Groups	219.032	24	9.126		
	Total	452.163	26			
Digital public services	Between Groups	40.035	2	20.017	2.062	0.014
	Within Groups	232.967	24	9.707		
	Total	273.002	26			

Source: own construction using SPSS.

4. Empirical Results

Following the described method, three significantly different clusters were determined for each of the analyzed years (2015, 2020, and 2025) to evaluate the digital performance in EU Member States in the context of the transition to a climate neutral economy.

Based on the analysis carried out, for 2015 we can identify three clusters. Cluster A-2015 includes 13 countries, namely Austria, Belgium, Germany, Estonia, Spain, France, Ireland, Lithuania, Luxembourg, Latvia, Malta, Portugal, and Slovenia. Cluster B-2015 groups 10 Member States, namely Bulgaria, Cyprus, Czech Republic, Greece, Croatia, Hungary, Italy, Poland, Romania, and Slovakia. The third cluster, C-2015, groups the remaining 4 countries, namely Denmark, Finland, the Netherlands, and Sweden. The characteristics of the clusters identified in 2015 are provided in Table 10.

Table 10. Characteristics for 2015 clusters.

Cluster	Country	Connectivity	Human Capital	Use of Internet Services	Integration of Digital Technology	Digital Public Services
A-2015	Austria	7.06	12.55	6.33	5.60	8.99
	Belgium	7.86	11.60	7.08	8.57	7.72
	Germany	8.92	12.82	7.30	5.70	6.35
	Estonia	9.67	13.97	8.51	4.94	11.59
	Spain	8.38	10.80	6.72	5.85	9.61
	France	7.66	11.06	6.69	5.18	6.87
	Ireland	6.57	11.86	6.22	9.26	9.15
	Lithuania	8.58	8.74	7.22	6.74	9.10
	Luxembourg	11.27	13.14	8.73	5.38	6.24
	Latvia	11.38	9.18	6.76	3.11	8.20
	Malta	8.18	13.34	7.16	7.13	10.68
	Portugal	7.71	7.98	5.23	6.02	10.13
	Slovenia	9.07	10.41	6.51	5.33	6.90
B-2015	Bulgaria	6.53	7.29	4.43	3.06	5.51
	Cyprus	4.36	8.39	5.62	5.00	7.28
	Czech Republic	8.10	11.21	6.39	7.44	4.96
	Greece	4.73	8.55	4.90	4.85	3.09
	Croatia	5.65	10.25	5.88	7.15	4.07
	Hungary	7.35	9.61	6.90	3.59	4.23
	Italy	5.90	7.70	4.81	4.44	6.91
	Poland	6.96	7.92	5.01	3.45	7.96
	Romania	8.73	6.87	3.26	3.35	4.67
	Slovakia	7.22	9.24	6.42	5.59	4.59
C-2015	Denmark	11.28	15.16	9.80	9.59	11.16
	Finland	9.91	18.05	9.47	8.43	10.82
	Netherlands	10.09	13.58	8.93	8.68	9.95
	Sweden	11.20	15.32	9.76	9.01	9.85

Source: own construction using SPSS.

For 2020, we have maintained the same grouping into three clusters, but their composition differs slightly, depending on the evolution of the variables analyzed. Cluster A-2020 groups 11 European countries: Austria, Germany, Estonia, Spain, France, Lithuania, Luxembourg, Portugal, Slovenia, Czech Republic, and Croatia. Cluster B-2020 brings together 9 EU countries, namely Latvia, Bulgaria, Cyprus, Greece, Hungary, Italy, Poland, Romania, and Slovakia. Cluster C-2020 groups 7 countries, namely Belgium, Ireland, Malta, Denmark, Finland, the Netherlands, and Sweden. The characteristics of the 2020 clusters are presented in Table 11.

Table 11. Characteristics for 2020 clusters.

Cluster	Country	Connectivity	Human Capital	Use of Internet Services	Integration of Digital Technology	Digital Public Services
A-2020	Austria	11.79	14.18	8.10	8.12	12.13
	Germany	14.85	14.10	9.23	7.91	9.96
	Estonia	12.96	16.66	9.81	8.23	13.40
	Spain	15.20	11.89	9.12	8.24	13.09
	France	12.46	11.86	7.96	8.41	11.51
	Lithuania	12.22	10.96	8.60	9.89	12.22
	Luxembourg	15.84	14.55	8.83	7.64	11.06
	Portugal	13.48	9.44	7.21	8.17	11.27
	Slovenia	12.56	12.09	7.76	8.19	10.61
	Czech Republic	11.22	12.16	8.12	9.92	9.36
	Croatia	10.29	12.29	8.32	8.29	8.36
B-2020	Latvia	15.44	8.76	8.10	5.66	12.76
	Bulgaria	9.62	8.48	5.50	3.57	9.26
	Cyprus	9.61	8.95	8.17	6.90	10.34
	Greece	8.34	8.70	6.91	5.64	7.73
	Hungary	14.95	10.46	8.38	5.06	8.67
	Italy	12.50	8.11	6.67	6.25	10.12
	Poland	12.84	9.32	7.45	5.25	10.11
	Romania	14.05	8.29	5.38	4.99	7.26
	Slovakia	11.87	10.45	8.00	6.51	8.34
C-2020	Belgium	13.01	12.60	9.17	13.17	10.76
	Ireland	11.42	14.10	9.31	14.86	12.09
	Malta	14.68	15.44	9.89	10.98	11.72
	Denmark	16.46	15.32	11.27	13.03	13.07
	Finland	14.79	19.61	11.45	13.41	13.05
	Netherlands	15.08	16.04	11.28	13.15	12.14
	Sweden	16.09	17.93	11.39	12.43	11.90

