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Comparison of international digitalisation indexes: A quantitative analysis perspective

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ABSTRACT

Objective: The objective of the article is to compare the available digitalisation indexes in the EU (European Union) and Pacific Asia. The first step to tackling the between-country digital gap is to measure digital development. However, the available indexes differ substantially in terms of construction, metric used, and the areas they cover.

Research Design & Methods: The first part of the study is a descriptive analysis of the scope and metrics used by three digitalisation indexes: digital economy and society index (DESI), ASEAN digital integration index (ADII) and digital intelligence index (DII). In the second part, we approach the problem from a quantitative perspective, using correlation coefficients and comparing countries' rankings obtained using different indexes. Lastly, we performed clustering analysis with the use of an agglomerative algorithm with Euclidean distances and the Ward method. The data covers 13 countries from the Pacific Asia and 24 from the EU.

Findings: We found that the specifications of indexes differ considerably, not only in the choice of particular metrics but in whole digitalisation areas. Some indexes include overall economic or social development measures that are not strictly related to the digital sphere. Despite that, for countries covered by two indexes, we found high correlations of scores: 0.932 between ADII and DII, and 0.883 between DII and DESI. Comparing rankings and using clustering analysis, we found that the indexes for Pacific Asia are more similar than for the EU, possibly because Asian countries are more heterogeneous both in digital and economic development.

Implications & Recommendations: Any study of the digital divide and its causes is affected by the choice of digitalisation measure. We found that DII and ADII indexes include some socio-economic metrics that may interfere with the results in the studies of the links between economic and digital development. Although the indexes' scores are quite highly correlated, in some cases, they can judge a country's development very differently. This is a problem, especially in the EU, where countries are more similar in digital development than in Pacific Asia.

Contribution & Value Added: The study compares digitalisation indexes from a quantitative perspective that has not yet been established in the literature. It shows how different indexes perform in ranking and clustering procedures. Researchers can use our article as a guide in choosing digitalisation indexes for the EU and ASEAN countries.

Article type: research article

Keywords: digitalisation index; index comparison; clustering; ASEAN; EU

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INTRODUCTION

One of the key phenomena transforming society and business today is digitalisation. According to Stolterman and Fors (2004), digitalisation refers to 'the changes associated with the widespread use of digital technology in all facets of human society.' Digitalisation has facilitated the creation of new business models by allowing businesses to use data and technology to develop innovative products and services. The use of digital communication services increases productivity across all industries (Nadiri *et al*., 2018). However, it has also raised some concerns, which include the digital divide.

The digital divide is a 'division between people who have access to and use of digital media and those who do not' (van Dijk, 2020). The extent of the digital divide can occur both within (van Dijk & Hacker, 2003) and across nations. In the latter case, the main causes of the digital divide are the economic (Billon *et al.*, 2010) and educational asymmetries (Cruz-Jesus *et al.*, 2018). However, as Cruz-Jesus *et al.* (2018) found, digital disparities within a country may also hinder its overall digital development. Although, in general, the world is on the path to digital convergence (Borowiecki *et al*., 2021), the gap between the countries advancing digital technology and the ones that lag is growing (Chen, 2019). In light of this, efforts to close this gap have become increasingly crucial. The first step is to measure the digitalisation progress and look into the gap's causes.

There are several indexes dedicated to that purpose. Each index has its characteristics, such as different Key Performance Indicators (KPIs), geographical coverage, data sources, periods of measurement, data aggregation methods, and even the areas of digitalisation covered by the index. According to research conducted by Kotarba (2017), the overall number of digital KPIs already exceeds 100 items, raising the problem of selecting the best metrics to monitor digitalisation progress with limited control budgets (Doong & Ho, 2012).

To compare the digitalisation progress between two regions we need a set of measures that (a) are available for both regions in the same or highly comparable form, and (b) cover crucial digitalisation areas. The first issue arises from the fact that some of the indexes are prepared by regional institutions and cover only a limited number of countries. The second is caused by the lack of agreement on what measures best suit the task of measuring digitalisation.

Our study focused on two regions, *i.e.* European Union (EU) and Pacific Asia. Should we compare the Digital Development Index (DDI) scores, the EU has a higher average (69.9) than Pacific Asia (62.1). However, the latter includes the most digitally developed country. Singapore with a DII score of 98.8 is over ten points higher than the most advanced European country – Finland.

In the EU, the digital economy and society index (DESI) is used to summarise indicators of Europe's digital performance and track the progress of EU countries. It consists of clearly defined sections on human capital, infrastructure, business, and government. The index is constructed by the European Commission and published annually since 2014.

Another considered index is the ASEAN digital integration index (ADII). It was created to provide evidence-based measures, so that ASEAN could assess its accomplishments in achieving its digital integration framework (ASEAN Digital Integration Index Report 2021, 2021). Index scores were computed in one round, but the data comes from global and longitudinal sources, so they can be reproduced further back in time and for other countries. Most of its underlying compounds are composite indicators themselves, gathered from outside sources. This index is provided by the ASEAN Coordinating Committee on Electronic Commerce (ACCEC).

Some institutions have also developed indexes to measure digitalisation on the global level. Among them are the digital intelligence index (DII) by the Fletcher School at Tufts University (Digital Intelligence Index, 2020), used in this study, and the World Digital Competitiveness (WDC) by the International Institute for Management Development. They differ in methodology, number of countries covered, and data availability. Some indexes, like WDC, only publish the ranking, not the underlying scores.

In this study, we approached the differences between indexes from a quantitative perspective, that has not yet been established in the literature. Our results show that despite differences in underlying measures and construction, considered indexes give quite similar results, especially in the ASEAN region. However, the inclusion of socio-economic metrics in the digitalisation indexes may interfere with the interpretation of these findings.

The remainder of the article is as follows. Firstly, we will describe the structure and dimensions of digitalisation covered by each index. Secondly, we will perform a quantitative analysis of their comparability. Lastly, we will draw conclusions and some recommendations.

