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The impact of digital transformation on European countries: insights from a comparative analysis

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Keywords: *digital transformation; technological development; economy 4.0; society 4.0; company 4.0; European countries*

Abstract

Research background: In the era of the digital revolution, the Internet, automation and robotisation, new industrial relations and dynamic interactions among different stakeholders are giving rise to new opportunities and challenges. The changes associated with the enforcement of the "Industry 4.0" concept require adaptation to these developments at different levels of the economy and society in order to support digital transformation.
Purpose of the article: The aim of this paper is to measure and assess the impact of digital transformation on European countries (EU). The comparative analysis of technological development in EU countries includes three dimensions: the digitalisation of society (Society 4.0), the ability of the economy to face the challenges of technological development (Economy 4.0), as well as the exploitation of ICT in companies (Companies 4.0).
Methods: The empirical section of the article was built on a two-stage analytical approach: (a) cluster analysis methods to assess differences and similarities between EU countries (Hierarchical Cluster and K-Means Cluster) and (b) the multi-criteria decision-making method (TOPSIS)

to rank countries according to the adopted evaluation criteria. For the purposes of this analysis, data from the Eurostat database have been applied.
Findings & value added: The results of this analysis demonstrate the impact of technological transformation on the economy and society in EU countries grouped according to a similar level of development, such as countries with high, medium and low performance. This has contributed to indicating the cohesion in technological development achieved by each country group and to recognising the digitalisation gap between EU Member States. The novelty of this study consists in applying the multi-stage, multi-criteria analysis based on cluster analysis and the TOPSIS method, as well as the comparative analysis of the impact of technological developments on the societies and economies of EU countries. This paper extends similar studies by focusing on the application of a broad range of indicators regarding a holistic perspective including three dimensions: societies, economies and companies. The results provide valuable insights into evaluating the technological progress in European countries.

Introduction

Less than a decade ago, mobile devices, social networks, cloud computing or analytical capabilities of companies were not well known, and hardly anyone expected just how profoundly they would affect business processes or social relations (Kergroach, 2017). Progressive digital transformation through the creation of connection networks between products, value chains and business models are perceived as new trends within the fourth industrial revolution, referred to as "Industry 4.0". In the era of Industry 4.0, the integration of intelligent, networked and autonomous digital and physical technologies such as the Internet of Things, robotics, autonomous vehicles and 3D printing create new opportunities for innovation and the development of business activities and the information society. The term "information society" appeared in the 1970s in reference to the famous technological wave theory of Alvin Toffler, an outstanding American sociologist and futurist (Toffler, 1980). It is associated with the knowledge-based economy and its counterparts, such as the digital society and digital economy.

In the EU, the concepts of Economy 4.0 and society 4.0 are treated as strategic areas of EU development. As part of the "Digital Europe Programme", the EU strives to create an advanced, intelligent 21st-century economy, owing to which Europe should become the most innovative, productive, "green" global economic power (European Union, 2019; Misuraca *et al.*, 2012). Owing to this, the digital transformation of European countries involves the continuous intensification of technological developments. However, the plan to digitise the European economy requires more than just universal access to free broadband wireless Internet and the abolition of roaming. The digitisation of the European economy, including the robotisation and automation of the production of components, gives rise to unprecedented new business opportunities.

From the holistic perspective, digital transformation involves the integration of the digital technology not only into economies, particularly businesses, but also into all areas of society, fundamentally changing the way individuals operate. Concepts such as Economy 4.0 or Society 4.0 mean both challenges and opportunities. They are based on breakthrough technologies that enable delivering new value to recipients. The development of technology affects changes in the socioeconomic context and defines a new model of industry based on system integration and networking, especially the integration of people and digitally controlled machines into the Internet and information technologies. The digital transformation is driven, among other factors, by a huge increase in the amount of data, computing power and connectivity, new forms of interaction between man and machine (touch interfaces or augmented reality and virtual reality) or the improved process of transferring digital instructions to the physical world, which can be seen, for example, in advanced robotics and 3D printing (Abolhassan, 2017; Matt *et al.*, 2015).

In order to meet these challenges and effectively use the opportunities associated with them, it should be emphasised that digital transformation requires new competencies and technological solutions to support developments for the information society and the economy, especially for companies.

Analysing the impact of the digital transformation on society and economy, various studies exist on current trends and challenges (Fitzgerald *et al.*, 2013; Kane *et al.*, 2019; Westerman *et al.*, 2014). There are also numerous research papers that compare the level of innovation and digitization of countries in different areas — economic, social or governmental. However, the authors usually focus on the analysis of one selected issue by using individually chosen sets of variables and various analytical methods. Thus, the research results obtained by different authors do not always allow for comparisons. Given that the issue of the impact of technological change on the socio-economic sphere and its adaptation to current challenges is complex and, at the same time, extremely important for the shaping of national and European agendas for digital competitiveness, there is a need to broaden the research approach both empirically and methodologically. Exploring the different dimensions of the impact of digital transformation on society and economy by using a multi-stage analytical approach based on different methods provides a more comprehensive and objective benchmark. Our research responds to this need, both in terms of the research framework and the methods used.

The aim of the article is to measure and assess the impact of digital transformation on European countries based on the comparative analysis in three dimensions: the digitalisation of society (Society 4.0), the ability of the economy to face challenges associated with technological development (Economy 4.0) and the exploitation of ICT in companies (Companies 4.0). From the perspective of contemporary challenges, the following research questions will be considered: (1) what is the level of technological development in EU countries? (2) how does digital transformation determine the development of EU countries? In order to achieve the goal of this study, a comparative analysis of selected indicators of digital transformation in the 28 EU member countries based on the public Eurostat statistics has been conducted. For data analysis, a two-step approach based on two various methods — cluster analysis and TOPSIS method — was applied. Our research provides a comparative assessment of individual EU countries in terms of their level of technological development in three areas. This enables the identification of those areas that should be addressed to a greater extent by the governments of individual countries shaping public policies for digital competitiveness. The findings provide an opportunity to identify a group of countries that have similar problems in adapting their socio-economic environment to the challenges of the technological development, in order to improve the alignment of EU policies targeted at Member States. In addition, the use of 2018–2019 data contributes to the assessment of countries immediately prior to the Covid-19 pandemic, providing a robust basis for further analysis on the digital acceleration forced by the pandemic.

The remainder of this paper is structured as follows: in the following section, a review of relevant literature will be conducted. In section 3, the research methodology and data sources will be described. The following section will present the results and discussion. Subsequently, the most important conclusions will be summarised and research limitations provided.

