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Contact to corresponding author: Walter Quadrini, walter.quadrini@polimi.it

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Nataliia Gavkalova
Warsaw University of Technology, Poland
orcid.org/0000-0003-1208-9607

Bartlomiej Gladysz
Warsaw University of Technology, Poland
orcid.org/0000-0003-0619-0194

Walter Quadrini
Politecnico di Milano, Italy
orcid.org/0000-0003-0081-2255

Claudio Sassanelli
Politecnico di Bari, Italy
orcid.org/0000-0003-3603-9735

Fredrik Asplund
KTH Royal Institute of Technology, Sweden
orcid.org/0000-0001-5704-4504

Muhammad Rusyadi Ramli
KTH Royal Institute of Technology, Sweden
orcid.org/0000-0002-3022-6110

Peter Detzner
Fraunhofer Institute for Material Flow and Logistics, Germany
orcid.org/0009-0005-6507-4873

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Jane Deville
University of Lincoln, United Kingdom
orcid.org/ 0000-0001-7255-1598

Miroslav Dragic
University of Banja Luka, Bosnia and Herzegovina
orcid.org/0000-0002-4634-4074

Tim van Erp
Flinders University, Australia
orcid.org/0000-0002-1694-4378

Amalia Georgescu
Gheorghe Asachi Technical University from Iași, Romania
orcid.org/0000-0003-4872-780X

Liz Price
University of Lincoln, United Kingdom
orcid.org/0000-0002-9801-7745

Galina Robertsone
Riga Technical University, Latvia
orcid.org/0000-0001-9244-8424

Sergio Terzi
Politecnico di Milano, Italy
orcid.org/0000-0003-0438-6185

Digital Innovation Hubs and portfolio of their services across European economies

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Keywords: *Digital Innovation Hubs; clustering; innovation ecosystem; digital transition; Industry 4.0; digitalization*

Abstract

Research background: Digital ecosystems in Europe are heterogenous organizations involving different economies, industries, and contexts. Among them, Digital Innovation Hubs (DIHs) are considered a policy-driven organization fostered by the European Commission to push companies' digital transition through a wide portfolio of supporting services.
Purpose of the article: There are DIHs existing in all European economies, but literature needs more precise indications about their status and nature. The purpose is to study a distribution of DIHs and differences in portfolios of DIHs' services across European economies. Therefore,

the paper wants to deliver more precise data on effects on national and European policies. This is required to define their final role and scope in the complex dynamics of the digital transition, depending on regional context and heterogeneity of industries.
Methods: Data on 38 economies was collected from the S3 platform (on both existing and in preparation DIHs) and further verified by native speaking researchers using manual web scrapping of websites of DIHs identified from S3. To find potential similarities of digital ecosystems in different economies as emanated by the existence of DIHs, clusterization (Ward's method and Euclidean distances) was applied according to the services offered. Economies were clustered according to the number of DIHs and the spread of DIHs intensity in different cities. The results were further analyzed according to the scope of the provided services.
Findings & value added: The applied clustering classified European economies in four different sets, according to the types of services offered by the DIHs. These sets are expression of the different digitalization statuses and strategies of the selected economies and, as such, the services a company can benefit from in a specific economy. Potential development-related reasons behind the data-driven clustering are then conjectured and reported, to guide companies and policy makers in their digitalization strategies.

Introduction

2011 is considered an important milestone in manufacturing since announced Industry 4.0 as a strategic initiative of the German government (Kagermann *et al.*, 2011). In 2015, the association of German digital and electronics manufacturers (namely Verband der Elektro- und Digitalindustrie, ZVEI e.V.) proposed the Reference Architecture Model Industrie 4.0 (RAMI4.0) (Schweichhart, 2016). This model addressed the digitalization topic in manufacturing, proposing reference standards and concepts that allowed manufacturing companies to add value to their operations and ease their supply chain by reframing themselves according to a data-centric perspective (Rüßman *et al.*, 2015). The broad consensus that this initiative gained in the research and manufacturing environment, as well as in the political community, made the so-called 'Industry 4.0' a stable topic of research (Teixeira & Tavares-Lehmann, 2022). However, despite the commitment of these communities, companies were not fully ready nor sufficiently mature to employ digital technologies in their processes and business (De Carolis *et al.*, 2017; Sassanelli *et al.*, 2020b). Therefore, several issues emerged when the effective acceptance of RAMI4.0 was analyzed: in particular, the research highlighted a significant difference in the implementation of technologies and methodologies of Industry 4.0 in big manufacturers vs small and medium enterprises (SMEs) (Da Silva *et al.*, 2020; Raj *et al.*, 2020; Ślusarczyk, 2018).

This shortcoming gave birth to several public and private initiatives aiming to ease the acceptance of RAMI4.0 among SMEs. Given the political will to increase the adoption of digital technologies across society (not only in manufacturing), in 2010 the European Commission (EC) submitted the Digital Agenda for Europe to the European Parliament, which outlined a series of initiatives designed to accelerate digitalization across Europe (EC, 2010). These initiatives were later (2016) implemented in the manufacturing dimension through the initiative of 'Digitising European Industry' (EC, 2018), defining Digital Innovation Hubs (DIHs) as entities aimed at supporting manufacturing companies (Quadrini *et al.*, 2022; Sassanelli & Terzi, 2022c; Crupi *et al.*, 2020) in their digital transition (Lamperti *et al.*, 2023; Paschou *et al.*, 2020). According to the EC perspective, DIHs are meant to be one-stop shops supporting companies in their digitalization journey, mainly through brokerage with technology and consultancy suppliers. However, their role can also include services such as the gathering of funding actions, defining business models coherent with increased digitalization, test-before-invest and training of human resources for new digital technologies a company may acquire (Sassanelli *et al.*, 2022b).

The EC identified four primary functions of DIHs in supporting SMEs digitization: networking, skills and training, test before investing, access to funding. Each of these four functions refer to actions that are needed for a successful ecosystem advancement. However, different DIHs aim to play different roles, either voluntarily or to address their actual capabilities. Therefore, DIHs might reasonably not struggle to address all four functions, and the way they could possibly address them could be approached differently (Asplund *et al.*, 2021). DIH can cover a wide spectrum of assets (technologies, capabilities, skills, and knowledge) and provide, often thanks to dedicated digital platforms, a growing and complete set of services to their potential users (technology providers and users). At this purpose, the Data-based Business-Ecosystem-Skills-Technology (D-BEST) reference model has been recently proposed by Sassanelli and Terzi (2022b) to configure the service portfolio of DIHs and model collaborative networks 4.0, in which DIHs are knowledge brokers and sources. However, so far, the D-BEST model has been applied only to analyse limited geographic areas (e.g., Quadrini *et al.*, 2022), without investigating the causes of the resulting configuration, or specific networks of DIHs (e.g., Sassanelli & Terzi, 2022b; Asplund *et al.*, 2021). In addition, while the D-BEST model turns out to be promising in performing DIHs portfolio configuration to unveil their characterizing functions, an extensive mapping and assessment of all the extant DIHs in the European landscape is missing so far in literature. This analysis would unveil DIH's final role and scope in the complex dynamics of the digital transition, depending on regional context and heterogeneity of industries.