LITERATURE REVIEW AND HYPOTHESES DEVELOPMENT

Previous Studies

There is limited research on the comparability of digitalisation indexes. A paper by Kotarba (2017) covers an analysis of metrics used to measure digitalisation activities with five main levels, moving from the metrics of the digital economy to society, industry, enterprise, and clients. We discussed and analysed qualitatively the similarities and differences between key performance indicators on each level.

Another paper by Stankovic *et al.* (2021) examined the relations between the digital competitiveness index and several economic performance indicators, such as GDP per capita, labour productivity, and employment rate. Moreover, Korzhyk *et al.* (2023) did a comparative study of different digitalisation indexes. They analysed the indexes' similarity by their coverage, methodology, ranking, structure, and weighting methodology. The study also proposed a new digitalisation index.

Digitalization Dimensions

Although designed to measure the same concept, digitalisation indexes differ substantially. They use different measures and vary in the areas of socio-economic life considered as parts of the digitalisation process. Typically, an index consists of several sub-indexes (pillars), computed from the scores of particular measures. Figure 1 presents the structure of pillars in three considered indexes. We provide shortened names used for convenience in brackets.

Though some of the pillars seem to have direct or at least similar counterparts in at least two indexes, their underlying measures may still substantially differ, as we will demonstrate later. To reliably compare indexes' content, we defined seven dimensions, namely (1) digital skills, (2) government, (3) cybersecurity, (4) businesses and trade, (5) innovation and research & development, (6) internet infrastructure, and (7) legislation. For instance, all three indexes include measures of internet infrastructure. DESI has the connectivity pillar dedicated solely to them. In the ADII, they are located in institutions & infrastructure pillar with some measures of government dimension. In the DII, they are split between two pillars, *i.s.* demand and supply. In the next sections, we will review how indexes covered particular digitalization dimensions. From that, we draw hypotheses about indexes comparability for the quantitative study.

Digital Skills Dimension

Digital skills refer to the knowledge and abilities required to use technology effectively in various settings. These skills encompass a wide range of areas, such as information and literacy, communication and collaboration, digital content creation, safety, and problem-solving (Vuorikari *et al.*, 2022). Moreover, digital skills serve as an increasingly influential factor in the other dimensions of digitalisation, such as the use of e-government (Rodriguez-Hevía *et al.*, 2020).

Digital skills gained the special attention of researchers after the COVID-19 pandemic, as it deepened the dependence on technology and digital exclusion (Li, 2022). Insufficient digital skills may hinder online education, thus deepening the digital divide between students (van de Werfhorst *et al.*, 2022). Table 1 depicts the indicators used by each index to measure digital skills.

Government Dimension

Governments in each country play an important role in the digitalisation process, especially in ensuring that digitalisation benefits all citizens and promotes inclusive economic growth. Some of the key roles might be in the form of policy formulation, digital infrastructure development, and digital skills development (Kafel *et al.*, 2021). Table 2 presents the measurements dedicated to this dimension.

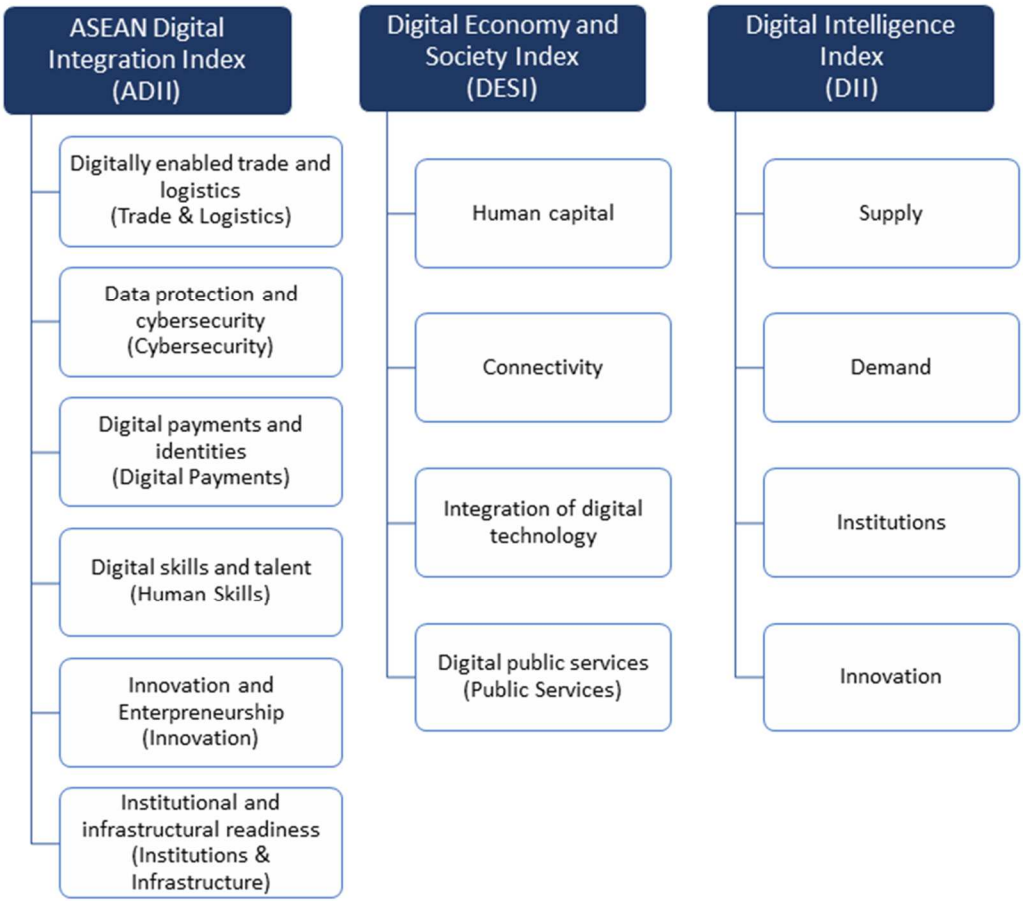

Figure 1. Structures of the analysed indexes
Source: own elaboration based on indexes' specification.

