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ORIGINAL RESEARCH PAPER

The relationship between digital development and economic growth in the European Union

László Török*

Department of Engineering Management and Enterprise, Industrial Process Management Institute, Faculty of Engineering, University of Debrecen, 4032 Debrecen, Ótemető u.2-4., Hungary

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ABSTRACT

Numerous studies have proven that digital development positively affects economic growth. This study aims to confirm or refute the positive impact of digital evolution on economic growth by applying the dimensions of the International Digital Economy and Society Index (I-DESI). The analysis refers to the period 2015–2020 of the European Union member states. The study's novelty is that the I-DESI index has yet to be used in research to investigate the relationship between the digital transition and GDP production. The present study, therefore, goes one step further than the previous typical DESI-GDP models. The research uses Pearson correlation and F-statistic analysis to show the relationship between the variables. The study confirms that digital development has positively impacted the economic growth of EU member states. This result was confirmed by both Pearson and Spearman correlation. However, the results are ambivalent. The empirical results indicate that the more digitally developed member countries had a higher GDP per capita. However, the positive effect is different. The results confirm that the development of digitalization and GDP increased more dynamically in the more digitally developed EU member states than in the less developed member states. Therefore, an increase in the backwardness of the less developed member countries and not a catch-up can be observed in the period under review.

KEYWORDS

digital transformation, I-DESI index, economic growth, European Union, F-statistics, regression analysis, exponential smoothing, spearman correlation

1. INTRODUCTION

Researchers interpret digital transformation mostly as support for the transformation of relationships [1–4]. The digitization transition is one of the most decisive global megatrends, covering all areas of the economy and society and significantly impacting national economies' competitiveness. Digital transition (transformation) has been widely used in the literature for about ten years. However, this concept was known before, and its spread was accelerated by the storage and processing of increasingly large amounts of data by companies that have grown enormously due to globalization [5]. This was when, after the global financial crisis, economic growth began to become robust in the world economy following the successful crisis management [6, 7] because of this, it became necessary that the information of value-creating processes should be processed differently from previous methods.

Each macroeconomic actor has different interests, roles, and responsibilities in the digital transition. The state's role in the transformation is significantly enhanced because it must formulate programs supporting digitalization in all areas of the digital development of society and must provide financial resources for their implementation. However, in the case of the digital transition, state (and supra-state entities such as the EU) responsibility begins earlier, even when EU (and national) legislation defines support for the digital transition as an essential goal and defines the principle and role of digitization.

Of course, it is impossible to expect only the state (and the supranational organization) to be solely responsible for implementing a process of such great importance as the digital

*Corresponding author.
E-mail: dr.torok.laszlo@eng.unideb.hu

transition. In such a robust technological and social transformation as the digital transformation, the citizens and their businesses have a specific role and responsibility in addition to the state.

1.1. The role and importance of digital transition

The last decade was characterized by the processes of technological development caused by Industry 4.0, which is still taking place at an ever-accelerating pace, and the most crucial element of the process is digitization. Digitalization achievements have become unavoidable for individual macroeconomic entities (households, businesses, state) [8–10]. At the same time, digital transformation has become a critical social and economic development factor. According to the mainstream approach, the researchers applied a digital transformation to the digitization transition experienced in company processes. However, parallel to the significant macroeconomic effects of Industry 4.0, the terminology can also be applied to the entire macroeconomics of [11, 12].

In general, it can be stated that shortening the digital transition period, improving access to technologies, and promoting technological adaptation and digital transformation are crucial for all national economies. Digital transformation has also become one of the cornerstones of innovation and sustainable growth. The previous finding also highlights that digitization has become such an unavoidable factor for economies that it is necessary to treat the digitization transformation as a critical issue [13–17].

The state's role is crucial in the digital transition to ensure an appropriate legal environment for technological provision, distribution, and access. This assurance can have different dimensions, such as the regulatory side, legislation, and giving indirect or direct subsidies to the entities involved in the digital transition [18–21]. However, state involvement is not limited to maximizing the positive returns of digitization, as digital transformation can have many downsides [22, 23].

Many published studies describe that, for developing economies, the technological development caused by Industry 4.0 can transform their previous economic development trajectory. The development based on productivity growth up to that point and parallel growing employment may be halted by digitization and automation of processes [24–27].

Digital transformation also transforms the competencies expected of employees performing public services. These changes affect all areas of the public sector, including the provision of digital public services and the development of public policy. To implement digital strategies and transformation requirements, the public administration must modify the competencies that the workforce and external stakeholders may need in the future [28].

A researcher believes that the development of digital technologies, led by the decentralized Internet, has brought significant transformations in the authority of national states. The study argues that digital technologies pose challenges to democratic government institutions, as there is a risk of their legitimacy being undermined by non-state actors using digital tools [29].

Other researchers examine the digital transition from the perspective of companies. According to research, although digital transformation changes certain things and processes in a company's operations, others remain the same. Their research identified three fundamental tensions at the heart of digital transformation: products vs. platforms, companies vs. ecosystems, and people vs. devices [30]. Another study found that increased corporate efficiency positively moderates the direct and indirect effects of the digital economy on corporate innovation [31].