For this reason, the purpose of the research is to discover the distribution of DIHs across European economies, analysing secondary data. First, dataset on DIHs from EC Smart Specialisation Platform (S3) was obtained for 38 economies (all EU and almost all non-EU) listed on S3 platform by EC) listed there. Then, portfolios of DIHs services were analysed (with few exclusions by native speaking experts in the field) using D-BEST reference taxonomy of services and data from DIHs websites (approaching as potential customer of DIH). Finally, economies were clustered basing on the delivered services and spread of DIHs in an economy.

The paper is structured as follows. The second section presents the state of the art obtained through a review of existing literature. The third section shows the research methodology adopted focusing on the way that secondary data were obtained (S3 platform and DIHs website) by (with minor exclusion) native speaking experts) and analysed (D-BEST taxonomy of services and clustering). The fourth section presents the results, i.e., obtained clusters (accordingly with services portfolio and spread of DIHs in an economy), which depict a picture of the effects of national and European policies regarding DIHs. Next on section discusses results focusing on proposing potential root causes of economies being clustered together and drafting initial guidelines for socio-economic development. Finally, the last section concludes the paper, also unveiling research limitations and further developments considering investigations of potential root causes and guidelines presented in the Discussion section.

Literature review

The digital economy plays a vital role in modern society development and influences quantitative indicators like Gross Domestic Product (GDP) or national income. Researchers emphasize the role of a sustainable digital economy and social reforms. The effective deployment and employment of digital technologies positively impacts social reforms, the sustainability of economy, and social governance mechanisms (Avotra *et al.*, 2021; Niu, 2022; Xianbin & Qiong, 2021, Stojanova *et al.*, 2022).

In recent years, several studies investigated the impact of the so-called Digital Transformation (DT) on SMEs, mainly focusing on the evolution that digital technologies led in specific sectors (e.g., tourism (Sánchez-Bayón, 2023)), or on specific SMEs dimension, such as the new marketing strategies and impact on these business entities (Silva *et al.*, 2022), even if several researches highlighted the benefits in terms of flexibility and adaptability that highly-digitalised SMEs demonstrated, in particular with respect to the recent crisis derived from the well-known COVID pandemic (Kuczewska *et al.*, 2023, Roba & Milos, 2023). Given this fragmented body of knowledge, another recent work (Skare *et al.*, 2023) managed to perform a wider quantitative analysis using digital economy and society index (DESI) on European SMEs, focusing on the impact of DT on general business objectives of SMEs: this analysis allowed the authors to demonstrate the significant effect of DT on the studied enterprises. In particular, the study highlighted areas such as access to credit, relationships with customers, competitivity and resilience towards changes in the regulation and in the market as main beneficials of companies' DT (despite some drawbacks in terms of cyber security, and access to skilled human resources).

For what concerns, in particular, one of the demonstrated hypotheses of the aforementioned study ("Digital transformation significantly lowers SMEs' regulatory burden"), the intrinsic nature of SMEs (often strongly linked to their geo-economic environment) requires supporting entities to be grounded in the same geographical environment: this burden means DIHs unevenly spread across the European territory in order to better respond to the specific needs of the local realities, despite the initial will of the EC to constitute a unique environment for digitalization (Asplund *et al.*, 2021). In 2020 the EU also launched the so-called 'European Digital Innovation Hubs', with the explicit purpose of creating a network of DIHs to further enhance digitalization of SMEs. Apart from funding details, the similarities of this initiative and its specialization towards SMEs witness the success (matured or potential) of the DIH paradigm.

Other evidence of this virtuous paradigm can also be found outside Europe. The Chinese government has promoted similar entities under the initiatives 'Made in China 2025' (Zenglein & Holzmann, 2019) and 'Shanghai International Industry 4.0 Collaboration Center' (a specific programme for the application of such technologies in Shanghai region). India founded the 'National Association of Software and Service COMpanies' (NASCOM, 2023), specifically intended for the technological development among SMEs and start-ups, and the programme 'Atal' (which promotes entrepreneurship and innovation, with a particular focus on SMEs) (AvianWe, 2023). While the United States of America (US) guaranteed support to the innovation in manufacturing SMEs through the initiative 'Manufacturing Extension Partnership' (MEP) (Robey *et al.*, 2019). US provides similar support in the 'National Network for Manufacturing Innovation' (Clark & Doussard, 2019), but it is not specifically addressing SMEs.

Still, there is a need for more studies on this subject. Europe aims to take a prominent place in the digital domination race even though it is currently still seen mainly as a competition between the US and China, especially with regard to artificial intelligence (Rikap & Lundvall, 2021). The US-China race is depicted as a competition between techno-globalism and techno-nationalism. Europe tries to find its own way, and for this reason it is important to have a clear picture of the current landscape of DIHs in Europe. Given the world-wide interest in this type of initiative, assessing the performance of the DIHs is deemed of high interest, as well as monitoring their health status and evolution. For this reason, the EC implemented a service (namely, the Smart Specialisation Platform, S3) which allows the exploration of a catalogue listing all the registered DIHs on a geographic base. This catalogue, however, is mainly grounded on user-supplied data (sometimes outdated) and does not consider the specific type of services offered by the DIHs.

Given the political interest on this topic, several studies have been recently published about the evolution of DIHs across Europe (Georgescu *et al.*, 2021). Some of these studies also investigated these entities though a quantitative approach: for example, DIHs have been evaluated according to their "status" (an indicator presented in the S3 platform expressing the operativity of the DIH, namely, "fully operational", "in preparation", or "potential from H2020") and their distribution appeared to confirm other researches testifying the growing interest of SMEs in topics, such as electronic data sharing, social media, big data and electronic invoicing (Georgescu *et al.*, 2022). Another work presented a more data-driven approach, which led to a DIHs' clustering based on the services offered, according to what declared in the S3 platform itself (Georgescu *et al.*, 2023). The limitation of this study, however, sits in the fact that it relies on the S3 platform's user-generated content and on the topology of the platform itself, more than on existing frameworks coming from literature. Finally, a last recent work has been proposed to methodologically identify the portfolio of services of a DIH (Sarraipa *et al.*, 2023), however, this article is limited to training-related services and focuses more on an inductive framework development than on an analysis of the existing services.