Table 1. The indicators used by ADII, DESII, and DII to measure digital skills

Index	Indicators for measuring digital skills	Pillar
ADII	Graduates in STEM	Human Skills
	Employment in knowledge-intensive services	Human Skills
	Active population skills	Human Skills
	Graduates skills	Human Skills
DESI	At least basic digital skills	Human Capital
	Above basic digital skills	Human Capital
	At least basic digital content creation skills	Human Capital
	ICT specialists	Human Capital
	Female ICT specialists	Human Capital
	Enterprises providing ICT training	Human Capital
	ICT graduates (% of graduates with a degree in ICT)	Human Capital
DII	Ability to adopt (literacy rate, human development index, GINI index)	Demand
	Ability to demand (disposable income per capita, middle-class households, GNI per capita, consumer credit per capita)	Demand
	Consumer spending (consumer expenditure, retailing per capita)	Demand
	Class digital divide	Demand
	Gender digital divide	Demand
	Rural digital divide	Demand
	Financial inclusion (% of the population using internet banking)	Demand
	Use of digital money	Demand
	Use of mobile digital money	Demand
	Talent availability	Innovation

Source: indexes' specifications.

Table 2. The indicators used by ADII, DESI, and DII to measure government

Index	Indicators for measuring government	Pillar
ADII	National identity cards	Digital Payments
	Digitalized ID system	Digital Payments
	Availability of government services	Institutions & Infrastructure
	Responsive government	Institutions & Infrastructure
DESI	e-Government users	Public Services
	Pre-filled forms	Public Services
	Digital public services for citizens	Public Services
	Digital public services for businesses	Public Services
	Open data (to what extent countries have an open data policy in place)	Public Services
DII	Effectiveness of institutions	Institutions
	Transparency	Institutions
	Government digital uptake	Institutions
	Government facilitation of ICT	Institutions

Source: indexes' specifications.

Cybersecurity Dimension

According to the International Telecommunication Union (2009), 'cybersecurity' is the collection of tools, policies, security concepts, security safeguards, guidelines, risk management approaches, actions, training, best practices, assurance, and technologies that can be used to protect the cyber environment and organisation and user's assets.

Table 3 shows the indicators used by each index to measure cybersecurity. Moreover, ADII has dedicated indicators to assess the cybersecurity performance of each country within its scope. Meanwhile, for DESI and DII, no indicators were found to measure this dimension. In ADII, most of the data sources used to calculate the indicators were gathered from the United Nations and ITU – Global cybersecurity index (ASEAN digital integration index report, 2021).

Table 3. The indicators used by ADII, DESI, and DII to measure cybersecurity

Index	Indicators for measuring cybersecurity	Pillar
ADII	Data protection measures	Cybersecurity
	Legislative cybersecurity capabilities	Cybersecurity
	Institutional cybersecurity capabilities	Cybersecurity
	Technical cybersecurity capabilities	Cybersecurity
	International cooperation	Cybersecurity
DESI	–	–
DII	–	–

Note: '-' means that the index did not measure the current dimension.
Source: indexes' specifications.

Businesses and Trade Dimension

Business and trade have been significantly impacted by digitalisation. This has changed how businesses run and made new types of trade possible (Nadiri *et al.*, 2018). Table 4 shows the indicators used by each index to measure businesses and trade in the digitalisation context.

Table 4. The indicators used by ADII, DESI, and DII to measure businesses and trade

Index	Indicators for measuring businesses and trade	Pillar
ADII	Support for trade/customs processes	Trade & Logistics
	Certificates and signatures	Trade & Logistics
	International standards for trade documents	Trade & Logistics
	Trade and transport infrastructure	Trade & Logistics
	Logistics services (measures the competence and quality of logistics services)	Trade & Logistics
	Banking platforms users	Digital Payments
	Financial transactions users	Digital Payments
DESI	SMEs with at least a basic level of digital intensity	Digital Technology
	Electronic information sharing	Digital Technology
	Social media (% of enterprises using)	Digital Technology
	Big data (% of enterprises analysing big data from any data source)	Digital Technology
	Cloud (% of enterprises buying cloud computing services)	Digital Technology
	AI (% of enterprises using any AI technology)	Digital Technology
	ICT for environmental sustainability	Digital Technology
	e-Invoices (% of enterprises sending e-invoices)	Digital Technology
	SMEs selling online (% of SMEs selling online)	Digital Technology
	e-Commerce turnover (% of SMEs' total turnover from e-commerce)	Digital Technology
	Selling online cross-border	Digital Technology
DII	Business practices	Innovation
	Postal delivery	Supply
	Traditional transport	Supply
	Access to financial institutions	Supply
	Electronic payments	Supply

Source: indexes' specifications.

Innovation, Research & Development Dimension

Digitalization and innovation have a reciprocal relationship. Digitalisation will support the innovation, research, and development processes, and vice versa. Szeles (2018) finds R&D expenditures to be one of the most important stimulants of digital development. Table 5 shows the indicators used by each index to measure innovation and R&D in relation to digitalisation. From the three indexes, only DESI did not include the aspects of innovation and R&D in its measurement.

Table 5. The indicators used by ADII, DESI, and DII to measure innovation, research & development

Index	Indicators for measuring innovation, research & development	Pillar
ADII	Collaboration in R&D	Human Skills
	Venture capital	Innovation
	R&D expenditure (as % share of GDP)	Innovation
	Innovative companies	Innovation
	Starting a business	Innovation
DESI	–	–
DII	Financing	Innovation
	Startup capacity	Innovation
	Value capture	Innovation
	Research and development	Innovation

Source: indexes' specifications.