Source: own construction using SPSS.

For the year 2025, the three clusters have been defined, reflecting the projected evolution of the analyzed variables. The A-2025 cluster groups 9 Member States, namely Austria, Czech Republic, Spain, France, Croatia, Hungary, Lithuania, Luxembourg, and Slovenia. Cluster B-2025 contains 10 countries, namely Denmark, Bulgaria, Cyprus, Greece, Italy, Latvia, Poland, Portugal, Romania, and Slovakia. Cluster C-2025 comprises the remaining 8 EU countries, namely Belgium, Germany, Estonia, Finland, Ireland, Malta, and the Netherlands. The characteristics of the 2025 clusters are presented in Table 12.

Table 12. Characteristics for 2025 clusters.

Cluster	Country	Connectivity	Human Capital	Use of Internet Services	Integration of Digital Technology	Digital Public Services
A-2025	Austria	16.51	16.10	10.05	10.05	15.02
	Czech Republic	14.55	11.28	10.28	11.69	13.76
	Spain	21.86	11.16	13.36	10.63	16.57
	France	17.64	12.94	9.11	11.64	28.39
	Croatia	14.68	14.31	10.62	9.33	12.29
	Hungary	20.41	10.10	23.71	6.53	13.95
	Lithuania	15.90	13.46	10.15	13.38	15.56
	Luxembourg	19.77	15.96	9.12	10.32	17.70
	Slovenia	16.16	13.60	9.22	10.95	13.98
B-2025	Bulgaria	11.30	7.46	6.74	4.10	13.07
	Cyprus	14.61	9.50	10.75	8.79	13.41
	Denmark	24.75	15.26	13.11	16.42	16.37
	Greece	13.18	8.34	8.93	7.17	12.36
	Italy	19.62	8.53	8.53	8.01	14.50
	Latvia	19.46	9.59	9.37	8.10	16.37
	Poland	17.93	10.72	9.90	7.98	14.53
	Portugal	19.14	10.45	9.16	7.64	12.21
	Romania	18.95	9.68	7.71	6.19	9.86
	Slovakia	15.56	7.47	9.77	7.79	12.55
C-2025	Belgium	16.50	13.35	10.89	17.50	13.37
	Germany	38.87	15.15	11.35	10.33	13.05
	Estonia	16.19	26.09	10.98	9.54	14.83
	Ireland	16.27	16.48	14.32	20.04	15.27
	Finland	18.84	21.25	16.94	18.23	16.80
	Malta	19.25	16.38	12.54	14.29	12.53
	Netherlands	18.45	18.66	13.97	17.60	14.47
	Sweden	21.48	21.31	13.52	15.56	13.91

Source: own construction using SPSS.

5. Discussion and Main Implications

According to the literature, it is undeniable that digital performance supports the transition to a climate neutral economy. Monitoring EU Member States in terms of the DESI is one of the most relevant measures that the European Commission is promoting, with the level achieved by each country on each of the relevant indicators being benchmarks for future action. In addition, the DESI indicators are a reliable barometer of Member States' performance in terms of improving coverage of very high capacity networks, improving citizens' digital skills, and digitalization of business and the public sector.

In the framework of the Next Generation EU Recovery Plan adopted on 27 May 2020, DESI takes a central role in the country-specific analysis of how the digital recommendations, specific reforms, and investments are implemented. Moreover, the Recovery Plan for Europe also promotes a number of other facilities that Member States can obtain through access to the EURO 723.8 billion in loans and grants available to support reforms and investments undertaken by EU countries [61]. This financial facility underlines the importance the European Commission attaches to the performance of the digitalization of the economy and society, on the one hand, and the support Member States receive to increase their sustainable economic performance, on the other.

The results of our research reveal that EU countries could be structured according to their digital performance evolution in time. Analyzing the components evolution and forecast of selected data, we were able to spot the countries that demonstrate a constant and consistent concern for promoting digital services and improving digital skills, but also countries that must increase their efforts to support measures promoted at the European level to facilitate the transition to a climate neutral economy.