Literature review

The essence of the digital transformation

Digital transformation is an interdisciplinary field of research. The concept of digital transformation is defined differently in literature, both in narrow and broader terms. In the narrow term, digital transformation can be defined as an organisational change in a company's business model triggered by digital technologies (Hess *et al*., 2016). Given the broad term, the digital transformation plays an important role in the public debate from two key perspectives: the technological and the perspective of industrial policies.

European research policies, together with national policy documents from various European countries, encourage the promotion of digital transformation that can simultaneously convey technological and social innovation as an opportunity (Compagnucci *et al*., 2017; European Commission, 2017; Mazali, 2018). The shaping of information societies and digital economies is the subject of many documents developed by the EU, which analyse the progress of the Member States in the field of digital competitiveness by applying the complex Digital Economy and Society Index (DESI). The five dimensions of the DESI include (European Union, 2018):

- Connectivity (Fixed Broadband, Mobile Broadband, Fast and Ultrafast Broadband and prices),
- Human Capital (Basic Skills and Internet Use, Advanced skills and Development),
- Internet Use (Services Citizens' use of Content, Communication and Online Transactions),
- Integration of Digital Technology (Business Digitisation and e-Commerce),
- Digital Public Services (eGovernment and eHealth).

In order to support digital transformation, changes must occur at various levels within both society and economy. Digital transformation is generating societal impact because it is affecting issues such as education, jobs, wages, inequality, health, resource efficiency and security (Dutton, 2014; Mazali, 2018). The digital transformation can be covered by five key areas of social life (van Deursen, van Dijk & van Helsper, 2014):

- economic – predominantly covering issues related to employment and job search, as well as the benefits of online shopping,
- social – including building social bonds and interpersonal communication, as well as the related increase of social capital,
- political – including, inter alia, participation in a political process (for example related to elections) or in non-institutional policy (for example in a public debate on political issues) and civic participation,
- cultural – covering broadly understood cultural activities and the sphere of education,
- institutional – including the use of public services and information, as well as medical services.

With regard to Economy 4.0, it is not just about collecting information, but about the fast processing of large amounts of data and their efficient use (WEF, 2020). The potential of Economy 4.0 is crucial for the development of new, innovative industries and services (EC, 2016). When analysing the digital maturity of the economy, often the question arises of how digitisation — understood as the process of using digital technologies and tools for doing business — spreads in individual sectors of the economy and how it affects its environment? The key components of the digital economy include, e.g. ICT infrastructure, the use of ICT in business relations, business environment which can act as a catalyst or slow down changes in the economy, digital competences (Denecken, 2015).

Due to the comprehensive dimension of the economy, special attention should be paid to enterprises. From the company's perspective, the digital transformation can be defined as a process of changes by exploiting digital technologies in a company's business model, products or organisational structures (Hess *et al*., 2016). In recent years, the number of papers addressing different technological and organisational aspects of digital transformation has increased significantly. The interest of enterprises in Industry 4.0 stems from the belief that technological development will contribute to an increase in the efficiency of enterprises and will have an impact on the emergence of new business models, services and products, which in turn will determine the position of national economies globally (Kagermann, 2014). The implementation of a business model based on digitisation and the creation of technologically advanced jobs is only possible given the availability of qualified personnel responsible for high-tech tasks.

To conclude, digital transformation influences many spheres of everyday life, work, or economy. Different measures are available that provide evidence of how technologies change social and economic development. Given that digital transformation is still in its conceptual phase and intends to incorporate a very dynamic technological concept covering many industries (IT, mobility, energy suppliers, construction, medicine, textile, etc.), there is a need to provide analysis around digital transformation at the societal, economic and company levels (not only at the individual level). However, the discussion about the social and economic effects of the new paradigm is still underdeveloped (Mazali, 2018). Therefore, the assessment of the impact of technological development on society and economy, as a comprehensive issue, requires the use of multi-criteria analysis methods.

Previous empirical comparative studies

The impact of digital transformation on the economy and society has already been analysed in international research papers. Since it is a highly multifaceted issue, a common research strategies are cluster analysis and multi-criteria decision analysis (MCDA). However, most studies are limited to one dimension (e.g. the economy) or one type of analytical method.

For example, hierarchical clustering was used, among others, by Zaharia and Bălăcescu (2020) to find homogeneous groups among the 28 EU Member States in terms of digitalisation. This study was based on the Digital Economy and Society Index (DESI) and two other indicators measuring education and residents' satisfaction. Piatkowski (2020) also applied the hierarchical method to study and compare EU countries, but only in terms of national labour markets from the perspective of changes and challenges of industry 4.0. The analysis of similarities between countries was based on Eurostat data. Similarly, Novkovska and Dumicic (2019) and Kašparová and Barva (2018) used the same approach to study youth behaviour in the digital world, grouping EU countries according to their similarities and differences. Another study limited to a single method based on hierarchical clustering was conducted by Mihai *et al*. (2018) and addresses the comparative analysis of EU countries on the impact of the digital economy on the health sector.

Furthermore, partition clustering methods, such as k-means or k-median, are applied less frequently than hierarchical ones and mostly as a complement to other analyses. Žmuk and Mihajlović (2018) used this type of method to extend their research on the impact of new information technologies on travelling and accommodation services by individuals in EU countries. Another study by Máchová and Lněnička (2015) is based on the e-government development index and includes the development in EU Member States between 2008 and 2014, using clustering of two types — hierarchical and partitioned.

Multi-criteria decision-making methods, including TOPSIS, which enables ranking of multivariate objects based on a synthetic measure, have been used for international comparisons, e.g. in the works of Balcerzak (2016) and Balcerzak and Pietrzak (2017). Balcerzak (2016) used TOPSIS to assess the relative position and potential progress in technological development of Central European economies that joined the EU after 2004. Balcerzak and Pietrzak (2017) chose the TOPSIS algorithm to assess and compare the level of development of the digital economy in the Visegrad countries at the regional level.

Our research combines both set of methods used by researchers in the analysis of multi-criteria issues. Moreover, based on a set of selected variables, we propose to measure the impact of digital transformation on European countries considering three key dimensions: society, economy and business. This enables not only cross-country comparisons, but also cross-dimensional ones.

Research methodology

Sampling and data collection

The key aim of this paper is to measure and assess the impact of digital transformation on EU countries by applying a comparative analysis including three dimensions: the digitisation of society (Society 4.0), the ability of the economy to face the challenges associated with technological development (Economy 4.0) and the exploitation of ICT in companies (Companies 4.0) of the 28 EU Member States. By comparing countries in these three areas, the analysis focuses on the differences and similarities in the technological development of EU societies and economies. The results of the ranking contribute to indicating the cohesion in technological development achieved by each country group and to recognising the digitalisation gap between the European countries (Filippetti & Peyrache, 2013).