Internet Infrastructure Dimension

The Internet infrastructure is the base of digital development. However, it may be the source of the digital divide, as it is highly dependent on the country's income (Doong & Ho, 2012). Table 6 shows the indicators used by each index to measure internet infrastructure. Both DESI and DII indexes include several KPIs of

internet infrastructure and usage, while ADII is restricted to only two. As Myovella *et al*. (2020) found out, mobile internet measures are more important in the Sub-Saharan region, while fixed broadband in the OECD countries. Any global measure of digitalisation should include at least these two measures.

Table 6. The indicators used by ADII, DESI, and DII to measure internet infrastructure

Index	Indicators for measuring internet infrastructure	Pillar
ADII	Mobile users	Institutions & Infrastructure
	Internet users	Institutions & Infrastructure
DESI	Overall fixed broadband take-up (% of households)	Connectivity
	At least 100 Mbps fixed broadband take-up	Connectivity
	At least 1 Gbp stake-up	Connectivity
	Fast broadband (NGA) coverage	Connectivity
	Fixed very high capacity network (VHCN) coverage	Connectivity
	Fibre to the premises (FTTP) coverage	Connectivity
	5G spectrum (the amount of spectrum assigned and ready for 5G use within the so-called 5G pioneer bands)	Connectivity
	5G coverage (% of populated areas with coverage by 5G)	Connectivity
	Mobile broadband take-up	Connectivity
	Broadband price index	Connectivity
DII	Device affluence	Demand
	Fixed broadband uptake	Demand
	Mobile broadband uptake	Demand
	Communications infrastructure	Supply
	Electricity	Supply
	Internet speed	Supply
	Mobile access affordability	Supply
	Mobile access availability	Supply

Source: indexes' specifications.

Legislation Dimension

The legislation dimension might have a big intersection with the government dimension, but we decided to separate it into another cluster, because the government does not always form all legislation. In some countries, other parties or groups may have the power to create laws, such as a constitutional court, a popular referendum, or a citizen's initiative. For instance, in Switzerland, citizens can propose and vote on laws through a system of direct democracy known as the citizen's initiative (Rachwał, 2014). Table 7 shows the indicators used by each index to measure legislation. In this case, DESI did not have any indicators that directly related to the legislation.

Table 7. The indicators used by ADII, DESI, and DII to measure legislation

Index	Indicators for measuring legislation	Pillar
ADII	Frameworks for transactions	Digital payments
	Intellectual property protection	Innovation
	Legal framework	Institutions and infrastructure
DESI	–	–
DII	Bureaucracy	Institutions
	Legal Environment for Businesses	Institutions
	ICT Regulatory Environment	Institutions

Source: indexes' specifications.

Summary and Hypotheses Development

A summary of dimension coverage can be found in Table 8. We can see that only ADII measures the cybersecurity dimension, while DESI and DII do not include that dimension in their metrics. Moreover, DESI did not include innovation and R&D or legislation in its metrics.

Table 8. Comparison of ADII, DESI, and DII

Dimension	Index		
	ADII	DESI	DII
Digital skills	+	+	+
Government	+	+	+
Cybersecurity	+	-	-
Businesses and trade	+	+	+
Innovation and R&D	+	-	+
Internet infrastructure	+	+	+
Legislation	+	-	+

Source: own study.

The descriptive part of our study shows, that although most dimensions seem to be covered in all indexes, the underlying indicators can be widely different. However, two different indicators can accurately measure the same concept. If this was the case, the analysed indexes could still be used interchangeably, because they would give comparable scores, even if based on different data.

Based on the qualitative comparison, we expect different indexes to give inconsistent results. However, ADII and DII are supposed to be more similar to each other than DESI and DII, because they cover almost the same dimensions. Due to its narrow focus, DESI may not be comparable with DII. Our reasoning can be stated in two hypotheses:

H1: Both DESI and DII do not give consistent digitalisation scores.

H2: Both ADII and DII do not give strictly consistent scores, but they are more similar than in the case of DESI and DII.

RESEARCH METHODOLOGY

The chapter focuses on quantitative analysis. The empirical research consists of two stages. Firstly, we used Pearson correlation coefficients to evaluate the relationship between the different indexes. Pearson's correlation coefficient is a measure used to assess the linear relationship between two continuous random variables. It takes values in the range from -1 to 1. The closer the absolute value of Pearson's correlation coefficient is to 1, the stronger the linear relationship between two variables (Schober *et al.*, 2018).

Moreover, we constructed and compared the ranking of countries according to each index. This helps us determine if two indexes would consistently answer the question of which of two given countries in 'better' in terms of digitalization. If this is not the case, the research of digitalisation is highly dependent on the choice of index. As evidenced by Kravchenko *et al.* (2019), the global ranking of countries may vary substantially according to different indexes.

In the third stage, we performed a cluster analysis. Cluster analysis is a set of methods that extract naturally occurring groups of the study population based on their similarity of specified characteristics. Using the distance function, the algorithm in hierarchical clustering combines each element of the set into larger and larger groups until a single cluster containing all objects is obtained. This is the so-called agglomeration method (James *et al.*, 2021). In this work, we used the Euclidean distance to determine the distances between analysed objects. Then, to group the object, we used the Ward method based on variance analysis. The Ward method aims to minimise the sum of the squared deviations about the group means at each stage of the algorithm (Ward, 1963). In other words, its goal is to minimize the total within-cluster variance. This method is considered the most efficient, even though it seeks to create small clusters (Stanisz, 2007).

We performed all computations on the interactions of the indexes, *i.e.* sets of countries included in both of them. Only the comparisons between ADII vs DII and DESI vs DII were possible since ADII and DESI did not have any countries in common. The data comes from 2019, as this year was available in all three datasets. Although digitalisation is a fast-paced process, our study focuses

on the structural differences between indexes, and not the current state of digitalisation itself. Therefore, the use of the most recent data is not as important here.