In order to better observe the clusters of countries at the level of each year analyzed, as well as to follow the evolution of the values of the variables defining the identified clusters more easily, we have centralized this information in Table 13.

Table 13. Mean values for 2015, 2020, and 2025 clusters.

Cluster	Connectivity	Human Capital	Use of Internet Services	Integration of Digital Technology	Digital Public Services
A-2015	8.64	11.34	6.96	6.06	8.58
B-2015	6.55	8.70	5.36	4.79	5.33
C-2015	10.62	15.53	9.49	8.93	10.44
EU-27 2015	8.16	10.99	6.74	6.02	7.65
A-2020	12.99	12.75	8.46	8.46	11.18
B-2020	12.14	9.06	7.18	5.54	9.40
C-2020	14.50	15.86	10.54	13.01	12.11
EU-27 2020	13.10	12.32	8.57	8.66	10.83
A-2020	18.23	13.42	11.87	11.09	16.36
B-2020	17.45	9.70	9.40	8.22	13.52
C-2020	20.73	18.58	13.06	15.39	14.28
EU-27 2025	18.44	13.50	11.26	11.11	14.69

Source: own construction using SPSS.

A main conclusion of the research carried out indicates that, by means of hierarchical cluster analysis, it is possible to demonstrate the existence of a relatively stable clustering of EU Member States over time, according to the components of the DESI index.

Thus, we can say that the analysis demonstrates that, since 2015, a cluster of European countries (C-2015) can be identified as strong supporters of sustainable development and the transition to a climate neutral economy, but also with high digital performance (Denmark, Finland, the Netherlands, and Sweden). Also in the same year, a cluster of countries with more modest performance (B-2015) is revealed, comprising countries from Southern, Central, and Eastern Europe (Bulgaria, Cyprus, Czech Republic, Greece, Croatia, Hungary, Italy, Poland, Romania, and Slovakia).

Looking at the evolution of the EU Member States in 2020, through the components of the DESI index, we identify the maintenance of the four performing countries grouped in the same cluster (C-2020), if they have been joined by Belgium, Ireland, and Malta, with above average performance. This joining is not by chance, as the three Member States display a consistent and coherent commitment to supporting sustainable development and increasing digital performance. The B-2020 cluster of the lowest performing EU countries has remained relatively constant since 2015, with the exception of the Czech Republic and Croatia, which, thanks to the political, economic, and social measures they have adopted as well as their sustained investment in new digital technologies, will, in 2020, become part of the A-2020 cluster, a cluster of European countries with above average digital performance.

These findings imply that econometric models could be identified and developed to accurately describe the evolution over time of DESI components in the coming years. At the same time, research can be carried out to identify the main factors influencing digital performance for the countries grouped in each cluster, so that the results can serve as a basis for the development of targeted policies to support the development of digital performance.

Based on the forecasting model, the grouping of Member States into three clusters is expected to be maintained in 2025, with the C-2025 cluster being the best performing of the countries analyzed. In the 2020 cluster, Germany and Estonia are expected to be present as well, countries with outstanding performance in the field of digitalization of the economy and e-government services, but Denmark and Sweden are expected to be part of the A-2025 cluster, possibly due to an expected slight reduction in growth rates compared to the other cluster members for which sustained growth rates are expected.

The analysis indicates that a core group of countries with more modest growth rates in digital performance, which have been grouped together since 2015, namely Bulgaria, Cyprus, Greece, Italy, Poland, Romania, and Slovakia (cluster B-2025), will remain in 2025. The research indicates that the grouping of these countries does not prove the existence of low digital performance, but that the rate of growth of the indicators analyzed is not comparable with the growth rates of the best performing countries, grouped in the C-2025 cluster.

If we aim to analyze the dynamics of the evolutionary process in terms of the digital performance of the Member States, we can also make some interesting observations. Thus, regarding the growth rate of the average values of the indicators analyzed for the cluster of the best performing countries (C clusters) compared to the EU average, we notice a reduction of the growth gap, due to the reduction of the growth rate of the values of the DESI components for the best performing countries, but also to the maintenance of a higher growth rate for the countries grouped in the other clusters. This observation has positive implications; the need for digital performance has been perceived and understood by all EU member countries, and the efforts made in this direction are not without results.

This result is also underlined by the observation that between 2015 and 2025 the gap between the cluster that brings together the lowest performing countries (cluster B) and the cluster that brings together the highest performing countries (cluster C) tends to narrow over time, with the highest catch-up rates being recorded for connectivity (from 38% in 2015 to 16% in 2025) and digital public services (from 49% in 2015 to 5% in 2025). At the same time, the lowest recovery rate is for human capital, for which a deceleration or an increase in the performance gap is estimated between the two periods analyzed (from 44% in 2015 to 48% in 2025). This requires increased attention from the responsible stakeholders and immediate measures to reverse the estimated trend.