One of the essential pillars of economic growth is a permanently and sustainably high investment rate. Nowadays, investments in digital and intangible assets, in particular, must be prioritized. Digital investments play an essential role in economic growth, as they increase GDP in the short term and contribute to the growth of potential GDP in the longer term. At the same time, its structure is also a fundamental addition to the growth of digital investments. Figure 1 shows the relationship between digital investments and economic growth.

1.2. Relationship of I-DESI index with DESI

This study uses the I-DESI index to examine how closely the variables included in it were related to the GDP

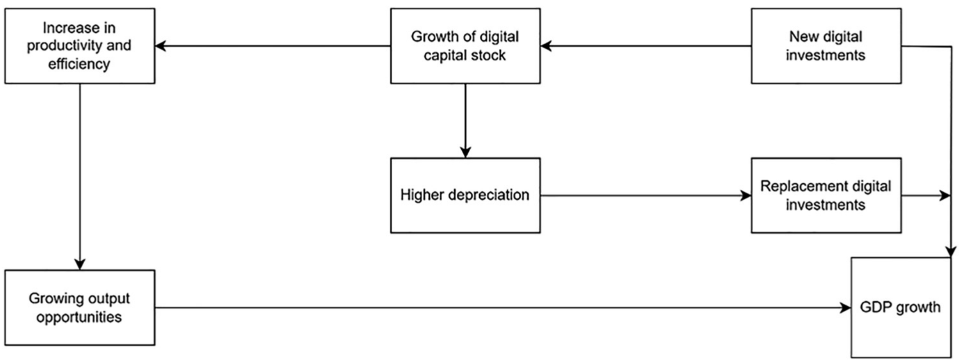

Fig. 1. The relationship between digital investments and economic growth (Own editing)

development of the EU member states. The indicator used to assess the current state of digital transformation was the DESI, the improved version of which is the I-DESI index. I-DESI is a composite indicator with which the European Commission aims to track the digital development of EU member states and compare them with the results of the rest of the world. The International Digital Economy and Society Index (I-DESI) enables international and member-country comparisons based on the DESI indicator. The methodology is the same in calculating the two indices; there are differences in the indicators used. 13 of the 38 DESI values are not included in the I-DESI indicators, while the I-DESI contains seven indicators that the DESI does not. The difference is basically because the technologies used by individual countries are comparable.

I-DESI consists of five primary dimensions: 1. Internet access (connectivity): wired and mobile broadband use; 2. human capital: digital knowledge of the population; 3. use of internet services (citizen internet use): online activity of the private sector; 4. integration of digital technologies (business technology): digitization of the business sector; 5. digital public services: demand and supply of online public services.

The main dimensions can be interpreted through another 24 sub-dimensions. Based on the report of the European Commission, the correlation of the main dimensions and sub-dimensions of DESI and I-DESI is strong. A correlation value of 0.89 was measured between the scores of an earlier period and the country ranking, so the comparative study of the two indicators can be performed with relatively high reliability.

The structure of the I-DESI indices will be found in the study's appendix.

1.3. The aim and hypothesis of the research

The research aims to confirm or deny the positive impact of digital development on economic growth using a modern indicator, the Dimensions of the International Digital Economy and Society Index (I-DESI). The analysis refers to the period 2015–2020 of the European Union member states. The modernity of the study is because the I-DESI index has not been used in research to examine the relationship between the digital transition and GDP production. Therefore, The present study takes a step further from the previous typical DESI-GDP models, fulfilling a pioneering role. The explanation for the omission of the I-DESI index is that it was created and started to be used for national and international comparisons by the European Commission only in 2015. No studies are using the international digital economy and society index in the literature, which indicates that the scientific use of this index has not yet begun. Therefore, including this indicator in macroeconomics can open a new field of research. Using the I-DESI indicator can create an opportunity to discover a new field of research that examines the digital development of the countries of the global economy and connects it to their GDP growth. This may raise new aspects and questions regarding economic and social development.

To conclude the introduction chapter, the study's hypothesis is as follows: It can be verified by empirical investigation that higher values of the dimensions of the international digital economy and society index have a more positive influence on economic growth than lower values of these dimensions. The theoretical approach assumes that digital development strongly influences GDP development; therefore, the Pearson correlation coefficient between I-DESI and GDP is expected to be close to 1. A value close to 1 also implies the linear relationship between I-DESI and GDP.

The study is divided into four parts. After the introductory part, the literature on the analyzed area is presented. The third part presents the research methods and the data used. The fourth part presents the research results and discusses the results. The last sections present the discussion and conclusions based on the research results.

2. LITERATURE REVIEW

There is very little international literature on the investigation of I-DESI, mainly in the information sheets of the European Commission. The well-known literature uses different measurement methods and ranking procedures to compare the previously created DESI index and its elements with macroeconomic variables, such as FDI, unemployment, etc. From the previous statement, it follows that the study will only be able to present technical literature that shows the relationship between DESI and various macroeconomic variables.

The relationship of DESI with other indices was analyzed in a study by [32]. Their results proved that 98 percent of DESI values are determined by previous years, a 1 percent increase in the consumption index results in a 0.2 percent increase, and a 1 percent increase in unemployment results in a 0.2 percent decrease in DESI values. Another study by [33] explored the relationship between DESI dimensions and labor market indicators. In the thesis, the 2018 DESI dimensions, positive (personal earnings, employment rate) and negative (labor market uncertainty, long-term unemployment rate) employment indicators, were analyzed using correlation and regression calculations. The researchers concluded that as the DESI value increases, the employment rate and personal earnings increase, as well as the long-term unemployment rate and labor market uncertainty, decrease, so the development of digitalization favors positive employment indicators. Another study examined the relationship between digitization and labor productivity and the global competitiveness index [34].