The quantitative analysis includes both the direct index values and the values of its constituent sub-indexes. We sourced ADII data from the ASEAN digital integration index report (2021). The Digital Planet website, which is an interdisciplinary research initiative of the Fletcher School's Institute for Business in the Global Context, provided the DII data (Digital Intelligence Index, 2020). Furthermore, we obtained the DESI data from the official website of the European Union (Digital Economy and Society Index, 2022).

RESULTS AND DISCUSSION

Indexes Correlations

Table 9 presents the number of observations in each dataset (on the diagonal), the number of observations shared by two datasets (below the diagonal), and Pearson's correlation coefficients between indexes. Out of 15 countries in ADII, DII reports values for 13 (87%, lacks values for Brunei Darussalam and Myanmar). The correlation between indexes was 0.932, which indicates they were highly comparable. DII includes 24 out of 27 countries reported in DESI (89%, without Malta, Cyprus, and Luxembourg), and the correlation is also at a promising level of 0.883.

Table 9. The number of observations and Pearson Correlation Coefficients between metrics

Index	DII	ADII	DESI
DII	90 obs.	0.932	0.883
ADII	13 obs.	15 obs.	–
DESI	24 obs.	–	27 obs.

Source: own study.

Ranking Comparison

Table 10 presents the comparison of values and ranks between ADII and DII. Singapore occupies the first place in both rankings. The only noticeable difference was that Japan came second according to ADII, but only fifth in DII. To examine this outlier, we analysed the scores of indexes at the pillars' level, compared with regional averages and South Korea, which came after Japan in ADII but outperformed it according to DII (Table 11).

Table 10. Comparison of values and ranks between ADII and DII

Country	DII score	ADII score	Rank according to ADII	Rank according to DII
Singapore	98.82	80.70	1	1
South Korea	83.09	75.73	3	2
New Zealand	80.46	75.62	4	3
Australia	80.09	74.94	5	4
Japan	77.76	76.51	2	5
Malaysia	69.03	72.85	6	6
China	61.89	70.68	7	7
Thailand	53.04	67.24	8	8
Indonesia	47.72	57.45	9	9
Vietnam	46.79	57.26	10	10
Philippines	44.29	53.99	11	11
Cambodia	32.31	37.60	12	12
Laos	32.14	36.57	13	13

Source: own study.

The high position of South Korea in DII clearly comes from supply (91.55) and demand (100) pillars, both significantly higher than the scores for Japan. It has also got a bit higher note in the innovation pillar. However, Japan was better when it came to institutions.

However, according to ADII, Japan performed better in all categories but institutions & infrastructure and innovation (although here only by a fraction). Interestingly, the institutions pillar, present in both indexes, gives an inconsistent ranking. This difference seems to come from the pillar definitions rather than specifics of these two countries, since the DII average for the region is way lower than scores for both South Korea and Japan. In contrast, according to ADII, Japan scored below the regional average, and South Korea barely surpassed it. Looking deeper into the pillars' construction, ADII's institutions & infrastructure contains indicators of mobile phones and internet users, digital government services and legal framework for digital innovation. On the other hand, DII's Innovation pillar has more indicators measuring governmental use of digital technology and broad legal environment, while the internet uptake was located in the Demand pillar (where, indeed, Japan scored lower than South Korea).

Table 11. Analysis of the discrepancies between Japan's and South Korea's scores

Index	Pillar	Japan	South Korea	ASEAN average
DII	Supply	79.78	91.55	64.13
	Demand	84.18	100	67.04
	Institutions	75.83	64.06	54.49
	Innovation	62.95	68.61	50.83
ADII	Trade & Logistics	93.36	89.28	71.63
	Cybersecurity	90.93	88.42	74.77
	Digital Payments	82.00	81.42	68.28
	Innovation	77.32	77.92	58.30
	Human Skills	54.77	53.77	51.15
	Institutions & Infrastructure	60.67	63.59	62.24

Source: own study.

Similarly, Table 12 contains the values and ranks for countries covered by DII and DESI. The first two places belong undisputedly to Finland and Denmark. Sweden comes third in DESI and the Netherlands in DII, but their scores are almost identical in both countries and we could call it a tie. The tails of the rankings are also consonant with Greece and Romania occupying the last two positions, but the middle hosted some major differences. Germany landed in the fifteenth place in the DESI ranking, while DII gave it fifth place. Meanwhile, Spain was high on the DESI ranking (5), but only in the fourteenth position according to DII. Countries like Lithuania, Latvia, and Croatia also got a lot higher position in DESI, compared to DII, while Poland, Czechia, Belgium, and France scored better in DII.

Table 13 shows the breakdown for the two most striking cases: Germany and Spain. The numbers are clear. All scores of DII pillars were higher for Germany, while the opposite was true for DESI pillars. Moreover, Spain in DII and Germany in DESI scored below the EU average in all cases but one (the supply pillar for Spain was a little better).

We saw no direct counterparts of one index in another, but DESI's Public Services should roughly represent DII's institutions, minus indicators of the legal environment. Interestingly, this is where we see the biggest differences between countries. DII defines areas of digitalisation by innovation, and supply and demand side. At the same time, DESI splits indicators between hardware (infrastructure) and human adoption, further divided between citizens (human capital) and businesses (integration of digital technology). Therefore, it is not straightforward to map these pillars from one index to another. However, in large part, they are based on similar indicators. For example, both cover mobile and fixed broadband uptake, internet speed and prices, technical staff training and availability, gender disparity, or digital public services. Thus, both indexes should give corresponding scores in aggregation.