To overcome the limitations of training-related services (Sarraipa *et al.*, 2023) and to still analyse DIHs according to a literature-based methodology, the authors decided to leverage on the D-BEST (previously known as ETBSD) (Sassanelli *et al.*, 2020a) reference model. This model was proven to be effective in configuring DIHs value proposition, build DIH customer journeys in their digitization path (Sassanelli *et al.*, 2020; Sassanelli & Terzi, 2022b, 2022c) and develop sustainable DIHs (Sassanelli & Terzi, 2022a; Zamiri *et al.*, 2021). D-BEST aims, indeed, to cluster the services provided by a DIH according to 5 macro-classes, namely Data (e.g., services regarding data acquisition, processing, analysis, and sharing), Business (e.g., incubation support, housing, access to funding, and business training), Ecosystem (e.g., community building and innovation development), Skills (e.g., deployment of maturity models and human resources' skills improvement) and Technology (e.g., IP management, technical support, and test-before-invest services). D-BEST was also proven to have flexibility in relation to application domains (Badicu *et al.*, 2021; Macedo *et al.*, 2021; Sassanelli *et al.*, 2022; Weiß *et al.*, 2023), to effectively support the development of digital collaborative platforms launched online by DIH networks (Sassanelli & Ferreira, 2022), to effectively support incubators (Costa-Soria & Sassanelli, 2022), and to include legal aspects (Razzetti *et al.*, 2022a, 2022b).

An exploratory study using the D-BEST methodology to structure a comparison between two different economies (Italy and Poland) has been recently published (Quadrini *et al.*, 2022). This study is an extension to that work and extends the dataset so it now covers economies at a pan-European level and also proposes for further investigation some relationships between the distribution of DIHs and the economies they operate in. This objective is reached through statistical modelling methods, namely Ward's method of clustering. The study focuses on diagnosing and analysing the current state as it is visible in secondary sources on the Internet (i.e., data about DIHs from EC's Smart Specialisation Platform S3 and websites of the DIHs listed there). The study looked at the distribution of DIH in different economies, DIHs' services portfolios, and the variation in both.

The purpose of the study was to cluster the studied economies concerning mentioned analyses. DIHs ecosystem in Europe was not synthetically quantitatively described until this study.

This study aims indeed to deepen the statistical evaluation of the DIHs present in the scientific literature (Georgescu *et al*., 2022), relying on data-driven approaches not fed by the information available on the S3 platform (Georgescu *et al*., 2023), but by an external investigation on DIHs activity based on the D-BEST methodology, which has been already been proved to be effective in an empirical comparison of different countries, even if in a limited dataset and without the robustness of a statistical evaluation (Quadrini *et al*., 2022). The long-term contribution lays in provision of a picture of DIHs ecosystem what could enable more informed policy decisions in future. Such a picture enriched with additional data about taken national level policy and strategic decisions, and coined with additional indices describing economies may constitute a basis for discovery of correlations between decisions, DIH ecosystem structures and macroeconomic effects.

Methods

Research framework and data collection

To address the objective of grouping the economies concerning variations in the spread of DIHs and variations in DIHs' services portfolios, a procedure has been designed for this study (Figure 1).

This study used data from the S3 platform of the EC (EC, 2023a). The platform contains data on "fully operational" DIHs and those "in preparation" from across Europe (including non-EU economies). The analysis covered data from all EU economies and non-EU economies listed on the S3 platform. Only Israel, Russia and Belarus were not considered, as they are only indirectly connected to the European ecosystem. Furthermore, to avoid the issue of (not-)recognizing a country (e.g., Kosovo), the authors decided to use the phrase 'economy' instead of 'country'. Analyses, therefore, covered the following 38 economies as listed on S3 platform: Albania, Austria, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Italy, Kosovo, Latvia, Lithuania, Luxembourg, Malta, Montenegro, the Netherlands, North Macedonia, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, the United Kingdom. Datasets with names and websites of DIHs were downloaded from the S3 platform covering both DIHs "fully operational" and "in preparation". Files were distributed to native speaking researchers, consultants and scientists working in 32 of the economies. Using researchers with knowledge of their specific economy helped to ensure a better analysis, including any national economy contexts. Collaborators were chosen and approached using a convenience criterion (e.g., belonging to research project consortia), and their tracked interests in the topic or similar topics (like publications, research projects, and/or academic positions).

Websites were analysed to discover if DIHs still existed and actively operated (eliminating inactive ones), and to discover the scope of the activities performed there (using the D-BEST framework (Sassanelli & Terzi, 2022c)). Collaborators checked if each DIH was still operating and was properly categorized, and updated the files extracted from the platform. The analysis covered only DIHs, excluding European DIHs (EDIH). This was because when the study was started there were still very few operating EDIHs (EC, 2023b), and currently most of them are labelled as 'candidate EDIH'.

For Denmark, Estonia, Malta, and Portugal native speakers could not be reached. Therefore, machine translation into English was applied with machine translation (Rivera-Trigueros, 2022) with DeepL (2023) tool (Hidalgo-Ternero, 2021), and English websites of DIHs were also examined. Data was collected from 1st May 2022 to 31st December 2022. The specific analysis of each DIH has been developed through a website investigation: simulating the perspective of an SME, a search for services was conducted on the DIHs websites, considered as a showcase of the business offer. Matrixes listing economies (as rows) and the number of D-BEST services offered by the DIHs of the specific economy (as columns) have been created to analyse common trends and characterizing clusters (understood as depicted in the next subsection). A particular focus has been given to the service distribution among different clusters, to check eventual relations between cluster analysis and the effective distribution of services in the different geographical entities.

Clustering

Multidimensional processes statistical modelling method, namely cluster analysis, was applied to study variations in the spread of DIHs and DIHs' services portfolios in different economies.

Clustering was performed considering the number of DIHs and their prevalence. The homogeneous (most similar) territory groups with typical characteristics were identified. The advantage of using cluster analysis (Xu & Wunsch, 2005), unlike other methods of classification, is the ability to generate groups or reveal the hidden groups structure within the data, that is, to divide the studied set of objects during the search for new structures into qualitatively homogeneous groups. "Cluster" denotes a group with homogeneous characteristics, provided there is no a priori information about observations. There are several methods of clustering research objects: tree clustering, k-means method, and two-way clustering (Xu & Wunsch, 2005). The first method enables a graphical interpretation of the distribution of enterprises into clusters. The second method, based on the previously proposed number of clusters, makes it possible to determine the observations included in each of them and to establish the contribution of the indicators to how the enterprises are distributed. The third method allows not only observations (enterprises) to be grouped, but also variables. To obtain consistent results, the first two methods of analysis were implemented.

The initial observations matrix has been formed at the first cluster analysis stage and data standardization has been performed (Table 1). Matrix elements normal standardization and normalization allowed to obtain a homogeneous set of studies. At the second stage, to obtain the structure detailed view and determine the number of clusters, using hierarchical cluster analysis method, namely Ward's (1963) method as a rule for combining clusters and Euclidean distance as a distance measure type, a dendrite has been constructed in a vertical form (Figure 3). Ward's (1963) method was used as it is often used for grouping objects, i.e. spatial classification, in which the intragroup variability is considered ensuring homogeneity within clusters and heterogeneity between clusters (Wierzbicka, 2020). Euclidean distance as a distance measure type was used. Tree clustering allowed to determine the preliminary number of clusters, and k-means made it is possible not only to establish the influence of variables on the clustering results, but also to classify the clusters according to the average of the evaluated variables. The cluster analysis is carried out in five stages, whose connection is shown in Figure 2.