Using cluster analysis, the researchers separated four clusters: the leaders, perspective countries, followers, and transitional countries. In this analysis as well, the Nordic countries were at the forefront. The relationship between DESI and labor productivity was proven, but the relationship between DESI and the competitiveness index was unclear. Other researchers have analyzed the relationship between sustainability and digitization using data from the

Visegrad countries [35]. In their study, they looked for correlations between the dimensions of the DESI, the gross domestic product (GDP), the human development index (HDI), and the social progress index (SPI) according to sustainability goals. In evaluating their results, they addressed the effects of the pandemic, which in 2020 caused a leap forward in the digitization of countries compared to the previous year's data. The correlation between DESI and GDP was confirmed by a study examining the situation of digital businesses in Central and Eastern Europe [36]. One study used DESI as an independent variable [37]. The study concludes that digitization positively and significantly affects economic growth, even if several control variables are considered.

A study examined the digital transition situation of countries that joined the EU earlier and later [38]. The lagging behind the countries that joined later was explained by the fact that the management in these countries had not yet gained experience during the short period of implementation of the free market economy, so they were not yet aware of the need for change. In addition, the relatively low research expenditures of the recently joined countries mean that the innovation capacity of these countries is still low compared to the "old EU" countries, despite the significant improvement experienced in recent years. According to [39], DESI has the same explanatory power if the model is modified by eliminating the pillars of Internet services and digital public services.

Connectivity is the dimension that has the greatest impact on digital transformation in the European Union. The authors also found that the DESI is a significant regressor for explaining GDP per capita changes in the European Union member states. For example, [40] examined the relationship between the digital transition and employment. They found that in helping the digital economy grow, the government should strengthen employment security policies and raise wages.

On the other hand, the digital economy should be used to create new industries to create new job opportunities in the economy. Ref. [41] examined the relationship between digital transformation and institutional flexibility. The results of our analysis show that the impact of organizational flexibility on digital transformation is maximal when digital proactivity and commitment to change are at a similarly high level. Ref. [42] examine the relationship between the business environment and corporate digital transformation. The results of the study show a significant positive relationship between the two. Further analyses show that the involvement of the professional managers of the company's top managers, the increase of investments in digital technology, and the increase of state subsidies related to digitalization promote digital transformation.

Other authors examine the contribution of corporate innovation in the production of the GDP of the national economy. For example, according to [43], reducing costs, increasing revenues, improving efficiency, and encouraging innovation are the main paths of digital transformation. The four tools described in the previous sentence are the ones that enable the development of businesses, however, among the four tools, the political impact of corporate innovation is the most significant.

Table 1 presents relevant studies on the relationship between digital transformation and the economy. When selecting the studies, including many regions and country groups in the sample was also important.

The article is divided into four parts. In the first part, we reviewed the specialized literature of the analyzed area. The second part presents the research methods and the data used. The third part presents the research results and discusses the results. The last part is a conclusion.

3. DATA AND METHODOLOGY

3.1. Data

The relationship between the dimensions of the international digital economy and society index and economic growth is based on a 27 cross-sectional, balanced data set (EU-27 member states) for 2015–2020, using a panel model approach. The study uses the panel data approach because it supports the coordination of individual heterogeneity and shows more informative data and more significant variability between the two variables. The explanation for the examined period is that the EC started calculating the I-DESI index in 2015, and the data for 2020 are currently available.

The examined period is relatively short. However, despite the short duration of the I-DESI index, it is important for scientific studies, because these studies help to understand the changes in the direction of the development of the digital economy and society in the EU (see the change in the value of the I-DESI index). Short-term analyses allow us to identify current trends and challenges in digitization. Through such investigations, we can monitor the changes occurring in the European Union member states in the field of digitization and examine its effects on social well-being.

The data in Table 2 show that there was a continuous increase in economic growth and the level of digital development until 2020, which trend was broken by the pandemic.

The EU I-DESI index and GDP/capita values increased in both 2021 and 2022. The values of the former rose to 0.50 and 0.52 respectively, and the values of the latter increased to 44.4 and 46.0. The conclusion can be drawn from these data that the outbreak of the pandemic in 2020 only temporarily broke the EU's economic growth and digital development.

From the data in Fig. 2, it is clear that the average GDP and I-DESI index increased until 2018 when a decline occurred. There was an increase in 2019, and then in 2020, the value of both variables decreased again.