The data applied in the analysis has been collected from the Eurostat public statistics and includes a set of indicators derived from the dataset in the field of:

- *Society 4.0* – measures Internet use by individuals for various purposes in their daily life, which indirectly informs about the level of development of the digital skills of societies.
- *Economy 4.0* – measures the ability of the economy to absorb modern technologies by assessing its innovation, human potential and participation in the technology domain.
- *Companies 4.0* – measures the use of ICT tools for running their business by companies.

For the selection and evaluation of secondary data, the following set of criteria was used, e.g.: methodology, accuracy, date of data collection, purpose of data collection and data content (Crowther & Lancaster, 2008). The Eurostat database includes a wide range of indicators on technological development in individual EU countries that reflect the complexity of the digital transformation at both the macro- and micro-economic levels (Table 1).

The employment of secondary data analysis is the right approach for many reasons. First, these data include extensive and comparable data from different countries. This is to stress that the publicly available data with a high sample size and representativeness leading to broader applications provides sufficient information to assess its external validity. Moreover, external validity can be considered as the generalisability of the research results (Bryman & Bell, 2007). Validity is important because it can help determine the use of those methods that are not only ethical and costeffective, but also methods that truly measure the research idea or constructs. Secondly, the public statistics data provide high-quality results through the possibility of eliminating questionable and incomplete materials and reduce the risk of participation in the study by people with limited knowledge and competence (Vartanian, 2011; Johnston, 2014). Thirdly, existing data support re-examination, thus creating the possibility of replication. This is especially important in proving the reliability of the research analysis (Crowther & Lancaster, 2008).

Data analysis methods

Given the research objective of the article, this study focuses on digital transformation in society, economies and companies. The analysis of multidimensional issues consisting of more than one feature requires an appropriate methodological approach. Different analytical tools can be used effectively, however applying more than one method allows us to see the research issue from various perspectives.

First, cluster analysis methods were used to search for similarities and differences between THE 28 EU countries. Second, one of the Multi-Criteria Decision-Making (MCDM) methods, namely TOPSIS, was applied in order to rank countries within three dimensions: Society 4.0, Economy 4.0. and Companies 4.0.

Cluster analysis, also referred to as segmentation analysis or taxonomy analysis, is a statistical technique applied to find homogeneous groups in data. It offers two general groups of methods: hierarchical (agglomerative and divisive) and partition (k-means and k-medians). Hierarchical methods apply a tree structure to group data (by observation or feature) and non-hierarchical methods are built on aggregation points, named centroids, around which groups are created (Caruso *et al*., 2018).

A different approach addressed to multidimensional issues is offered by Multi-Criteria Decision-Making (MCDM) methods. In general, MCDM is relevant to structure and decision-making, as well as planning highly complex problems (Aruldoss *et al*., 2013). This group of methods offers a varying range of useful tools enabling the evaluation, assessment and ranking of alternatives across diverse areas (Yoon & Hwang, 1995; Tzeng & Huang, 2011). The TOPSIS algorithm is among the most easily applicable ones used for solving complex problems, alongside others, such as AHP, ELECTRE and PROMETHEE (Tzeng & Huang, 2011). TOPSIS, initially developed by Hwang and Yoon (1980) is defined as "an approach to identify an alternative which is closest to the ideal solution and farthest from the negative ideal solution in a multi-dimensional computing space" (Qin *et al*., 2008, p. 2166). Characterising the compound issue by a set of attributes, the "ideal solution is composed of all best attribute values attainable, and the negative-ideal solution composed of all worst attribute values attainable" (Yoon & Hwang, 1981). Aside from its application in traditionally perceived decision-making processes, TOPSIS is successfully implemented in scientific research, where the purpose is to assess and rank objects based on an aggregated measure built on a set of features.

The analytical procedure draws on both types of methods: cluster analyses and MCDM. The methodological procedure includes the following strategies:

- Variables selection – choice of variables from the Eurostat database. Reduction of variables due to substantive and statistical criteria. Filling in individual data gaps using available data according to the most current state. Creating a set of cross-sectional data, basically for the year 2018 or 2019, with some exceptions for 2017.
- Cluster analysis – grouping of EU countries in terms of similarity in the values of their characteristics. Clustering was carried out on raw data using Ward's agglomeration method and Euclidean distance, based on the dendrogram evaluation of the number and variety of clusters created, rerunning the cluster analysis by using the k-means procedure with a reasonable amount of previously defined clusters. The initial centres of clusters were created in an attempt to maximise the distance between them.

Countries' ranks were determined by applying the TOPSIS method to evaluate their performance in three defined dimensions and placing them in the proper order as compared to the remaining 27 EU Member States. The procedure specification in TOPSIS provides for the following, general steps (with equal weights for each variables):

Step 1. Construct normalised decision matrix

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum x_{ij}^2}} \text{ for } i = 1, \dots, m; j = 1, \dots, n \tag{1}$$

where:
x_{ij} – the original matrix;
r_{ij} – the normalised matrix.

Step 2. Determine the positive ideal (2) and negative ideal solution (3):

$$A^{+} = \{v_1^{+}, \ldots, v_n^{+}\} \tag{2}$$

where:
$v_i^{+} = \{max(v_{ij}) if j \in J^{+}; min(v_{ij}) if j \in J^{-}\}$

$$A^{-} = \{v_1^{-}, \ldots, v_n^{-}\} \tag{3}$$

where:
$v_i^{-} = \{min(v_{ij}) if j \in J^{+}; max(v_{ij}) if j \in J^{-}\}$

Step 3. Calculate the L2-distance between the target alternative i and the positive ideal alternative:

$$S_i^{+} = \left[\sum (v_j^{+} - v_{ij})^2\right]^{1/2} for i = 1, \ldots, m \tag{4}$$

and L2-distance between the target alternative i and the negative ideal solution:

$$S_i^{-} = \left[\sum (v_j^{-} - v_{ij})^2\right]^{1/2} for i = 1, \ldots, m \tag{5}$$

Step 4. Calculate the performance score $\boldsymbol{C_i}$

$$C_i = \frac{S_i^{-}}{\left(S_i^{+} + S_j^{-}\right)}; 0 < C_i < 1 \tag{6}$$

Step 5. Rank the alternatives according to $\boldsymbol{C_i}$; i = 1, …, m

The value of C_i score reaches the value between 0–1.

Results presentation and analysis — the results have been compared in several ways: coherence between the investigated fields, diversity within the overall group, and observable spatial patterns.

It should be emphasised that the use of different analysis methods significantly supports the main research question of to what extent digital transformation determines the development of European countries?