The cluster analysis may help developing a set of management recommendations to promote the development of the digital ecosystems in Europe. This would be based on the comparison of the results between clusters and the direction of state policy in each economy to create conditions for the intensive spread of DIHs. Two key indicators for each of the 38 European economies were chosen as initial data for cluster analysis:
X1 – the total number of existing DIHs;
X2 – the intensity of the spread of DIHs in the territory for a certain economy (the spread intensity of DIHs).

The prevalence of DIHs is defined as a combination of the two indices (X1; X2). The latter indicator was calculated as the ratio of the number of cities where DIHs currently operate to the total number of DIHs in each economy. All stages of cluster analysis were performed in the specialized application program package Statistica 10.0 based on current statistical data obtained from official sources, as of 2022.

Results

The investigation on the S3 platform returned 656 DIHs which were analysed (Table 1). Among them, 429 were "fully operational", and 227 "in preparation". Following website analysis some DIHs were excluded as inactive (66) or duplicated (18). Finally, the sample of 572 DIHs remained for further analyses (388 "fully operational" and 184 "in preparation"). Table 1 details a breakdown of the analysed sample per economy and per DIH status, showing data collected from S3 platform vs data verified by researchers from website analysis. The number of DIHs per economy varies, possibly due to the big differences in the size of considered economy (Table 2). In general, larger and better-connected economies may have a higher number of DIHs. For some economies, the smaller number of DIHs may be a strategic choice and/or an effect of the economy size (such as Malta, 1; Cyprus, 2; or Estonia, 2), while for others this situation probably emerges from fewer and weaker bonds to EU (e.g., Turkey, 2; and Ukraine, 2), or lower level of economy development (e.g., Albania, 2; Kosovo, 2 — and less bonds to EU as well). The number of DIHs may also depend on the number and type of SMEs in the economy. Some economies may have fewer SMEs whilst in other ones the type of SME may not require a DIH support. On contrary, the largest number of DIHs is observed for the few largest European economies (Spain, 65; Italy, 54; Germany, 54; and France, 49).

According to the results (Figure 3), as per graph and table of the amalgamation schedule, it was possible to propose a hypothesis dividing the studied economies into 4 clusters, according to the indicators characterizing the level of development and distribution of DIHs. At the next stage, a non-hierarchical clustering method has been applied, i.e., the k-means method.

Table 2 presents the clusters distances matrix constructing results, the average clusters values and Euclidean distances. The distances matrix between clusters can be used to determine the quality of the performed clustering. The greater the distance between clusters and the smaller the distance between elements of clusters, the better the clustering is performed. In our case, 4 clusters have been obtained, characterized by internal homogeneity (similarity between the elements included in the cluster and a small distance between them) and external isolation (the distance between the elements within the cluster is much smaller than the distance between the clusters). The full list of clustered economies is presented in Table 3. The first cluster is represented by Germany (the closest to the cluster centre), the second by Portugal, the third by Hungary and Norway, and the fourth by Greece/Lithuania. Thus, we have the most typical economy representatives for the clusters. Special attention has been paid to the quality of the resulting clustering, which, corresponds to three quality functionals, namely: the sum of the squared distances to the class centre, the sum of the internal class differences between objects, and the total intraclass variance tended to a minimum (i.e., all criteria accepted minimum values are required).

The quality clustering result based on the average values determination of the indicators is presented in Figure 4. The quality of the performed clustering has been confirmed using discriminant analysis [1; 3]. Several criteria for assessing the classification quality have been applied: the Wilks λ-statistic and the F-statistic. Thus, Wilks λ-statistic has been used to assess the ability of the discriminant function to recognize classes in a multidimensional feature space. Its values close to the 0 value (in this case λ = 0.0323173) indicate a high recognition of the discriminant function and a good discrimination of objects. The significance of the F-statistic ($F>F_{table}$)

also confirms the differences between groups. In this case, F_{table} equals 3.26 (for α=0.05; k1=1, k2=n–m–1=38–2–1=35), while F equals 50.1893.

Table 4 contains the classification matrix. Based on these results (see the column Percent Correct - 100%), it can be concluded that the economies are correctly divided into 4 groups/clusters using cluster analysis. Table 5 reports the collected numbers about the service portfolio analysis according to the different geographic entities and to the D-BEST structure.

The clustering results may suggest a relationship between the number of DIHs and the level of socio-economic development. However, without further analysis using socio-economic data, it was not possible to conclude that relationship existed for sure. Quite influential was also the prevalence of DIHs across the territory of a considered economy. One limitation of the study is that even well-developed economies, but with a small number of cities, will fall into same cluster as bigger and less-developed economies (as both could have similar number of DIHs and cities of residence). Analysing the obtained results, it is possible to draw conclusions regarding the characteristics of the given clusters and from these a set of policy recommendations is proposed to increase the level of development of digital ecosystems in European economies (author's proposals in Table 6).

Cluster 1 economies (i.e., France, Germany, Italy, Netherlands, and Spain) may have several common factors that allow them to be clustered together. These economies are generally characterized by high GDP, strong economies, well-developed infrastructure, and high standards of living for their citizens. These economies share some sets of characteristics that might lay behind clustering them together:

– high level of economic and infrastructure development, making modern technology accessible to many people (Popović *et al.*, 2022);
– high quality education, creating highly qualified specialists and consumers capable of using digital technologies (Hryhorash *et al.*, 2020);
– political stability and economic growth, creating favourable conditions for investment in digital technologies (Sarangi & Pradhan, 2020);
– high level of cultural integration, allowing the use of digital technologies for national interests and improving the quality of life for citizens (Leidner & Kayworth, 2006);
– geography and demographics: high and/or dense population, high number of cities (Beaudry & Green, 2002).