3.2. Method

In the methodological part, two procedures will be applied. First, the study uses Pearson correlation to examine the

Table 1. Significant studies on the relationship between the digital transition and the economy

Author(s)	Period	Sample	Variables	Method	Result(s)
Chemic et al. (2023)	2014–2019	European Union	GDP, labor productivity, export	Linear regression	There is a strong correlation between digitization and productivity and GDP, and a weak correlation between digitization and exports
Yang et al. (2023)	2013–2020	Companies from 29 provinces in China	Panel data of listed companies	Transaction cost theory and geoeconomics	A strong positive U-shaped relationship between digital transformation and corporate sustainability
Erres et al. (2021)	2015–2020	Visegrad 4 countries	DESI index and SDG goals	Country ranking based on indicators, comparison with EU average values	GDP in this research correlates strongly with SDG targets. The degree of digitization of a country depends on its GDP.
Stavtskyy et al. (2019)	2013–2018	28 European countries	Consumption index, unemployment, DESI elements	Panel regression	1% increase in the consumption index results in an approximately 0.2% increase in DESI, and a 1% increase in unemployment results in a decrease of approximately 0.2 DESI.
Olczyk et al. (2022)	2015–2020	European Union	Elements of DESI-index	Sensitivity based analysis	Connectivity has the greatest impact on digital transformation. DESI is a significant regressor in the change in GDP
Chen et al. (2022)	2007–2019	3,778 listed companies in China	Workshare Digital economy Technological progress Output flexibility	Two-way fixed effect model	There is a digital divide in the effects of changes in factors, skewed and returns to scale of heterogeneous industries
Nguyen et al. (2023)	2019	206 Dutch companies	Digital proactivity, Motivation, Organizational flexibility	OLS regression, Complementary analysis	Digital proactivity, commitment to change, and organizational flexibility all contribute to digital transformation.
Luo et al. (2023)	2013–2020	All Chinese A-share companies	Factors in the development of digital transformation	Multivariate regression analysis	A better business environment significantly improves the company's digital transformation, by involving senior managers and increasing digital input, it attracts more state support related to digitalization.
Peng & Tao (2022)	2012–2020	1,578 Chinese-listed companies	GPM, CER, ROA, ROE, and other variables	Lag regression analysis, General momentum estimation	According to digital public policy, innovation performance is the main driving force for improving corporate performance.

direction and strength of the relationship between the two variables. With the F-statistics method, the study attempts to answer whether there is a demonstrable relationship between the two variables and whether this relationship is linear or non-linear.

3.2.1. Correlation analysis. First, examining the correlation between GDP and the I-DESI index in each member state is advisable. Correlation analysis helps to understand the relationship between digital development and economic performance in the EU member states during the period under review. However, a Shapiro-Wilk test should be performed before testing to determine whether the correlation coefficients follow a normal distribution.

Shapiro-Wilk test results: Sample size (n):27, Average (x): 0.597870, Median: 0.6126 Sample Standard Deviation (S): 0.304095, Sum of Squares: 2.404321, b: 1.468148, Skewness: −0.885387, Skewness Shape: negative_skew Asymmetrical, left/

Table 2. GDP per capita (in thousand U.S. dollars), I-DESI index, and (r) values of EU member states

	2015		2016		2017		2018		2019		2020		
Country	GDP	I-DESI	GDP	I-DESI	GDP	I-DESI	GDP	I-DESI	GDP	I-DESI	GDP	I-DESI DE	Pear. (r)
AU	50	0.49	53	0.49	54	0.52	57	0.52	59	0.54	55	0.52	0.89
BE	44	0.58	49	0.48	51	0.50	53	0.49	54	0.59	52	0.52	0.84
BG	18	0.36	20	0.37	22	0.42	23	0.40	24	0.36	24	0.40	0.41
CY	32	0.42	36	0.46	39	0.47	41	0.47	43	0.47	42	0.47	0.89
CZ	34	0.41	36	0.39	39	0.45	41	0.47	43	0.50	41	0.47	0.94
DK	49	0.61	52	0.65	56	0.65	58	0.70	59	0.68	59	0.70	0.92
EE	29	0.55	31	0.56	34	0.54	36	0.57	38	0.60	38	0.57	0.67
FI	43	0.63	45	0.64	48	0.65	49	0.68	51	0.70	50	0.68	0.94
FR	42	0.48	44	0.51	46	0.50	48	0.57	49	0.51	46	0.57	0.52
EL	27	0.38	27	0.40	27	0.41	29	0.40	30	0.38	29	0.40	−0.11
NL	49	0.55	50	0.59	52	0.64	56	0.68	58	0.68	58	0.68	0.94
HR	22	0.40	22	0.46	23	0.42	25	0.35	27	0.48	29	0.35	−0.11
IE	48	0.49	51	0.49	69	0.51	71	0.60	78	0.62	86	0.60	0.86
PL	24	0.31	25	0.35	27	0.34	28	0.36	30	0.42	33	0.36	0.61
LV	21	0.41	23	0.42	24	0.44	25	0.41	27	0.52	29	0.41	0.32
LT	25	0.41	27	0.40	28	0.42	29	0.44	31	0.50	34	0.44	0.60
LU	98	0.57	102	0.62	107	0.65	109	0.62	114	0.62	117	0.62	0.51
HU	23	0.38	25	0.42	26	0.45	27	0.41	28	0.46	30	0.41	0.41
MT	30	0.49	33	0.50	35	0.51	38	0.48	40	0.58	45	0.48	0.12
DE	43	0.50	45	0.50	47	0.52	48	0.58	51	0.55	53	0.58	0.82
IT	36	0.34	36	0.39	36	0.38	37	0.38	40	0.43	42	0.38	0.44
PT	27	0.41	26	0.38	28	0.44	29	0.41	30	0.49	32	0.41	0.41
RO	17	0.33	19	0.35	20	0.42	20	0.42	21	0.36	22	0.42	0.68
ES	32	0.44	32	0.50	32	0.47	32	0.47	34	0.57	35	0.47	0.39
SE	42	0.58	44	0.59	45	0.63	46	0.65	47	0.69	49	0.65	0.81
SK	25	0.36	26	0.37	27	0.41	28	0.39	29	0.47	30	0.39	0.59
SL	28	0.42	29	0.43	29	0.45	30	0.47	31	0.50	32	0.47	0.82
EU	42	0.46	43	0.48	45	0.48	41	0.47	44	0.57	42	0.48	0.59

Data sources: GDP: GDP per capita: [44]; I-DESI (2015–2018): [45]; I-DESI (2019): [46]; I-DESI (2020): [47], Pearson's coefficient (own editing).