Table 12. Comparison of values and ranks between DESI and DII

Country	DII score	DESI score	Rank according to DESI	Rank according to DII
Finland	87.30	0.1353	1	1
Denmark	87.17	0.1301	2	2
Netherlands	85.48	0.1263	4	3
Sweden	85.07	0.1299	3	4
Ireland	82.32	0.1167	6	5
Germany	79.27	0.0959	15	6
Estonia	76.66	0.1164	7	7
Austria	75.42	0.1030	9	8
Belgium	74.51	0.1000	13	9
France	72.99	0.0987	14	10
Czechia	68.68	0.0930	16	11
Lithuania	68.02	0.1055	8	12
Slovenia	67.35	0.1022	11	13
Spain	66.95	0.1176	5	14
Portugal	65.75	0.1008	12	15
Latvia	65.06	0.1025	10	16
Poland	63.58	0.0744	21	17
Slovakia	63.01	0.0831	19	18
Italy	61.27	0.0859	18	19
Hungary	57.75	0.0805	20	20
Bulgaria	57.14	0.0701	22	21
Croatia	56.60	0.0877	17	22
Greece	56.54	0.0638	23	23
Romania	54.06	0.0559	24	24

Source: own study.

Table 13. Analysis of Germany's and Spain's cases

Index	Pillar	Germany	Spain	EU average
DII	Supply	79.48	77.17	75.51
	Demand	85.35	78.84	79.45
	Institutions	83.51	63.97	68.69
	Innovation	61.82	41.01	48.53
DESI	Connectivity	0.0820	0.1030	0.0811
	Public Services	0.1291	0.1700	0.1347
	Human Capital	0.1063	0.1214	0.1117
	Integration of Digital Technology	0.0661	0.0760	0.0684

Source: own study.

Possibly, in the cases of some countries (like Germany and Spain), the differences between them accumulated in the indicators that were only included in one of the indexes, hence such a great dismatch. For example, DII devotes a large part of the demand pillar to general macroeconomic indicators, such as disposable income or consumer expenditure, and its innovation pillar measures mostly the availability of capital. It is only natural that a wealthier country, such as Germany, would receive a higher score, regardless of the actual digitalisation level. On the other hand, DESI measures qualities like a level of digital skills among the population, which are better developed in Spain and not covered by DII.

Clustering Analysis

We may assess the similarity of existing indexes by comparing the connections between countries created based on the structure of each index. For this purpose, we performed a cluster analysis using the more detailed data at the pillars' level. Instead of one value for a country, we have a set of pillar scores. The clustering algorithm will find the countries that are not only at a similar level of digital development,

but also have similar structure of that development, *i.e.* the same pillars are relatively well or underdeveloped. Consequently, we obtained a dendrogram showing the relationships between the selected countries. By creating several independent diagrams depicting these links based on the different sets of pillars that make up the analysed indexes and comparing them with each other, we assessed the similarity of the existing indexes.

Figure 2 presents a comparison of two created dendrograms based on two different sets of pillar connections between countries. On the left are the results of grouping countries by DII pillars, and on the right are the results of clustering by DESI pillars. The X-axes posted below the diagrams reflect the distance between the successively merged countries or groups of countries. The lower the joint of two countries or two groups of countries is, the more similar the values of their indicators are to each other. Between the dendrograms, there are lines connecting the names of the corresponding countries. The green and purple colours indicate those pairs of connections that are the same in both cases. It is easy to see that there are only two such cases (Slovakia – Italy, and Belgium – Austria). This means that only those pairs of countries are combined at the same stage (have the most similar values of pillars) in both indexes. Connections between other countries differ on these dendrograms.

In Figure 2, one bigger group of countries overlaps in both dendrograms. It includes the Netherlands, Denmark, Finland, Sweden, and Ireland. This group consists of countries containing the highest values of the DII and DESI indexes (each in the top 6). Unsurprisingly, it stands out from the other groups. Connections between the other countries are more diverse, as indicated by the numerous intersections of lines connecting the corresponding names of countries. Lots of differences in connections between countries and groups of countries suggest that the pillars in the DII and DESI indexes are not the same.

Figure 3 presents the clustering of countries based on DII pillars (on the left) and ADII pillars (on the right). In this case, we created connections for 13 countries (for those that appeared in the DII and ADII indexes). Compared to the diagrams created from the DII and DESI pillars, the dendrograms in Figure 3 are much more similar. There are still only two pairs of countries (Laos – Cambodia and New Zealand – Australia) that are combined at the same stage in each graph, but there are no big differences between the other connections. The smaller number of intersections of lines connecting the corresponding names of countries and the similarity of the connections show that the analysed pillars of the DII and ADII indexes are quite similar.

We assessed the similarity of dendrograms by two coefficients: Baker and Cophenetic correlations. The first depends on the position of the branches, but it does not take into account their heights. On the other hand, the value of the Cophenetic correlation coefficient is affected by the heights of branches (Baker, 1974; Sokal & Rohlf, 1962). We obtained Baker's correlation coefficient of 0.83 from DII and DESI, and 0.93 between DII and ADII's dendrograms. The Cophenetic coefficients were 0.78 and 0.96 respectively. This suggests that the compared dendrograms were highly similar. However, in the case of connections created from DII and ADII pillars, the similarity was more apparent, as evidenced by the higher values of both correlation coefficients.

Discussion

As pointed out by other authors (*e.g.* Kotarba 2017), we found little homogeneity in the analysed digitalisation indexes. Both the particular choice of measurements and their aggregation into pillars were different in DESI, DII, and ADII. However, we noticed that the values of the indexes were still highly correlated and gave similar ratings. Thus, our empirical analysis gave new insight into previously only descriptive comparisons.

We noticed that global (DII) and regional indexes (DESI, ADII) were more correlated in Southeast Asia, where the countries were more diverse in terms of digital and economic development. Thus, the results of the studies using a digitalisation index as a dependent or independent variable (see, *e.g.* Jovanović *et al.*, 2018; Kryzhanovskij *et al.*, 2021) may depend on the index chosen, especially if they are made in a group of similarly developed countries.