Above considerations posed additional questions: whether a high number of SMEs in a country leads to having a high number of DIHs or does it need a high number of DIHs for SME development? All these factors together make these economies highly developed in the use of digital technologies and similar in their development of DIHs. The reason for the inclusion of some economies in cluster 2 or 3 rather than cluster 1 potentially lays in one or more of the following factors:

- policy decision: some policies might strategically decide to focus on a smaller number of DIHs, which cover a wider scope of services (Rissola & Sörvik, 2018);
- ability to leverage EU policy: four out of five members of cluster 1 (France, Germany, Italy and the Netherlands) are founding members of the EU, and the fifth (Spain) is currently one of the strongest political forces within the EU; the ability to leverage an EU policy such as DIHs might be greater for economies that are more entrenched in the institutions of the EU;
- lack of investment in digital infrastructure: these economies may have limited resources for investment in digital technologies, which affects their ability to develop and implement digital solutions (Toader *et al.*, 2018);
- slower adoption of digital technologies: these economies may have a slower adoption of digital technologies compared to other economies in the cluster, which affects their level of digitalization (Nicoletti *et al.*, 2020);
- limited digital skills and literacy: a lack of digital skills and literacy among the population may be a barrier to the spread use of digital technologies (Nikou *et al.*, 2022);
- resistance to change: in some economies, there may be cultural or political resistance to the adoption of digital technologies, which slows their implementation and use (Steers *et al*., 2008; Turja & Oksanen, 2019);
- national/entrepreneurial culture: former Soviet bloc countries have shorter entrepreneurship experience, many of the business ideas being developed out of need, not from an entrepreneurial education and a vision to develop sustainable businesses, with the use of digital technologies (Steers *et al.*, 2008);
- geographical/demographic factors: the geography and demographics may also play a role in their level of digitalization (e.g., limited access to technology in rural areas, fewer young people who are comfortable with technology, or population density and distribution itself) (Beaudry & Green, 2002).

Cluster 2 and cluster 3 could look heterogenous while considering that Switzerland, Sweden, the UK (developed economies) are in the same cluster as Albania or Malta, which are significantly smaller. However, the reason for such clustering could be a strategic choice of developed economies (e.g., to limit the number of DIHs), less power to leverage EU policy, or a limited number of cities (density) in some economies (e.g., Sweden or Portugal). Considerations for cluster 2 and cluster 3 led to a further question: if some economies have a larger part of their SMEs operating in sectors that would not benefit or naturally seek out support from a DIHs (e.g. is manufacturing more likely to use DIHs than tourism in general?). One additional factor to be studied is if some economies are more technology-focused. However, looking at the economies in a cluster, it is not obvious to claim that there is such a difference.

It is likely that the reasons for Greece and Lithuania being at the bottom of the adoption of digital technology support centres are due to a combination of factors such as lack of funding, lack of skilled workers, lack of government support, and insufficient infrastructure (Bartolini *et al.*, 2017). Each economy is characterized by its own unique set of challenges and opportunities, and the rate of adoption of digital technology will vary based on a range of factors. To answer the question of why Greece and Lithuania are in the cluster of least development of DIHs, additional analysis may be required such as:

– market research: an examination of the competitive (dis)advantages of these economies and the innovation impact growth and development of digital technologies in such contexts; an analysis of SMEs' sector;
– policy research: an analysis of the political initiatives aimed at supporting the development of digital technologies in these economies;
– educational research: an assessment of the availability/quality of educational programs in digital technologies and their impact on developing a qualified workforce in these economies.

The clustering developed based on the total number of DIHs per economy and DIHs prevalence, can also find further support when looking at the analysis performed according to the D-BEST methodology (Table 5). The economies in Cluster 1 are characterized by a high number of DIHs — France (49), Germany (60), Italy (68), the Netherlands (45), and Spain (82) and almost all have a certain balance among the offered services (see numbers from Table 5), apart from the Data dimension, where data-related services are offered by 40 DIHs out of 304 (biased by Germany, where are offered by 21 on 60 hubs).

The fourth cluster includes economies with a high number of DIHs (33 in Greece, 19 in Lithuania) where the coverage of services seems 'saturated' (in other words, DIHs offer a wide set of services): data-related services are offered by almost 60% of DIHs, business-related ones by more than 88%, ecosystem-related ones by 69%, skills-related ones by almost 85%, and technology-related ones by almost 81%. The distribution of services appears homogeneous in the DIHs of the two economies, even if only 3 of the 19 Lithuanian hubs offer data-related services.

For the two most populated clusters (namely cluster 2 and cluster 3), it appears to be no clear difference between the population number of their DIHs. The main difference, according to the D-BEST analysis, lies in the fact that the technology services are more available in the DIHs of cluster 2 (82% of the DIHs offer these services, compared to only 62% in cluster 3). The other dimensions appear comparable, with services for data (28% vs 32%), business (64% vs 68%), ecosystem (63% vs 60%), and skills (50% vs 62%) not presenting such differences.

Notable exceptions are Portugal, Sweden, and the United Kingdom (cluster 2), as well as Poland, Luxembourg, Norway, Slovenia, and Turkey (cluster 3), where the services respect a distribution closer to cluster 4 but may have not been included in that cluster because of the DIHs prevalence. The United Kingdom could have been top included in cluster 4, but the high representation of technology services (17 on 22) constitutes a further affinity to cluster 2.

Discussion

In this research, as a preamble to the study of the economic impact of digitalization on the level of economic development, the quantitative characteristics of DIHs have been analysed. The results obtained in the first part of the study indicate that it may be possible to explain the relationship at least partly between the level of socio-economic development by the number of DIHs. However, the problem of their concentration in several centres arises, which in some cases levels out the quantitative component.

In summary, there are a number of main drivers influencing the distribution of DIHs and how they can support SME development including funding schemes, skills levels of workers, government support and infrastructure. These elements, taken singularly or jointly, are key to foster the further consolidation of DIHs as innovation ecosystems and to support the shift towards digitalization of European companies, depending on both the context in which they are placed and the characteristics of their organization. Significant outcome of the study is listing of potential reasons of clustering results. Those listings are supported with evidence from literature as presented in the section Results. Testing if the hypothesised potential reasons lying behind economies clustered together are true or false, constitute tangible research agenda for policy makers and academic. Discovering such phenomena would allow to make more informed decisions about further directions and strategic initiatives in the field.

This research provides a set of contributions to both knowledge and practice. From the theoretical perspective, it provides some insight into the presence of DIHs in each region and its socio-economic development, which may also relate to the potential degree of innovation of companies in that region. Secondly, it clusters the DIHs in Europe into four main clusters based on their prevalence in each region, and characterizes their offer based on the D-BEST reference model. Finally, it suggests four main drivers (funding schemes, skills level of workers, government support, and infrastructure) which may help provide a direction to socio-economic development of European countries, using DIHs as a means of innovation.

From the practice point of view, European companies can identify the socio-economic context in which they are placed by looking at the cluster to which their country belongs. In this way, they can exploit the four clusters and guidelines provided by this research to examine how their local DIHs can support their digital transformation (and through which kind of services as mapped by the D-BEST model), to understand where in Europe they could eventually look for additional support, and/or to make them aware potential collaborations between local DIHs and foreign ones with the aim of bolstering their digital innovation (collaboration among multiple DIHs is also supported by the D-BEST model used in this research) (Haidar *et al.*, 2024).