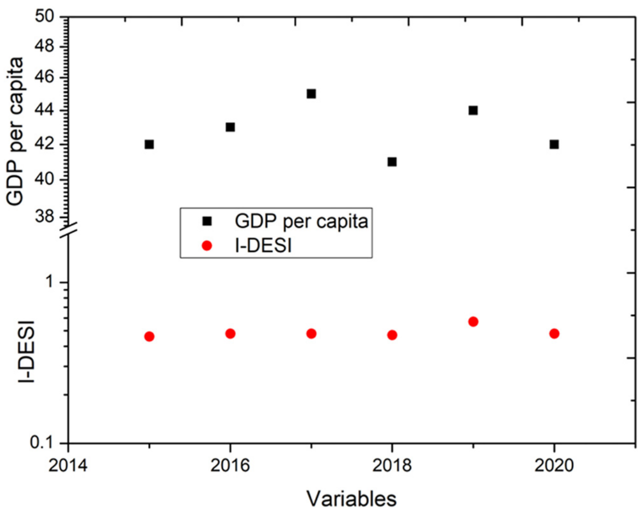

Fig. 2. European Union average GDP and I-DESI index values (2015–2020)

negative skew, long left tail (pval = 1.952), Excess kurtosis: 0.261507, Tails Shape: normal tails, Potentially Mesokurtic, normal like tails (pval = 0.764), *P*-value: 0.0111297.

1. H0 hypothesis: Since *P*-value > α, we accept the H0.
2. *P*-value: The *P*-value is also 0.0111297; hence, if we reject H0, the chance of type1 error (rejecting a correct H0) would be too high: 0.01113 (1.11%); the more significant the *P*-value, the more it supports H0.
3. The statistics: W is 0.896494. It is in the 99% critical value accepted range: [0.8944: 1.0000].

Figure 3 illustrates that the correlation values between economic growth and digital development follow a normal distribution. It follows that the calculated (r) value can be used for analysis.

The correlation coefficient is determined by formula (1). This correlation coefficient is also known as Pearson's correlation coefficient:

$$r = \sum (X_i - \overline{X})(Y_i - \overline{Y}) \Big/ \sqrt{\sum_i^n (Xi - \overline{X})^2 + \sum_i^n (Y_i - \overline{Y})^2} \quad (1)$$

where: n is the number of data points, X_i is the first variable i. data point, Y_i is the second variable i. data point, $\overline{X}$ is the average of the data points of the first variable, $\bar{Y}$ is the average of the data points of the second variable. After

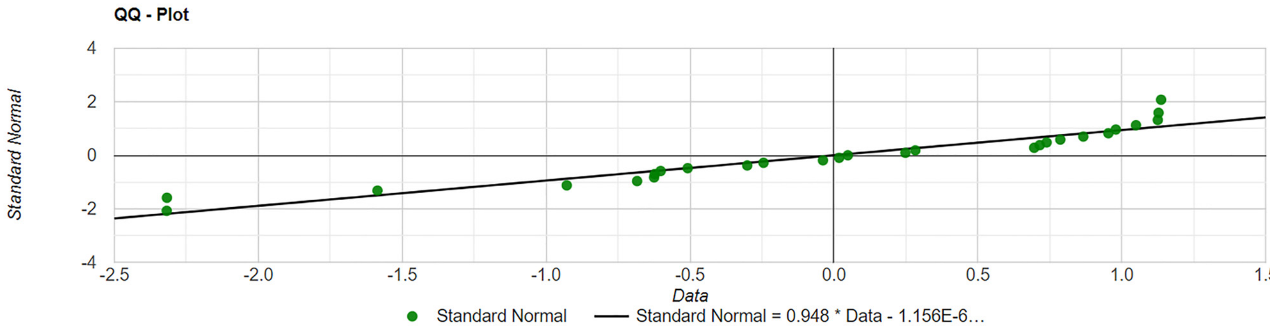

Fig. 3. Distribution of correlation values (r) between GDP and I-DESI indices of EU member states

the test showed that the Pearson correlation values calculated with the GDP and I-DESI index values of the EU member countries follow a normal distribution, these values in the 1. were recorded in a table and used further.

3.2.2. F-statistic analysis. The study also wants to answer whether there is a linear relationship between the two variables (GDP and I-DESI) in the examined period. The F-statistic can be calculated using the following formula:

$$F = MSE/MS \tag{2}$$

where: F is the value of the F-statistic, MSR is the between-group variance or explained variance, and MSE is the within-group variance or unexplained variance. The MSR and MSE values are calculated during the ANOVA (analysis of variance) procedure. ANOVA divides the data into different groups and measures how much the data varies between and within each group. The F-statistic was performed to answer the question of linearity, the calculation of which can be seen in Table 3.