Digitalization in EU Member States creates positive knock-on effects on the economy and society in the long term, in terms of sustainability and climate neutral economy. Moreover, the evolving digital transformation of the economy and society generates a number of multiplier, knock-on effects, new challenges, opportunities, and unique solutions for all areas of activity, across all geographical and economic regions. Thus, the results obtained are similar to the results published by Grigorescu et al. [62], Bánhidi et al. [63], Sevgi [64], or Diebolt and Hippe [65].

The digitalization of economic and social activities is bringing about a number of other changes, in particular in the labor market and its employment structure, which unfortunately in some markets and in some countries can lead to real and profound crises. We justify this conclusion by the fact that both the demand for and supply of labor in the IT industries and beyond are fundamentally changing, generating a certain pressure in particular on the education system, which is unable to estimate and rapidly implement the latest sustainable practices and knowledge required by the labor market.

We implicitly consider the need for specialists in the field of artificial intelligence, experts in the processes of digitization of the sustainable economy in the creation and implementation of innovative global networks adapted to the sustainable economy.

Nor should we neglect the fact that the sustainable, climate-neutral economy generates profound changes, including in terms of the management of economic and public entities, which must be fully in line with the transition to a climate-neutral economy.

The COVID-19 pandemic has had a significant impact on the EU economy and society, significantly changing the role and perception of digitalization and accelerating its pace. Digital transformation processes have accelerated and added urgency for governments to respond, so a key challenge is how to govern and harness the wave of digital data for the global good [66]. At the level of the European Union, but also beyond its borders, there are constant concerns to create and adapt public policy frameworks to manage digital performance.

While we are identifying increasingly elaborate and detailed policies in developed countries that address climate change, concerns remain that those most at risk in the transition to a climate-neutral economy are the least developed countries, which face significant challenges in contextualizing scientific research, bridging the gaps, and where the people most affected by climate change and least integrated into the process of technologization and digitalization continue to live [67,68].

Policy makers and all stakeholders are concerned about the possible developments and opportunities opened up by the digital economy. Digital public policies must foster agility, innovation, and value creation, while the participation of all members of society becomes a priority objective in order to embrace all the opportunities generated by digital progress and innovation, and numerous published reports and research indicate that this is happening every day [69–72].

The digital performance of EU Member States is therefore both a catalyst and a consequence of the changes that the economy and society are facing today, in particular those related to the transition to a green, climate-neutral economy. In this context, we believe that our study has a major contribution to make to the scientific process of substantiating macro and micro economic decisions concerning today's society, which is threatened in the medium and long term by climate change.

6. Conclusions

Our research examined digital performance in EU Member States in the context of the transition to a climate neutral economy, analyzing the current state of the art and the prospects of evolution until 2025. The extremely rapid pace of evolution, as well as the importance that digitization has on the economic development of contemporary society, justify a greater attention to this topic.

Based on the available DESI data, using cluster analysis, we analyzed how EU countries can be grouped based on the evolution of their digital performance, in order to highlight existing differences as well as development opportunities. The results indicate that, around the core formed in 2015 by four high digitally performing countries from the North of Europe in 2015, other countries have gradually clustered, so that in 2025 we estimate that a number of eight Member States will be part of the group of the most digitally performing countries. These countries are decisively committed to the transition to a climate-neutral economy, and all European and non-European countries pursuing the same sustainable development goals can take up their public policies and examples of good practice.

The results of the research generate implications for all stakeholders. For policy makers, it is important to get an overview of the potential evolution of the main indicators related to digital performance, in order to be able to intervene in time to correct development gaps and to support appropriate directions for action. The results of our study can also provide all stakeholders with a fresh and different perspective on digital performance in EU countries, as well as the potential for growth in the years to come.

We also underline that the results obtained from this research will contribute to a better understanding of how EU member countries evolve and cluster according to digital performance, generating new challenges to all stakeholders by providing relevant information to policy makers, researchers, the business community, and NGOs who demonstrate a genuine concern and unconditional support for the transition to a climate neutral economy.

This research should also be analyzed considering its potential limitations, but also for opening new directions for further research. Not to be neglected is also the existence of certain potential research constraints arising from the availability of data and from the methodological framework used for the analysis. Therefore, given that cluster analysis is considered a hypothesis generating technique and not a hypothesis testing technique, we can identify the structures existing between the variables under analysis, but we cannot demonstrate the reasons for their existence through this research methodology.

New research directions could be generated, expanding the set of variables used, aiming at identifying a generalized model or exploring narrower models, in order to be able to track the effectiveness of public policies and strategies adopted at the level of the countries under analysis, and to assess the medium and long term effects on local and regional economies, and on society as a whole.

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