The presented study shows an approach to European economies clusterization not present in the current literature. There studies oriented on clusterization of European economies, but they do not cover full European dimension. They are also not focused on clustering accordingly to the performance of DIHs's performance, nor address directly any other programs oriented on fostering digitization of the economy. The complex multi-method study was conducted by Małkowska *et al.* (2021) who demonstrated the impact of technological transformation on the economy and society in EU countries grouped according to a similar level of development using clustering and Technique for Preference Ordering by Similarity to Ideal Solution. Homogeneous groups from EU countries were discovered in terms of digitalization concerning Digital Economy and Society Index (DESI), and two indices that address education and residents' satisfaction (Zaharia & Balacescu, 2020). EU countries were clustered in terms of national labour markets and Industry 4.0 challenges by Piątkowski (2020). There are also studies on clustering EU states accordingly to youth behaviour in the digital world (Kašparová & Barva, 2018). Digital service economy development stage served (from underdeveloped to fully developed) to define clusters of European regions (not country economies) as proposed by Capello (2023). The study presented in this paper covers not only the European Union, but all European economies on a state level. Another contribution is taking a picture of DIHs ecosystem landscape considering categorization of all European economies regarding their performance accordingly with their DIHs' landscape what would allow extensive comparative analyses.

First category of work about DIHs services portfolio is focused on analysing functions of DIHs services (Asplund *et al.*, 2021), the D-BEST framework development itself (Sassanelli *et al.*, 2020) and extending it with additional classes of services (Razzetti *et al.*, 2022b, 2022a). Second category of current works exploiting taxonomies of DIHs' services is focused on microeconomic perspective as they show potential support for SMEs digitization (Sassanelli *et al.*, 2022; Sassanelli & Ferreira, 2022, Sassaneli & Terzi, 2022c), developing DIHs sustainable value proposition (Sassanelli *et al.*, 2022a; Sassanelli & Terzi, 2022b, Zamiri *et al.*, 2021), or assessing existing DIHs, e.g. interoperability assessment (Semeraro *et al.*, 2021). Third category tackles the meso-economic perspective, e.g., building the value proposition of DIHs to foster ecosystem sustainability (Sassanelli & Terzi, 2022a). Presented study extends previous works on D-BEST framework in a way it shows D-BEST applicability for macroeconomic and comparative analyses of economies. Available studies have not exploited the potential of analysing economies due to their DIHs ecosystem characteristics expressed in DIHs prevalence and DIHs' portfolios. Limited study for Poland and Italy was available, but it considered only services portfolio and not the prevalence of DIHs (Quadrini *et al.*, 2022).

This research can also assist company managers and policymakers in their daily activities and operations by helping them determine the kind of services they could obtain from local and foreign DIHs. They could also identify potential collaborations with DIH managers and policymakers to mitigate the gaps around the four drivers identified in this paper as responsible for developing DIH action (and therefore their financial, technical and professional support towards local companies) in their region.

This research provides policymakers with a clear picture of the status of DIHs in the European territory regarding presence, prevalence, and main features and services provided. They are also given a set of drivers they should leverage to push DIHs innovation and digitalization action. DIHs are indeed considered a one-stop-shop, playing the role of knowledge brokers (Crupi *et al.*, 2020), but also of digital innovation ecosystems able to develop a tailored customer journey for both technology users and technology providers through the provision of a set of assets, knowledge, skills and services (Georgescu *et al.*, 2023; Sassanelli & Terzi, 2022c). DIHs can also support the process of digital technology transfer to companies (Sarraipa *et al.*, 2023). Policy makers can refer to the guidelines developed in this research to point the way for an effective socio-economic development driven by the supportive action of DIHs and to maximize the exploitation of the assets characterizing the single DIHs placed in the different regions, countries, industries, and clusters.

Conclusions

This research investigated the relationships between the DIHs distribution and the economies they operate in, suggesting the importance of digital ecosystem to support national economic development. To address this scope, the study analyzed data about existing DIHs, covering 38 economies (all EU economies and almost all non-EU economies listed on S3 platform by EC). Data were analyzed using the five macro-dimensions of the D-BEST reference model for DIHs service portfolio configuration, with the final aim of identifying the common and distinctive features of DIHs. A cluster analysis was applied to study the current level of digital technology development in European economies, focusing the attention on the number of DIHs per economy analyzed and their local prevalence (i.e., the spread of DIHs intensity in each region). Based on these two main dimensions, the national economic development status, and on the D-BEST categorization of DIH services, four main clusters were detected and DIHs were allocated to them based on the economy they sat within. The application of cluster analysis enabled the formulation of recommendations for enhancing the development of digital ecosystems in Europe. This is achieved by comparing results among clusters and identifying effective directions for government policies to support the growth of DIHs within each cluster.

The main levers of the influence of digitization of society on the growth of economic and social indicators have been determined. Therefore, the main potential drivers (i.e., funding schemes, skills level of workers, government support, and infrastructure) to analyze the actual distribution of DIHs and to support their development and integration with the local regions in the different clusters, economies and industries analyzed have been identified. Based on them, a set of policy recommendations has been proposed to increase the level of development of digital ecosystems in European economies.

The limitation of the study is that it has not proven causality (clustering cannot identify a causal relationship). However, there are good arguments (identified in the literature) why the suggestions listed in Results section might be real relationships (and not just spurious data "noise"). However, those suggestions should be verified/validated using other research methods what constitutes further research potential. Another limitation is unavailability of other studies approaching to categorise economies regarding their performance accordingly with their DIHs' landscape what would allow extensive comparative analyses.

However, the current research has also several other limitations. First, this article examines the level of digital economy development in 38 national economies based on a list of functioning DIHs. Although this was taken from official sources, which may not always correspond to the real situation due to the lack of universal approaches to organizing activities and measuring the effectiveness of DIHs, even in the EU. Secondly, index of the spread of DIHs intensity in different cities can be challenged. Each national economy has territorial, geographical, institutional, political, cultural peculiarities that can influence this index, but those are not considered in this study. Thirdly, the world situation is very dynamic, the process of globalization is very influent, so the data being analyzed can change very fast. This may lead to distortion of the results of the study. In addition, the new clusterization with other indices could be performed in the same economies to confirm or refute the trends learned in this study. Future research should, therefore, be carried out on this topic to gain a better understanding of the results. The present study demonstrates great potential for further analysis focused on characteristics of DIHs as depicted by delivered services and different characteristics of economies, e.g.:

- general economy measures like GDP, population and its density, number of companies and their types with breakdown for sectors, global competitiveness index (GCI), ease of doing business (as assessed by World Bank), regions, etc.;
- education and science measures like degree of education and number of students in higher education (delivered by Eurostat), number of universities, publications yearly, etc.;
- digitization and innovation measures like Digital Economy and Society Index (DESI) (Liu, 2022), Global Innovation Index (Dutta *et al.*, 2022), patenting developments, smart specializations as found on EC platform;
- trade and exports measures like trade balance, total exports and imports, exports diversification (as assessed by World Bank); sustainability measures like SDG index (Sachs *et al.*, 2022).