After this, there is an interpretable F-statistic, which can be used to check for significance. From the F-distribution table, the P-value of the F-value: ≈0.5702 $P \approx 0.5702$. The explanation of the value of the F-statistic and the conclusions that can be drawn from it will be described in the Discussion chapter.

Table 3. Calculation of F-statistics to examine the linearity between GDP and I-DESI

Operation	Calculation	Value
GDP average	50 + 53+…+31 + 32 = 3,156/162	52,50
SSR calculation	$(52{,}5 \times 0.8958–50)^2$+ $(52{,}5 \times 0.8371–53)^2$…$(52{,}5 \times 0.8154–32)^2$	36,071
MSE calculation	SSD/n-k = 2,729.83/27–2 = 2,729.83/25	109,19
MSR calculation	SSR/k-1 = 36,0713/1*	36,071
F-statistic	F = MSR/MSE = 36,071/109,19	0,3302

* where k is the number of independent variables, here it is one because only the I-DESI index is used.

3.2.3. Regression analysis. With regression analysis, the study seeks an answer to how much GDP per capita increased in the EU member states between 2015 and 2020 when the value of the I-DESI index increased by 0.1 units.

The linear regression equation can be written in the following form:

$$y = \beta 0 + \beta 1 \cdot x + \varepsilon \tag{3}$$

where: y is the dependent variable (GDP values), x is the independent variable (I-DESI index values), β 0 is the shift (intercept) or constant value that shows what the value of the dependent variable is when the value of the independent variable is 0. β 1 the slope or regression coefficient, which shows how the value of the dependent variable changes when the value of the independent variable increases by one unit. ε is the error or residual variable from the model, which is because not all data points can be perfectly fitted to the regression line. The result of the calculation is shown in Table 4.

The explanation of the result data in Table 4 is described in the Discussion chapter.

3.2.4. Exponential smoothing to show the dynamics of growth. With this method, it can be shown that the growth of economic growth and digital development slowed down or accelerated in the analyzed countries during this period. The formula for exponential smoothing:

$$S\_t = \alpha * X\_t + (1 - \alpha) * S\_(t{-}1) \tag{4}$$

where: S_t is the smoothed value in the current period (t). X_t is a value measured in the current period (t) (e.g. annual change). S_(t − 1) is the smoothed value calculated in the previous

Table 4. Regression of GDP and I-DESI index

	Coefficient (Estimated coefficients)	Standard error	t-stat (t-statistics)	P-value	95% confidence interval
Intercept (permanent member)	60.1820	10.3010	5.8371	0.0000	[39.3931, 80.9709]
I-DESI index	4.1151	12.1803	0.3381	0.7382	[-20.6848, 28.9149]

period (t-1). α (alpha) is a weighting factor that weights the smoothed value of the previous period with the measured value of the current period. This value is between 0 and 1.

In Table 5, during the exponential smoothing, the α (alpha) smoothing factor shows a value of 0.2. The value of α is a value between 0 and 1 and determines the weight with which the value of the previous period is taken into account in the next period.

3.2.5. Linear regression slope and interceptor, spearman correlation. The study examines the relationship between the two variables (I-DESI and GDP per capita) using additional methods. Table 6 presents these methods and results.

The results are shown in 4.5. the study is presented in a subchapter.

Table 5. Results of the exponential smoothing calculation

	GDP	I-DESI	α
2015	42.0000.	0.46000	0.2000
2016	3.0000	−0.1000	0.2000
2017	3.6000	−0.1400	0.2000
2018	3.8800	−0.1640	0.2000
2019	3.9404	−0.1728	0.2000
2020	3.9220	−0.1750	0.2000

Table 6. Results of testing with SRL, LI, and SC methods

Country	Slope of Linear Regression (SLR)	Linear Interceptor (LI)	Spearman Correlation (SC)
AU	0.0008	0.4546	0.4286
BE	0.0009	0.4487	0.9429
BG	0.0002	0.4377	−0.2571
CY	0.0009	0.4504	0.8286
CZ	0.0008	0.4493	0.8286
DK	0.0008	0.4508	0.9429
EE	0.0005	0.4636	−0.6000
FI	0.0008	0.4512	0.8286
FR	0.0007	0.4526	0.5143
EL	0.0008	0.4492	0.7143
NL	0.0008	0.4520	0.8286
HR	0.0006	0.4600	−0.5714
IE	0.0008	0.4513	0.8857
PL	0.0003	0.4622	−0.6000
LV	0.0007	0.4525	0.4571
LT	0.0006	0.4544	0.2571
LU	0.0008	0.4494	0.9429
HU	0.0007	0.4527	0.4857
MT	0.0008	0.4509	0.7714
DE	0.0008	0.4516	1.0000
IT	0.0007	0.4532	0.8286
PT	0.0008	0.4502	0.5714
RO	0.0004	0.4568	0.6286
ES	0.0007	0.4530	0.7429
SE	0.0008	0.4523	0.8286
SK	0.0007	0.4530	0.5143
SL	0.0008	0.4494	0.8286
EU	0.0008	0.4509	0.6000

4. RESULTS

The study presents the results in four subsections.