Research results and discussion

Cluster analysis results

Based on the research objective, an analysis will be conducted on the impact of technological development on the societies and economies of the EU Member States, including similarities and differences between the countries. The research focus will be drawn on three dimensions: society, economy and companies.

Society 4.0

The measures of digitisation of societies are expressed in the percentage of people using the Internet for the given purposes and having above elementary/basic overall digital skills. The dendrogram with the results of the hierarchical cluster analysis for 28 countries is shown in Figure 1. The visual evaluation of the dendrogram suggests determining the number of 3 to 5 distinct clusters, depending on the distance cut-off criterion.

Given two most distant clusters, it can be stated that a small group of countries, including Italy, Poland, Portugal, Croatia, Cyprus, Greece, Romania and Bulgaria, clearly differs from the other 20 states. However, the two latter ones — Romania and Bulgaria — vary significantly from the rest. The analysis of the remaining 20 countries also shows some diversity between them. The dendrogram allows for indicating two or even three distinct clusters within this sample. The Nordic countries form the most homogenous cluster, along with the United Kingdom, Estonia and the Netherlands. A further 14 states form a much more diverse group than the previous one. Based on the above findings and several tests of different cluster amounts, three groups were finally accepted for processing k-means clustering. The results are included in Table 2, Figure 2 as well as in Table 3.

The obtained results generally coincide with those reached using the agglomeration method. The ANOVA outcomes indicate that the main criteria determining the state belonging to a given group are: % of individuals using the Internet for online banking, % of individuals using the Internet for sending/receiving e-mails, % of individuals using the Internet for interaction with public authorities and % of individuals using the Internet with a high frequency (Table 3). However, the values of all variables differ significantly between clusters. A graph presenting the mean values of variables shows a simple order of clusters — from the highest digitalised level of society to the lowest (Figure 2). Undoubtedly, the reason for such classification is interdependence between the measures.

By focusing on the leading group, consisting of six countries, the United Kingdomis characterised by the largest distance from the centre of the cluster, which indicates that this country is different to the remaining group members. In the second cluster (medium performers), the most distant from the centre of the cluster are Germany, Hungary and Latvia. While the first and the second cluster can be considered relatively homogeneous, in the third cluster (low performers), two countries are significantly more distant from the others — Romania and Bulgaria.

The cluster analysis shows that the level of digitization of EU societies varies considerably. It should be mentioned that the correlation of the individual digitization indicators could influence the results of the classification.

Economy 4.0

The second category of research — Economy 4.0 — is measured by a set of diverse features concerning the innovativeness of the economy, the contribution in modern technology goods production measured by their export and human potential. The generated dendrogram is flatter and indicates the existence of three larger to five smaller clusters (Figure 3).

Similar to the analysis on societies, the Nordic countries together with the Netherlands form the core of one, relatively homogenous, cluster. The next cluster, illustrated by the middle branches of the hierarchical tree, includes almost all of the countries in Central and Eastern Europe and only single ones from Western Europe. The third cluster, presented on the above dendrogram, seems to be the most diverse and connects both the wealthy Western countries (i.e. France, Belgium, Luxembourg), with the Eastern European countries (i.e. Czech Republic, Slovenia and Estonia) (Table 4). The composition of the third cluster in particular has been changed following the application the k-means method.

In general, the country's groups identified in this analysis are characterised by less discrepancy in terms of the mean values of variables for clusters in comparison to the dimension of Society 4.0. Figure 4 and the data in Table 5 show that the primary criterion differentiating these groups of countries is the number of patent applications to the EPO per million inhabitants. The Western European countries gathered in clusters 1 and 2 dominate in this field.

It is apparent that the new EU countries from Central and Eastern Europe are unable to compete with the wealthy and more innovative of the

West European economies. The final and largest cluster presents the weakest countries in all the studied measures in the field of economy.

Companies 4.0

A similar analysis is carried out to assess the digitisation and use of ICT tools in enterprises. In this case, the indicators applied are more diverse and concern the use of IT tools and the Internet in company operations, digital securities and delivering digital training to employees. The dendrogram suggests that there are three to six meaningful clusters in the sample (Figure 5). Although there exist similarities to the results of the previous analysis, a closer look at the dendrogram shows that the allocation of some countries between groups has changed. For instance, Poland is most similar to Hungary and Slovakia but it also belongs to the same cluster as Italy and Portugal (Figure 5).

Based on the analysis using the k-means method, the EU countries were divided into three groups. The k-means cluster analysis provides slightly different results to the agglomeration one. Although the division of countries is largely similar to the classification by Society 4.0, it differs in the details (Table 6).

The core of the leading cluster are also the Nordic countries with the Netherlands and the United Kingdom, but this group covers additional members such as Belgium, Ireland and Malta. The medium performance cluster is the widest and includes both Western European countries, as well as new members from Central and Eastern Europe. The country farthest from the centre of the cluster is Germany, which indicates that it differs most from its group members. In turn, the low performance group is the least numerous and, besides Bulgaria, Greece, Poland and Romania, also includes Latvia and Hungary. The key criteria determining belonging to a given group during the clustering process were two main indicators: % of the enterprises buying cloud computing services used over the Internet and % of enterprises using any social media (Table 7).

The differences between clusters are presented in Figure 6. The chart shows, however, that clusters differ in value for all of their variables. Lines indicate some hierarchy between clusters depending on indicator value. The highest values were recorded in relation to indicators such as: enterprises with a website, enterprises using ICT security measures (pages password authentication, enterprises using any social media. Whereas the lowest values present such indicators as: enterprises buying cloud computing services used over the Internet, enterprises having received orders online, enterprises that provided training to develop/upgrade the ICT skills of their personnel.

The cluster analysis demonstrates the relatively significant diversity of EU countries concerning the impact of modern technologies on societies and economies, as well as the ability to absorb technological innovations by individual states. A clear hierarchy arises, where highly developed and economically wealthier countries are generally the most technologically advanced. The results also suggest some regional patterns. Further on in the article, these results will be verified based on synthetic measures built by the TOPSIS method.

TOPSIS analysis

Based on the TOPSIS method, the ranking of the 28 EU Member States within the three main categories: Society 4.0, Companies 4.0. and Economy 4.0 was developed (Figure 7). The results are presented in the form of a heat map and the details are included in Table 8. For the graphical presentation of the results, the values of synthetic measures have been divided into ten groups. The dark red colour indicates the countries with the highest value of synthetic measures. Dark green indicates the lowest values of the TOPSIS measures. Denmark ranked at the top. It achieved the highest results in all three dimensions. The Nordic countries have traditionally indicated the highest values of technological and innovative performance. Denmark, the Netherlands, Sweden and Finland deviate considerably from the other countries as regards both factors, indicating a higher propensity to reach the highest values (Castelo-Branco *et al.*, 2019). Besides these countries, the following states are also at the top of the list in the selected categories: Austria, Belgium, Estonia, the Netherlands, Ireland, Luxemburg, Malta, Germany and the United Kingdom. Among the countries with the weakest results are Bulgaria and Romania, but also Poland, Slovakia, Lithuania, Latvia, Hungary, Cyprus and Italy. Romania achieved the lowest score in all three categories. These results conform with other studies (Naudé *et al.*, 2019; van Deursen & van Dijk, 2011).