For this purpose, clusterization, but also correlation analysis techniques could be applied. The authors propose, in the framework of future studies, to highlight additional characteristics of DIHs, the analysis of which will confirm or refute the hypothesis that the share of DIHs in the national economy directly correlates with GDP. To perform a comprehensive economic impact assessment a combination of both quantitative and qualitative methods shall be applied. Additionally, it is important to consider the time frame over which these impacts are assessed, as the full economic benefits of DIHs may materialize over an extended period.

Moreover, European DIHs (EDIHs) should be included in further analysis as the concept matures. The number of DIHs is not a representative indicator without considering the qualitative characteristics, which were considered for each of the DIHs by the authors and will be described using correct research methods in subsequent publications.

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Annex

Table 1. Total prevalence of DIHs per economy

Economy	Data from S3				Data verified			Spread intensity X2	Standardized values X1	Standardized value X2
	Fully operational	In preparation	Inactive	Duplicate	Fully operational	In preparation	Total X1			
Albania	0	4	2	0	0	2	2	0.500	-0.796	-0.532
Austria	10	5	2	0	9	4	13	0.615	-0.124	0.024
Belgium	15	14	0	5	11	13	24	0.783	0.487	0.831
Bosnia and H.	2	2	0	0	2	2	4	0.750	-0.674	0.673
Bulgaria	1	6	0	0	1	6	7	0.429	-0.491	-0.877
Croatia	12	4	1	0	12	3	15	0.600	-0.002	-0.050
Cyprus	2	1	1	0	2	0	2	1.000	-0.796	1.879
Czech Rep.	9	4	0	0	9	4	13	0.846	-0.124	1.137
Denmark	9	3	2	0	7	3	10	0.700	-0.307	0.432
Estonia	4	2	4	0	2	0	2	0.500	-0.796	-0.532
Finland	19	3	2	2	18	0	18	0.500	0.182	-0.532
France	25	24	0	0	25	24	49	0.673	2.077	0.304
Germany	33	27	6	0	31	23	54	0.648	2.382	0.182
Greece	27	6	0	0	27	6	33	0.091	1.099	-2.505
Hungary	8	2	1	0	8	1	9	0.556	-0.368	-0.264
Italy	53	15	7	7	44	10	54	0.600	-0.307	-0.050
Ireland	6	5	1	0	6	4	10	0.685	-0.796	-0.532
Kosovo	1	1	0	0	1	1	2	0.500	-0.552	-1.336
Latvia	5	1	0	0	5	1	6	0.333	0.121	-2.092
Lithuania	18	1	1	1	16	1	17	0.176	-0.613	-1.014
Luxembourg	1	4	0	0	1	4	5	0.400	-0.857	1.879
Malta	0	2	1	0	0	1	1	1.000	-0.735	-1.336
Montenegro	1	2	0	0	1	2	3	0.333	1.404	-0.659
Netherlands	27	18	6	1	25	13	38	0.474	-0.735	0.272
N. Macedonia	1	2	0	0	1	2	3	0.667	-0.368	-0.264
Norway	6	3	0	0	6	3	9	0.556	-0.063	-0.188
Poland	7	7	0	0	7	7	14	0.571	2.382	0.361
Portugal	6	5	3	0	4	4	8	0.875	-0.429	1.276
Romania	10	4	0	1	9	4	13	0.615	-0.124	0.024
Serbia	4	8	3	1	3	5	8	0.750	-0.429	0.673
Slovakia	2	2	0	0	2	2	4	0.500	-0.674	-0.532
Slovenia	10	2	0	0	10	2	12	0.500	-0.185	-0.532
Spain	63	19	17	0	53	12	65	0.600	3.055	-0.050
Sweden	11	6	2	0	11	4	15	0.867	-0.002	1.236
Switzerland	2	5	0	0	2	5	7	1.000	-0.491	1.879
Turkey	3	0	0	0	3	0	3	0.667	-0.735	0.272
Ukraine	2	1	1	0	2	0	2	0.500	-0.796	-0.532
UK	14	7	3	0	12	6	18	0.833	0.182	1.075
Sum	429	227	66	18	388	184	572			

Table 2. Euclidean clusters distances

Cluster	Euclidean Distances between Clusters; Distances below diagonal; Squared distances above diagonal			
	No. 1	**No. 2**	**No. 3**	**No. 4**
No. 1	0.000	3.973	3.785	4.067
No. 2	1.993	0.000	1.298	6.472
No. 3	1.946	1.139	0.000	2.319
No. 4	2.017	2.544	1.523	0.000

Table 3. Members for each cluster and distances

Cluster	Economy	Distances from respective cluster centre
No. 1	France	0.235
	Germany	0.139
	Italy	0.251
	Netherlands	0.776
	Spain	0.565
No. 2	Albania	0.253
	Belgium	0.617
	Cyprus	0.601
	Czech Rep.	0.137
	Malta	0.627
	Portugal	0.107
	Serbia	0.367
	Sweden	0.224
	Switzerland	0.511
	UK	0.357
No. 3	Austria	0.395
	Bosnia and H.	0.439
	Bulgaria	0.320
	Croatia	0.416
	Denmark	0.528
	Estonia	0.253
	Finland	0.456
	Hungary	0.129
	Ireland	0.285
	Poland	0.324
	Kosovo	0.253
	Latvia	0.647
	Luxembourg	0.431
	Montenegro	0.674
	N. Macedonia	0.532
	Norway	0.129
	Romania	0.395
	Slovakia	0.173
	Slovenia	0.205
	Turkey	0.532
	Ukraine	0.253
No. 4	Greece	0.375
	Lithuania	0.375

Table 4. Classification matrix

Group	Percent Correct	Rows: Observed classifications; Columns: Predicted classifications			
		G_1:1 p=0.131	G_2:2 p=0.263	G_3:3 p=0.553	G_4:4 p=0.053
G_1:1	100	5	0	0	0
G_2:2	100	0	10	0	0
G_3:3	100	0	0	21	0
G_4:4	100	0	0	0	2
Total	100	5	10	21	2

Table 5. D-BEST analysis of clusters

Cluster	Economy	DIHs	Services				
			Data	Business	Ecosystem	Skills	Technology
No. 1	France	49	3	38	45	24	17
	Germany	60	21	36	36	34	41
	Italy	68	8	45	37	40	32
	Netherlands	45	4	24	26	16	20
	Spain	82	4	58	58	32	36
	Sum	304	40	201	202	146	146
No. 2	Albania	19	10	15	10	10	16
	Belgium	29	7	18	19	10	14
	Cyprus	5	1	3	2	1	3
	Czech Rep.	13	3	8	10	7	8
	Malta	2	0	1	0	0	0
	Portugal	11	0	8	7	8	8
	Serbia	12	1	7	5	3	3
	Sweden	17	3	10	13	12	15
	Switzerland	7	5	5	5	3	6
	UK	21	8	12	15	12	17
	Sum	136	38	87	86	66	111
No. 3	Austria	16	5	9	5	9	13
	Bosnia and H.	4	1	4	1	2	2
	Bulgaria	7	4	5	5	6	6
	Croatia	16	1	10	11	4	8
	Denmark	12	3	7	5	4	6
	Estonia	6	0	1	1	0	1
	Finland	22	1	14	14	10	16
	Hungary	10	1	5	6	6	2
	Ireland	11	9	8	3	7	10
	Kosovo	12	8	9	8	10	5
	Latvia	7	2	3	3	5	4
	Luxembourg	5	5	5	5	5	5
	Montenegro	3	1	3	2	2	1
	N. Macedonia	3	0	3	2	1	1
	Norway	9	4	9	9	4	7
	Poland	14	1	14	10	11	11
	Romania	14	3	5	11	8	6
	Slovenia	12	8	12	10	10	10
	Turkey	3	1	3	2	2	3
	Ukraine	5	3	2	1	3	2
	Sum	191	61	130	115	109	119