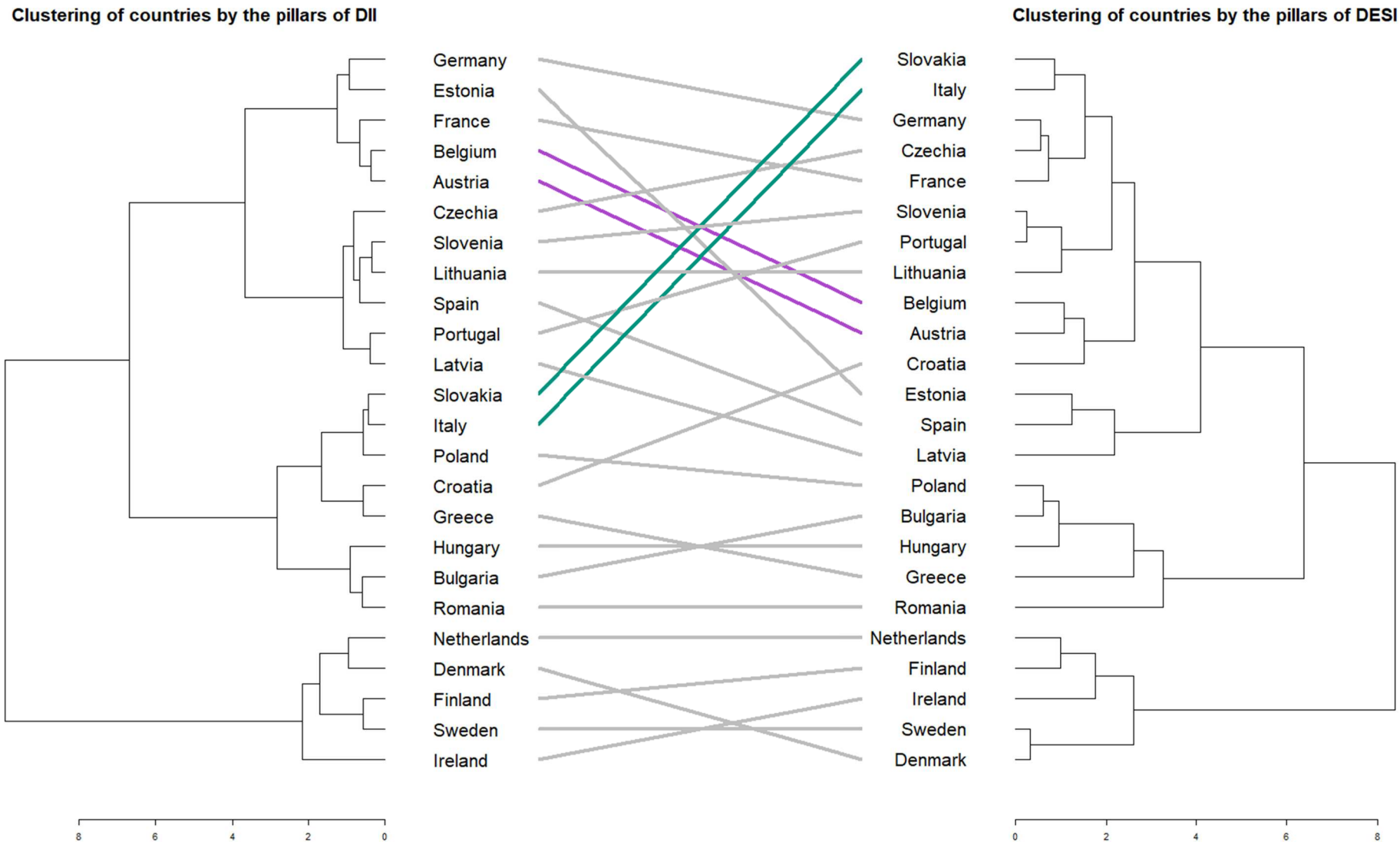

Figure 2. The clustering of countries based on DII pillars (on the left) and DESI pillars (on the right)

Source: own elaboration.