The created ranking of technological developments in all European countries supports previous results of cluster analysis and is generally consistent with other similar studies, including the most well-known DESI Index (Annual Index of Digital Economy and Digital Society) published by the European Commission (Urbaniec & Czaja, 2019). While individual countries may differ slightly in the rank achieved due to the index structure, data composition, and methodology used, the overall trends are convergent.

The heat map also facilitates assessing how coherent the results of the individual countries are in all of the studied fields. There is a certain group of countries leading in one domain, with medium and low performance in others. Such countries include, for example, Estonia, Slovenia, the Czech Republic and Malta. The results can support building policies to strengthen a selected area of technological development.

The spatial distribution of TOPSIS analysis results (Figure 8) indicates that achievements in technological development and innovation are regionally interdependent. This may be the result of spillover and even imitation processes. Strong ties between economies and societies sharing the same cultural roots and situated in geographical proximity to one another promote the dissemination of knowledge and technological development. The challenge is to ensure that positive processes within European integration also include countries that are geographically more distant and need support to bridge the gap that exists between leaders in technological development and underperforming countries.

Conclusions

Based on the literature review, it can be concluded that the issue of digital transformation is complex and multilevel. Digital transformation is not only a matter of social inequalities but also the competitiveness of the economy, because it builds an ecosystem for more technologically advanced products and services, as well as for raising digital competences necessary on the labour market. Advancing technological development creates many opportunities as well as threats for societies, economies and companies.

This paper has aimed to provide a measurement and evaluation of the impact of digital transformation on 28 EU member countries based on comparative analysis in three dimensions: the digitalisation of society (Society 4.0), the ability of economies to face the challenges of technological development (Economy 4.0) and the exploitation of ICT in companies (Companies 4.0). This research has shown that measuring how European countries are adopting digital transformation is challenging. The analysis provides evidence that three homogeneous groups of countries in all dimensions of the analysis (Society 4.0, Economy 4.0 and Companies 4.0). However, the research findings demonstrate that the level of digitalization of EU societies, economies and companies varies considerably. The main reason for the differences in the development of the information society and digital economy in European countries is primarily a low level of digital skills and the ineffective use of modern technologies in some countries.

Although the identified differences in technological development and, therefore, the technological gap in EU countries can result from various reasons, the key to meeting the challenges of digital transformation, however, is the ability to use the Internet not only for entertainment purposes but also in order to improve social and professional standing. It requires a change in the approach to modern technologies, greater educational and professional activity, as well as launching businesses based on new technologies.

Various empirical studies have demonstrated significant differences in actual knowledge of digital technologies among the population, depending on economic, educational, geographical and demographic differences (van Deursen & van Dijk, 2011). Important factors possibly affecting the digital transformation in European countries include, among others, age, education, income, location, culture, language and disability (van Dijk, 2013; Laukkanen, 2016).

To counteract the challenges related to the fourth industrial revolution, it is necessary to increase spending on research and development (i.e. stimulating innovation of the economy) and to support beneficial processes related to the digitalisation and computerisation of society by increasing the availability of these services. Governments must provide policies, incentives and programmes to increase and retrain the workforce. Meanwhile, the private sector needs to invest more in skills training.

Further support of digital transformation at the political, economic and social levels is necessary because the digital economy and society are crucial for innovation, growth, employment, as well as European competitiveness. The digital economy applies to every sector of industry and public service, profoundly affecting people’s daily lives (Peppard & Ward, 2016). The proliferation of digital technologies has a huge impact on the labour market and the types of skills needed in the economy and society. Therefore, digitalisation means that every citizen should have at least the basic digital skills enabling them to be able to live, work, learn and participate in contemporary society. The dynamics of digital transformation is a very complex field dependent on many factors affecting the results, which makes it difficult to accurately determine causality and predict consequences.

To conclude, this paper contributes to the research on digital transformation in many ways. Firstly, the study covers a broad research perspective with three dimensions: societies, economies, and enterprises. Secondly, it has referred to the selected indicators reflecting the technological developments in the field of Society 4.0, Economy 4.0, as well as Companies 4.0 based on the author's compiled set of indicators. Thirdly, for the purposes of data analysis, both the cluster analysis and TOPSIS method were applied.

Future studies may be targeted towards the research question of how companies and society can support digital transformation. There is also room for more comparative studies, either to seek validation for the existing indicators or to provide a profound explanation of research results. Further studies can also focus on the diverse opportunities and constraints resulting from the fourth industrial revolution for individual European societies, economies and businesses to present a more in-depth understanding of current challenges. Given that this study includes pre-pandemic Covid-19 analysis, future studies could also focus on comparisons of how the current situation has changed as a result of the pandemic.

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Annex

Table 1. Key indicators of digital transformation in European societies, economies and companies

Variables (S – Society, C – Companies, E – Economies) [Eurostat data code]	Mean	Std Dev.
S1 – Frequency of Internet use: once a week (including everyday)	84.32	7.84
S2 – Individuals using the Internet for sending/receiving e-mails	72.86	14.19
S3 – Individuals using the Internet for online banking	58.5	21.88
S4 – Individuals using the Internet for interaction with public authorities (last 12 months)	57.18	19.53
S5 – Individuals having ordered/bought goods or services online for private use (in the last three months)	47.43	17.37
S6 – Individuals using cloud services in order to save documents, photos, music, videos or other files	36.07	11.95
S7 – Individuals with above elementary/basic overall digital skills	32.57	10.67
E1 – Patent applications to the EPO per million inhabitants	82.88	91.76
E2 – Total R&D personnel and researchers in all sectors as A % of total employment	1.33	0.57
E3 – Export of high technology products	11.91	7.03
E4 – Persons with tertiary education (ISCED) and/or employed in science and technology	48.42	9.19
E5 – Graduates in tertiary education, in science, maths, computing, engineering, manufacturing, construction per 1,000 inhabitants aged 20-29	17.91	6.1
C1 – Enterprises purchasing cloud computing services used over the Internet	29.00	14.82
C2 – Enterprises with a website	76.32	12.88
C3 – Enterprises using any social media	55.93	14.31
C4 – Enterprises having received orders online	19.07	7.93
C5 – Enterprises using ICT security measures: strong password authentication	74.14	10.34
C6 – Enterprises using ICT security measures: encryption techniques for data, documents or e-mails	36.79	10.41
C7 – Enterprises using ICT security measures: VPN (Virtual Private Network extends a private network across a public network to enable secure exchange of data over public network)	40.14	12.31
C8 – Enterprises that provided training to develop/upgrade ICT skills of their personnel	23.071	8.14

Note:
[a] % of individuals; [b] % of total employment - numerator in full-time equivalent; [c] % of total exports; [d] % of active population From 25 to 64 years; [e] per 1000 of population aged 20-29;
[f] % of all enterprises without financial sector (10 persons employed or more).