Table 5. Continued

Cluster	Economy	DIHs	Services				
			Data	Business	Ecosystem	Skills	Technology
No. 4	Greece	33	28	30	19	22	29
	Lithuania	19	3	16	17	12	13
	Sum	52	31	46	36	44	42

Table 6. General clusters characteristics according to the level of digital innovation canters development and distribution

Cluster	Cluster characteristics	Recommendations
Cluster 1	High DIHs development and distribution level: It has the highest number of existing DIHs and a higher-than-average DIHs' spread intensity.	Processes in economies have proved to be balanced, and they should be continued with this regard of DIHs prevalence. Governments' support for the creation and development of DIHs is the result of an effective state policy, the purpose of which is the growth of Gross Domestic Product and National Income and effective investment policy.
Cluster 2	Average DIHs development and distribution level: It shows lower than average values in terms of number of existing DIHs, but the highest intensity of DIHs spread on the territory.	The mechanisms for DIH support, including within government, business and society, should be reinforced in these economies. This will facilitate dialogues, involve all necessary resources, and provide a democratic decentralization. A stronger attention from EU policy makers regarding establishing DIHs could be merited, as large benefits could come out of modest efforts to support policy implementation.
Cluster 3	Low DIHs development and distribution level: It has the lowest indicators of the existing digital innovation centres number (DIHs) and a lower-than-average intensity of the DIHs' spread.	The policy of DIHs activity regulation should be improved at the different levels: national economy (macro), inter-regional (meso) and local authorities (micro). The incentives for creating DIHs should be proposed in different places. Big data could be an opportunity to analyze, form plan of DIHs spreading and define the extra quality indicators.
Cluster 4	Lowest DIHs development and distribution level: The average values for the existing DIHs number are demonstrated, together with the lowest intensity of the DIHs' spread on the territory.	The situation should be changed with the help of government (extra stimulus for creating and distributing DIHs), business (to involve resources), extra stimulus from local authorities (e.g. where special economic zones are launched).

Figure 1. Research procedure

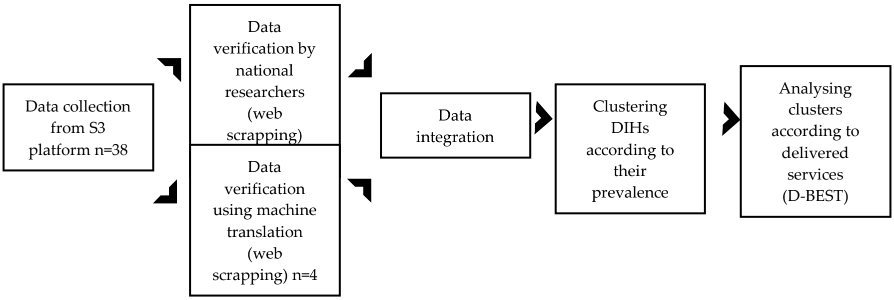

Figure 2. Cluster analysis stages

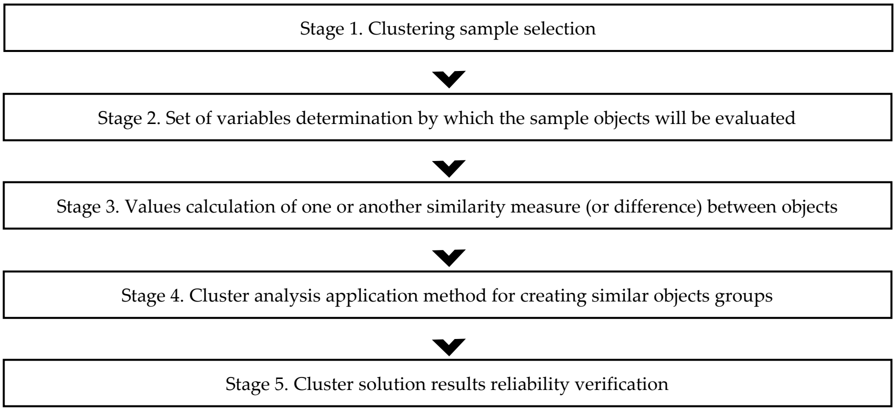

Figure 3. Vertical dendrogram

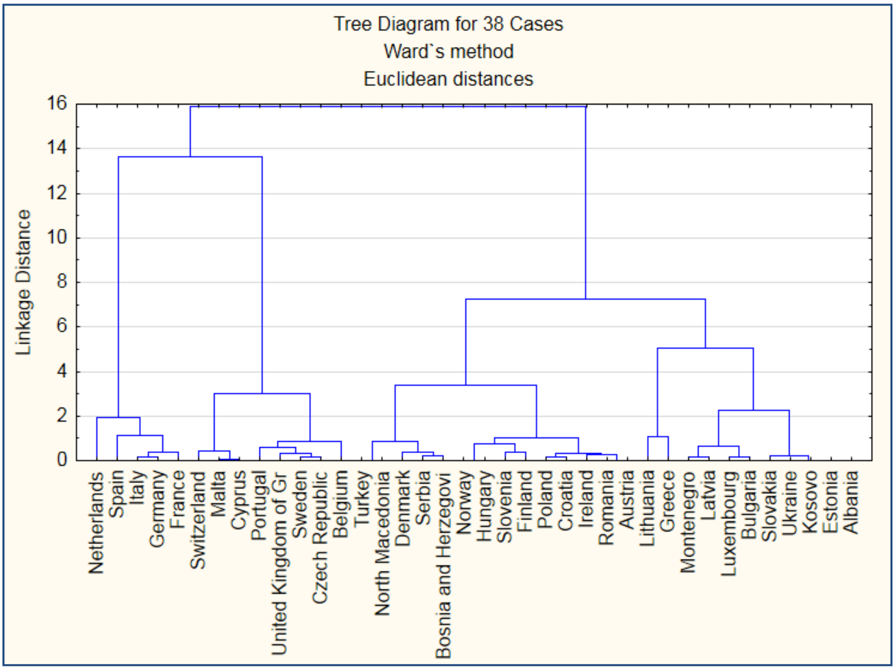

Figure 4. Plot of means for clusters