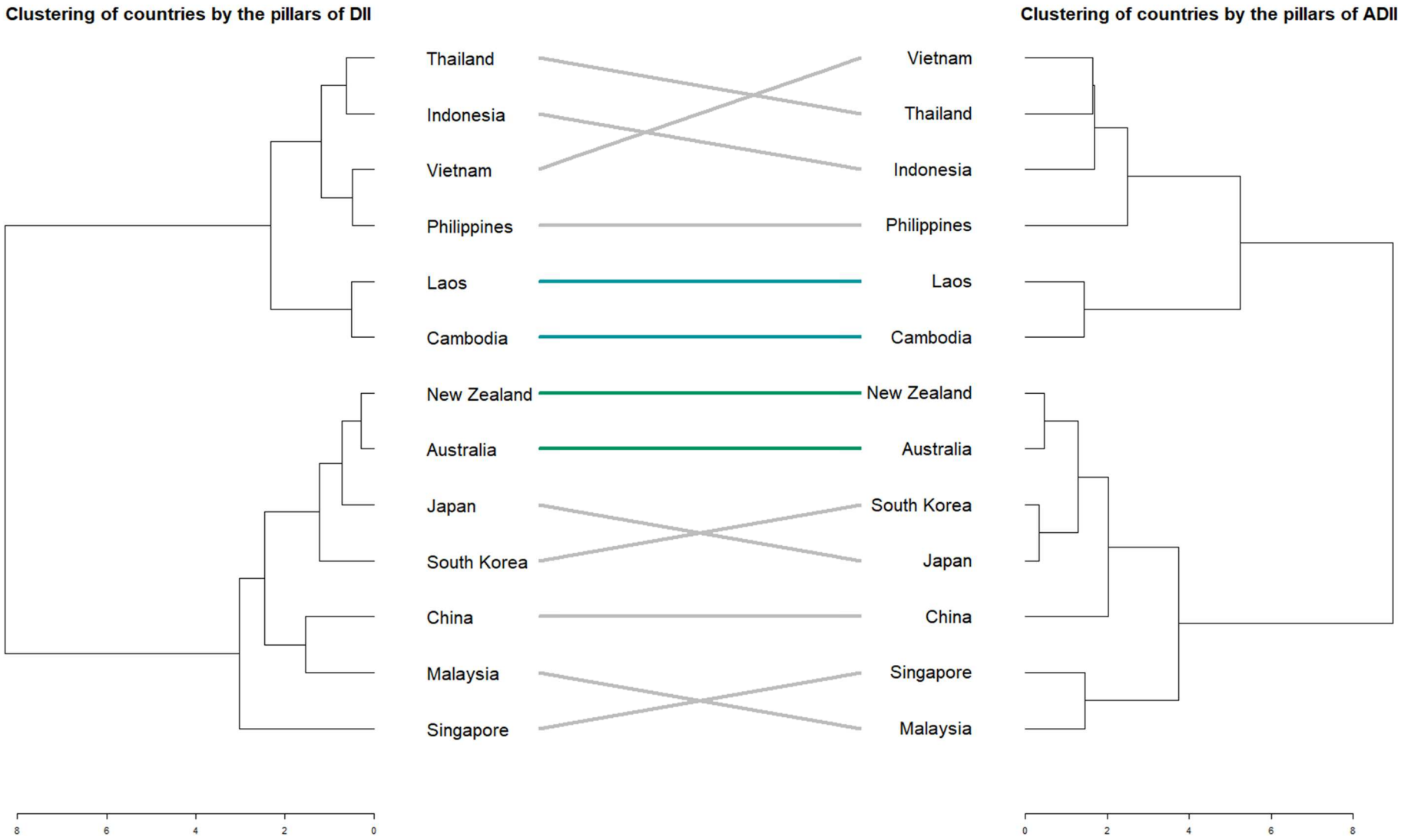

Figure 3. The clustering of countries based on DII pillars (on the left) and ADII pillars (on the right)

Source: own elaboration.

CONCLUSIONS

We aimed to compare indexes measuring digitalisation in the European Union, Southeast Asia, and in the global context, respectively DESI, ADII, and DII indexes. We described the detailed composition of each index and demonstrated how the differences impacted their comparability. Our main finding was that the considered indexes were indeed highly comparable: 0.93 correlation between ADII and DII in ASEAN and 0.88 between DESI and DII in the EU. This disproves our hypothesis that indexes would be incomparable, but is in line with the prediction, that we would find a greater resemblance between DII and ADII. However, we found that this is more likely to result from the dependence between economic and digital development than from the actual similarity in the index definition.

Considering this, further research may use the available index to measure and compare the digitalisation progress between nations and regions, especially between the region of the European Union and Southeast Asia. From the comparison, we may get insight into which areas the digital divide exists and start to investigate the root cause of the gap and find possible solutions to it. However, there are still some cases in which the indexes give inconsistent scores, so any research will be affected by the choice of digitalisation metric.

Out of the three investigated indexes, DESI is the most precise digitalisation measure. It consists of four pillars. The Human Capital pillar covers the proliferation of basic and advanced digital skills in society and the availability of ICT specialists. Connectivity pillars cover fixed and mobile internet infrastructure availability and prices. Next, the Integration of the Digital Technology pillar measures the adoption of digital technology in the business sector, while Digital Public Services describes the availability and usage of digital public services. However, DESI omits some potentially important aspects of digitalisation, such as cybersecurity or the legal environment.

Noteworthy, ADII fills these gaps by including the cybersecurity pillar and a few indicators of the legal framework for electronic transactions and intellectual property protection even though the other pillars are less precise. For example, they cover aspects such as transport infrastructure, availability of venture capital or R&D expenditure (regardless if it is related to digital companies).

However, DII goes even further. In the demand pillar – apart from internet usage and digital affluence – there are strictly macroeconomic measures, such as the GINI index or consumer spending. The institutions pillar has a measure for e-government development, but also the effectiveness of institutions, corruption control or tax rates. The supply pillar provides measures of traditional transport and postal services, and the innovation pillar is not restricted to digital innovation.

It is true that digitalisation does not form out of the void and depends on economic development (Mubarak, *et al.*, 2020). However, the DII score could increase simply because of economic advancement, even if the digital development of the country had not increased. Moreover, its comparability to other indexes may stem from the relationship between economic and digital development. In that case, in an economically diverse region, DII may be more comparable to other measures of digitalisation, but it will lose its relevance for a group of countries on a similar development level. Here, the EU group is more homogenous than ASEAN. The greater similarity of rankings and clustering between ADII and DII (compared to the DESI-DII pair) may result both from more similar index composition and higher dependence of score on economic development.

Furthermore, in the case of the EU, the similarity of the digitalisation process is also affected by index construction. In our clustering analysis, only the cluster of the most digitalized countries persisted in both indexes. In other words, the way one defines the pillars will affect which countries are deemed to be similar in their road to digitalization.

The data availability somewhat limited our study. Firstly, we could only use pillar-level aggregations without the underlying measurements. Secondly, not all countries are covered by all indexes, and our sample was rather small in the Pacific Asia region. Lastly, the digitalisation indexes are computed only once in a few years, so the data is already quite outdated. Especially if we consider the fast-paced changes in the IT industry. Still, our findings may help researchers and managers prepare and interpret international comparisons. The knowledge of similarities and differences between

globalisation indexes is a key to the correct analysis of digital development and digital divide and should not be dismissed as just the methodological detail.

Concluding, our findings mean that any studies on digitalization in economic or social contexts would be dependent on the choice of indexes. Many of the indexes include indicators related to overall economic development rather than strict digitalization, which can lead to inconsistent results.

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