Source: own calculation based on the data from Eurostat (Science, technology, digital society; skills-related statistics) [1] 2019; [2] 2018; [3] 2017.

Table 2. Members of clusters generated by k-means method in the field of Society 4.0

High performance (Cluster 1)	**Medium performance (Cluster 2)**	**Low performance (Cluster 3)**
Denmark, Estonia, Netherlands, Finland, Sweden, United Kingdom	Belgium, Czech Republic, Germany, Ireland, Spain, France, Latvia, Lithuania, Luxembourg, Hungary, Malta, Austria, Slovenia, Slovakia	Bulgaria, Greece, Croatia, Italy, Cyprus, Poland, Portugal, Romania

Table 3. EU State Members' grouping and cluster specification by k-means cluster analysis method (Society 4.0)

Variables	**Cluster1**		**Cluster 2**		**Cluster 3**		**ANOVA**					
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Między SS	df	Wewn. SS	df	F	Istotn. p
S1 - Frequency of using the internet: once a week (including every day)	93.50	2.81	85.71	3.91	75.00	5.24	1227.75	2	430.36	25	35.66	0.000
S2 - Individuals using the internet for sending/receiving e-mails	89.83	4.26	75.43	6.50	55.63	9.23	4197.29	2	1236.14	25	42.44	0.000
S3 - Individuals using the internet for internet banking	86.00	5.80	61.57	8.59	32.50	15.68	10077.57	2	2849.43	25	44.21	0.000
S4 - Individuals using the internet for interaction with public authorities (last 12 months)	81.50	10.06	59.71	7.29	34.50	13.89	7753.75	2	2546.36	25	38.06	0.000
S5 - Individuals having ordered/bought goods or services for private use over the internet (in the last three months)	67.50	10.00	49.93	10.79	28.00	9.32	5524.43	2	2620.43	25	26.35	0.000
S6 - Individuals using cloud services to save documents, photos, music, videos or other files.	52.00	9.01	35.00	7.64	26.00	7.01	2349.86	2	1508.00	25	19.48	0.000
S7 - Individuals with above basic overall digital skills	46.83	5.037	32.29	5.18	22.38	8.81	2053.29	2	1019.57	25	25.17	0.000

Table 4. Members of clusters generated by k-means method in the field of Economy 4.0

High performance (Cluster 1)	**Medium performance (Cluster 2)**	**Low performance (Cluster 3)**
Denmark, Germany, Netherlands, Austria, Finland, Sweden	Belgium, Ireland, France, Italy, Luxembourg, United Kingdom	Bulgaria, Czech Republic, Estonia, Greece, Spain, Croatia, Cyprus, Latvia, Lithuania, Hungary, Malta, Poland, Portugal, Romania, Slovenia, Slovakia

Table 5. EU State Members' grouping and cluster specification by k-means cluster analysis method (Economy 4.0)

Variables	**Cluster1**		**Cluster 2**		**Cluster 3**		**ANOVA**					
	Mean	**Std. Dev.**	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**	**Między SS**	**df**	**Wewn. SS**	**df**	**F**	**Istot. p**
E1 - Patent applications to the EPO per million inhabitants	238.25	26.30	101.72	33.67	17.55	14.07	215268.0	2	12093.23	25	222.51	0.000
E2 - Total R&D personnel and researchers in all sectors as % of total employment	1.96	0.22	1.69	0.24	0.96	0.36	5.4	2	2.43	25	27.69	0.000
E3 - Exports of high technology products	12.83	5.24	16.20	10.46	9.96	5.62	176.6	2	1158.31	25	1.91	0.170
E4 - Persons with tertiary education (ISCED) and/or employed in science and technology	56.48	4.57	54.35	9.11	43.17	6.92	1042.3	2	1238.04	25	10.52	0.000
E5 - Graduates in tertiary education. in science. math.. computing. engineering. manufacturing. construction per 1000 of population aged 20-29	238.25	26.30	20.08	11.08	16.46	3.65	79.6	2	923.60	25	1.08	0.356

Table 6. Members of clusters generated by the k-means method in the field of Companies 4.0

High performance (Cluster 1)	**Medium performance (Cluster 2)**	**Low performance (Cluster 3)**
Belgium. Denmark. Ireland. Malta. Netherlands. Finland. Sweden. United Kingdom	Czech Republic. Germany. Estonia. Spain. France. Croatia. Italy. Cyprus. Lithuania. Luxembourg. Austria. Portugal. Slovenia. Slovakia	Bulgaria. Greece. Latvia. Hungary. Poland. Romania

Table 7. EU State Members' grouping and cluster specification by k-means cluster analysis method (Companies 4.0)

Variables	**Cluster1**		**Cluster 2**		**Cluster 3**		**ANOVA**					
	Mean	**Std. Dev.**	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**	**Między SS**	**df**	**Wewn. SS**	**df**	**F**	**Istotn. p**
C1 – Enterprises buying cloud computing services used over the internet	48.75	9.71	24.79	3.96	12.50	3.62	5002.64	2	929.36	25	67.29	0.000
C2 - Enterprises with a website	88.13	5.89	77.07	8.39	58.83	8.52	2957.47	2	1520.64	25	24.31	0.000
C3 – Enterprises using any social media	73.75	4.40	52.71	7.82	39.67	8.04	4272.17	2	1253.69	25	42.60	0.000
C4 - Enterprises having received orders online	28.00	5.45	17.43	5.46	11.00	2.61	1066.43	2	629.43	25	21.18	0.000
C5 - Enterprises using ICT security measures: strong password authentication	81.38	6.39	72.43	9.28	68.50	12.91	650.63	2	2238.80	25	3.63	0.04
C6 - Enterprises using ICT security measures: encryption techniques for data. documents or e-mails	44.63	9.054	34.79	10.09	31.00	7.51	748.48	2	2178.23	25	4.30	0.025
C7 - Enterprises using ICT security measures: VPN (Virtual Private Network extends a private network across a public network to enable secure exchange of data over public network)	52.25	8.40	40.21	7.35	23.83	5.08	2768.74	2	1324.69	25	26.13	0.000
C8 - Enterprises that provided training to develop/upgrade ICT skills of their personnel	31.00	4.07	22.86	5.99	13.00	4.38	1112.14	2	677.71	25	20.51	0.000