4.1. Results based on mean I-DESI and correlation values

Based on the average I-DESI values for 2015–2020, Finland, Denmark, the Netherlands, Sweden, Luxembourg, Estonia, and Ireland are at the top of the EU rankings. At the bottom of the ranking are Lithuania, Slovenia, Slovakia, Poland, Hungary, Romania, and Bulgaria.

Another study result shows the significant positive impact of the I-DESI index, which expresses the progress of the digital transition and the development of digitalization at the international level on economic growth (GDP). The correlation between the dependent (GDP) and independent (I-DESI) variables proves that in the EU member states with the highest (r) values, the same I-DESI index and GDP per capita values are outstanding, too. Denmark, Finland, the Netherlands, Ireland, and Austria are leading countries. Regarding the correlation between the two variables, Spain, Lithuania, Malta, Croatia, and Greece are at the bottom of the EU rankings. Based on the results, the correlation between the variables is positive except for two member countries, so they move together in the same direction.

As a result of the K-means clustering, the study arranged the EU member states into six groups based on the correlation coefficients. The mean values of the clusters show that the member countries have similar correlation values within the groups, which indicates the correlation between digital development and economic performance.

Figure 4 shows how many of the 27 member states of the EU were classified in each cluster. The classification was based on how strong a correlation was between the economic growth and digital development of the given country.

The purpose of clustering is to group countries with similar characteristics into one, and thus reveal noticeable differences or similarities between countries according to the correlation data. The correlation clustering between I-DESI and GDP can well reflect countries with similar digital development and economic performance.

In the first cluster, there are two member countries for which the correlation value is negative, so there is an inverse relationship between the GDP and I-DESI index values. In the case of Greece, this classification can be explained by the fact that the value of GDP practically did not change. In addition, the average of the I-DESI index, representing its digital development, even decreased. Another member country belonging to this cluster is Croatia. The explanation for the negative correlation coefficient of the member country is that although the real GDP per capita increased minimally, the value of the average I-DESI index decreased during the examined period.

The second and third clusters included three member countries: Malta, Latvia, and Spain. The correlation between these member countries' GDP and I-DESI index values is already positive, which means that the increase in their digital development has positively affected GDP production.

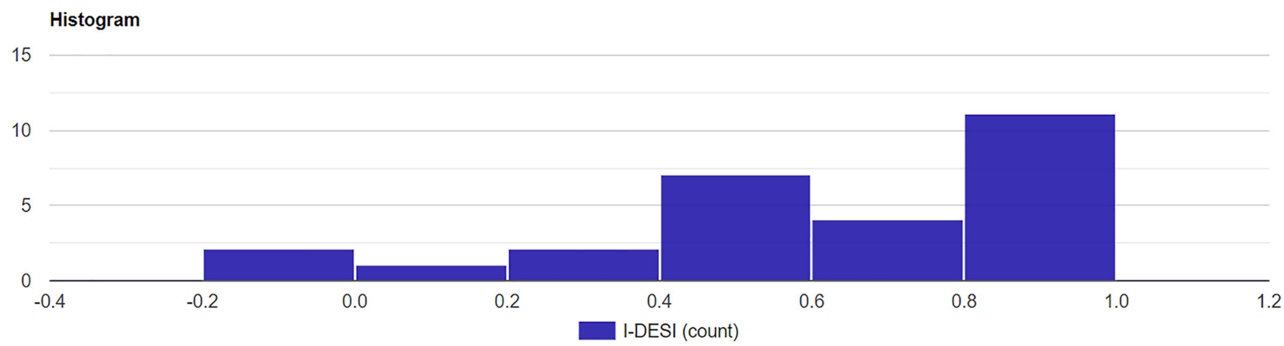

Fig. 4. Clusters of EU member states based on the correlation between GDP and I-DESI values

The fourth and fifth clusters include those member countries with a moderately strong and positive relationship between the two variables. These countries are Portugal, Hungary, Bulgaria, Italy, Luxembourg, Slovakia, France, Lithuania, Estonia, Romania, and Poland. It can be stated that the increase in the level of digital development in these member countries contributed moderately to the growth of the member countries' GDP.

The sixth cluster includes the member countries with a strong correlation between digitization development and GDP output. These countries are Sweden, Slovenia, Germany, Ireland, Belgium, Cyprus, Denmark, Austria, Netherlands, Czech Republic, and Finland.

Empirical data reveal another connection. When it was examined what position the old and new member states of the EU occupy in the correlation of the GDP and I-DESI index, it was found that the old member states (14 countries) could make better use of the opportunity provided by the development of digitalization. No. 1 According to the data in the table, only two of the 11 member states at the top in the order (Slovenia and the Czech Republic) are new; the rest are old members of the EU. At the same time, four of the six-member states at the back in the order are new member states, the exceptions being Spain and Greece.

However, the positive effects of digitization do not appear immediately. For example, [48] compared the development opportunities of the Central European countries that joined the EU later, the so-called digital challengers, with two other groups of European countries, the digital leaders and the Big 5, which includes the largest economies (France, Germany, Italy, Spain, and the United Kingdom). Based on the data, digital challengers have grown faster than other European economies in terms of economic growth over the past five years. Despite this, the digital challengers are still lagging behind the other two country groups, which indicates that digitization has significant economic growth reserves, the positive effects of which will only be felt later.