Table 8. Performance score and EU Member States rank by TOPSIS

28 EU Member States	Society 4.0		Economy 4.0		Companies 4.0	
	Topsis	Topsis	Topsis	Topsis	Topsis	Rank
Austria	0.611	0.759	0.525	0.525	0.759	3
Belgium	0.619	0.724	0.716	0.716	0.724	7
Bulgaria	0.071	0.227	0.175	0.175	0.227	22
Croatia	0.367	0.212	0.510	0.510	0.212	23
Cyprus	0.401	0.051	0.512	0.512	0.051	27
Czech Republic	0.485	0.528	0.621	0.621	0.528	13
Denmark	0.958	0.877	0.890	0.890	0.877	1
Estonia	0.712	0.300	0.440	0.440	0.300	20
Finland	0.775	0.787	0.804	0.804	0.787	2
France	0.602	0.654	0.410	0.410	0.654	9
Germany	0.626	0.678	0.648	0.648	0.678	8
Greece	0.323	0.472	0.241	0.241	0.472	15
Hungary	0.418	0.325	0.312	0.312	0.325	18
Ireland	0.665	0.638	0.791	0.791	0.638	10
Italy	0.248	0.487	0.327	0.327	0.487	14
Latvia	0.510	0.150	0.291	0.291	0.150	26
Lithuania	0.494	0.263	0.392	0.392	0.263	21
Luxembourg	0.691	0.751	0.498	0.498	0.751	4
Malta	0.548	0.159	0.698	0.698	0.159	25
Netherlands	0.871	0.724	0.715	0.715	0.724	6
Poland	0.348	0.311	0.306	0.306	0.311	19
Portugal	0.367	0.427	0.505	0.505	0.427	16
Romania	0.058	0.047	0.088	0.088	0.047	28
Slovakia	0.481	0.210	0.380	0.380	0.210	24
Slovenia	0.463	0.600	0.478	0.478	0.600	11
Spain	0.566	0.393	0.462	0.462	0.393	17
Sweden	0.907	0.732	0.796	0.796	0.732	5
United Kingdom	0.799	0.561	0.651	0.651	0.561	12

Figure 1. Dendrogram for the 28 EU Member States in the field of Society 4.0

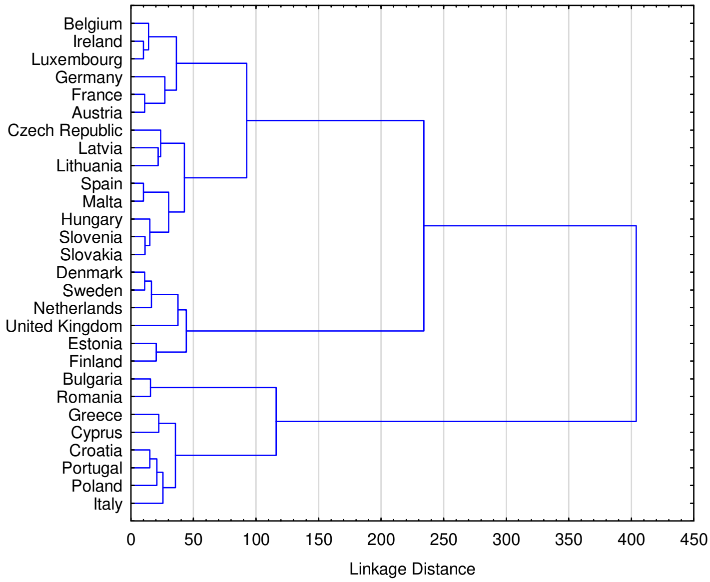

Figure 2. Graph of mean values of variables for clusters in the field of Society 4.0

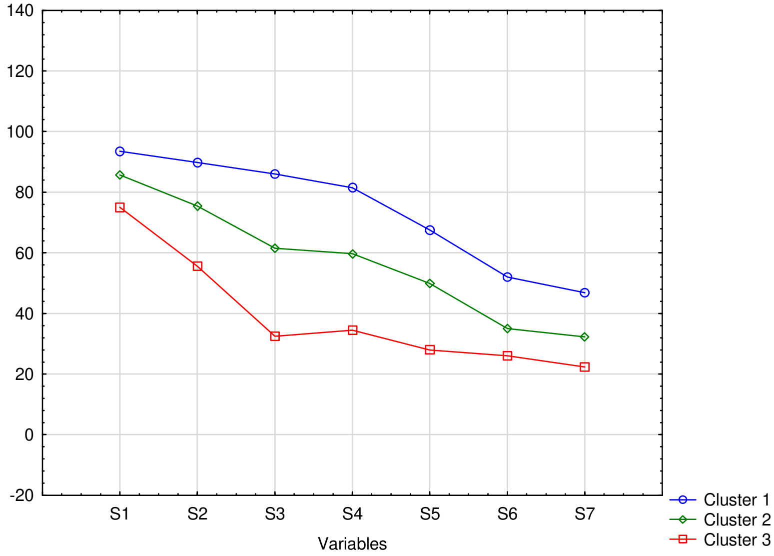

Figure 3. Dendrogram for 28 EU Member States in the field of Economy 4.0

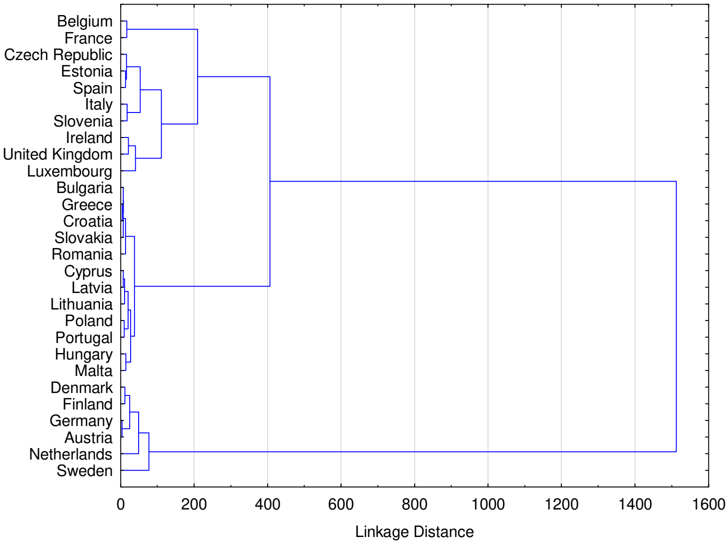

Figure 4. Graph of mean values of variables for clusters in the field of Economy 4.0

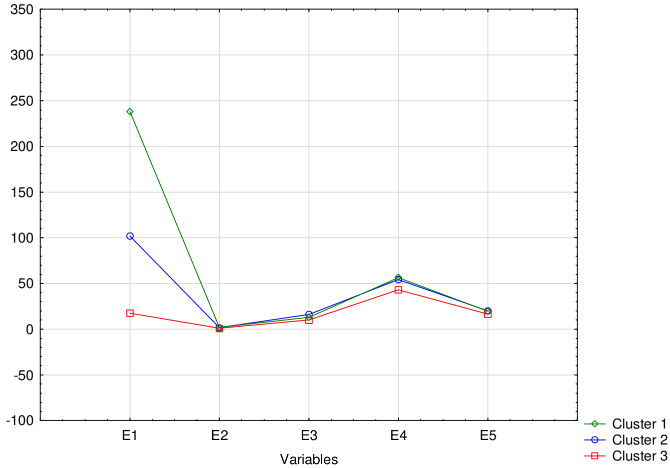

Figure 5. Dendrogram for 28 EU Member States in the field of Companies 4.0

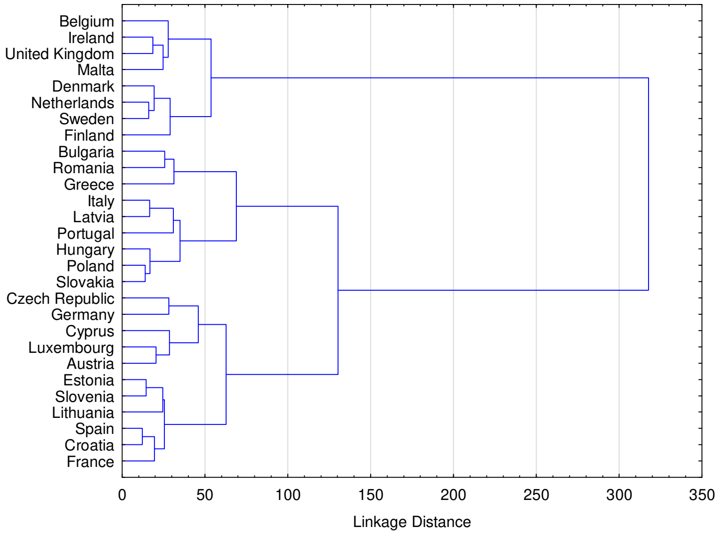

Figure 6. Graph of mean values of variables for clusters in the field of Companies 4.0

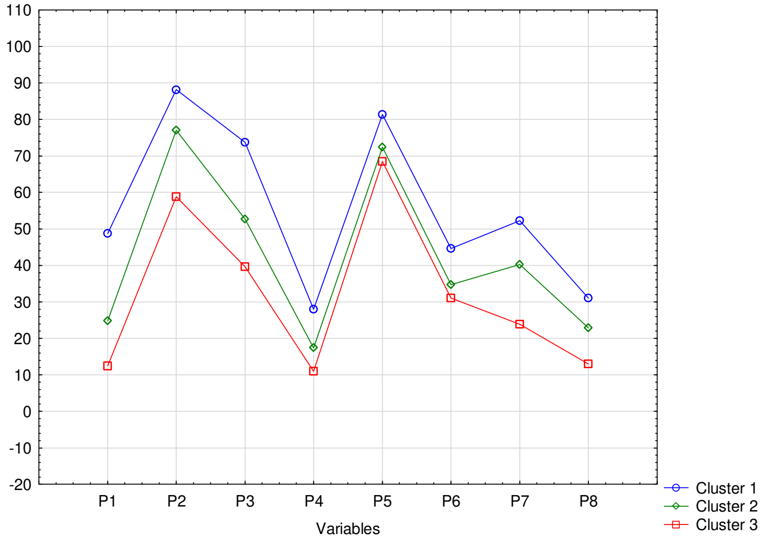

Figure 7. Heat map for TOPSIS synthetic measures

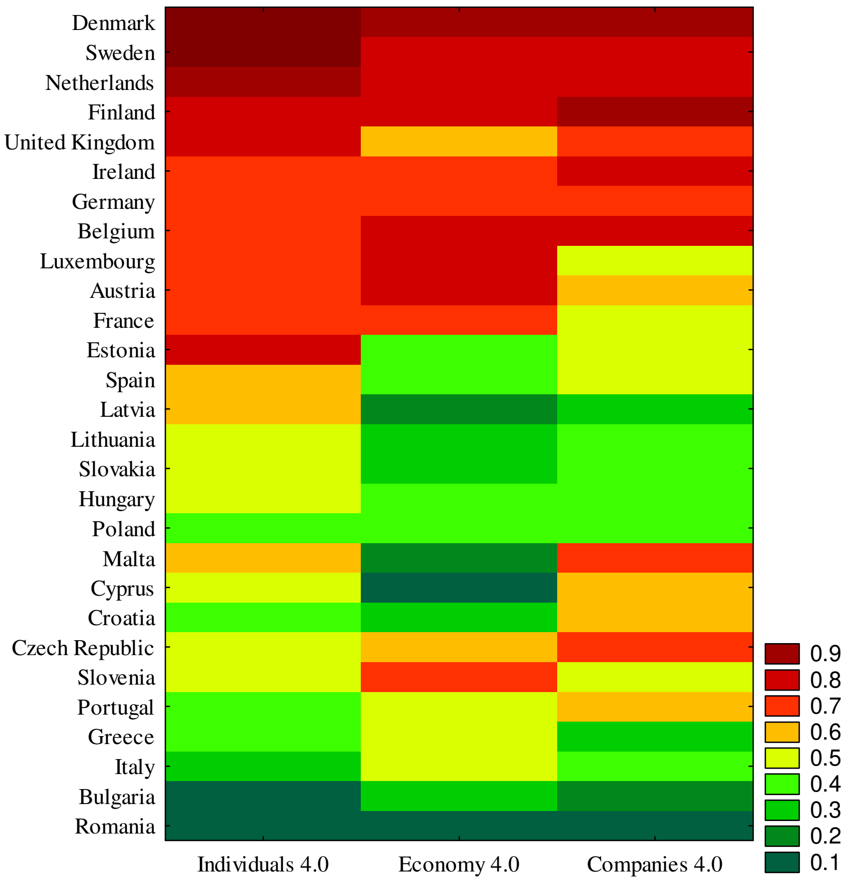

Figure 8. EU Member States by TOPSIS synthetic measures