4.2. Result of linearity test

According to the results of the linear relationship test performed using K-statistics, since this *P*-value is high (0.5702, more significant than 0.05), we cannot be sure there is a significant relationship between GDP and the I-DESI index. However, the data shows no linear relationship between GDP and the I-DESI index in the EU member states between 2015 and 2020. This means there is a correlation between the GDP of the 27 member states of the EU and the I-DESI index over the years, i.e., a change in one variable is accompanied by a change in the other variable. However, the relationship cannot be traced with a simple, straight line; finding a linear function that accurately describes the relationship between the two variables is impossible. A linear relationship would mean that the relationship between GDP and the I-DESI index is in a straight line, i.e., it increases or decreases evenly over the years. However, the relationship is not linear because the relationship between the two variables is not simple. The proof, recognition, and understanding of the non-linear relationship in this study is necessary because it indicates that the relationship between the GDP of the EU member states and the I-DESI index is complex.

4.3. Result of regression calculation

In the analyzed model, GDP per capita is expected to increase by 4.1151 units if the I-DESI index increases by 0.1. Based on the results, it can be concluded that the relationship between the I-DESI index and GDP per capita is not linear, and the coefficient of the I-DESI index is not significant. This means that changes in the values of the I-DESI index have little effect on GDP per capita growth. The model generally does not explain changes in GDP through changes in the I-DESI index.

4.4. Result of the exponential smoothing calculation

The 2015 GDP value (S_1) was 42, and in the first year, the smoothed value calculated based on the α value changed only slightly, increasing to 42.2 by 2016. Because of the α value, the smoothed value changes slowly, which indicates that the values of previous years still affect the current value. By 2020, the smoothed GDP value has increased to 3.92, which shows that annual GDP growth has decreased between 2015 and 2020 based on exponential smoothing.

The 2015 I-DESI index value (S_1) was 0.46, and in the first year, the smoothed value calculated based on the α value changes in a negative direction, decreasing to −0.1 by 2016. Because of the α value, the smoothed value of the

I-DESI index also changes slowly, but it can be noticed that it moves in a negative direction, which may suggest that the negative changes of the previous years affect the current value. By 2020, the smoothed I-DESI index value had decreased to −0.17504, which shows that based on the exponential smoothing, the annual change of the I-DESI index showed a negative direction between 2015 and 2020.

4.5. Linear regression slope, interceptor, and spearman correlation results

The slope shows how much the GDP per capita (dependent variable) changes with a unit change in the I-DESI index (independent variable). Based on the values in Table 6, with a unit change in the I-DESI index, the largest GDP growth would occur in Austria, Belgium, Cyprus, the Czech Republic, Denmark, Finland, the Netherlands, Luxembourg, Malta, Germany, Portugal, Sweden, and Slovenia. On the other hand, the lowest GDP growth is expected in the case of Bulgaria, Poland, and Romania with a change in the value of the I-DESI index of one unit.

The values of the Linear Interceptor (LI) show the theoretical value of the estimated GDP per capita when the value of the I-DESI index is zero (that is, there is no digital development). According to this theory, Estonia, Poland, and Croatia would be at the top of the order within the EU, and the Czech Republic, Greece, and Bulgaria would be at the bottom of the order.

Spearman correlation also detects non-linear relationships. A high value indicates that there is a strong monotonic relationship between I-DESI and GDP. This means that if the value of I-DESI increases, GDP also increases, but certainly not uniformly. Based on this theory, the increase in the value of I-DESI (non-linearly) has the most intensive effect on the growth of the GDP of Germany, Belgium, Denmark, the Netherlands, Finland, and Luxembourg in that order. In contrast, the GDP growth of Poland, Estonia, Croatia, Bulgaria, and Lithuania is least affected by the increase in the value of the I-DESI index.

5. DISCUSSION

The elements of the international digital economy and society index, which describes the state and current situation of the digital transition, directly impact the GDP in all EU member states. The extent of the effects is different in the individual member states. The relationship between the I-DESI index and GDP is more robust; the Pearson correlation coefficient is relatively high in, for example, Finland (0.9436), the Netherlands (0.9401), and Denmark (0.9171). However, suppose these results are compared with the data of the other examined EU member states, where the correlations are lower or even harmful. In that case, it can be concluded that the correlation cannot be accidental.

Based on the study's results, it can also be safely stated that there is a relationship between the elements of the I-DESI index and GDP growth, but this relationship is not linear. No study results would show that changes in the value of the elements of the international digital economy and society index have a linear and one-way relationship with economic development. In other words, it cannot be concluded that digital development necessarily and surely entails economic growth.

It was already described in the study's introduction that the I-DESI indicator had not been examined in connection with economic growth before. The structure of the I-DESI index is similar to the DESI indicator, so the results of studies that examined the relationship between the latter index and economic growth will be described below. The theoretical basis for comparability is that a correlation value of 0.89 was measured between the DESI and I-DESI scores and the country ranking, so the two indicators can be converted [49].

Several studies conduct country-by-country assessments, comparing different countries or regions based on the main factors of the DESI index. A study compares the Baltic States with the European Union. It is critical of the factors of the DESI index, given that it sees the primary driver of digitalization and its impact on the economy in other factors than several researchers [50]. Another study used the co-plot method to visualize and classify EU member states based on their correlations with similar variables. The best-performing European Union (EU) countries correlate strongly with at least one of these indicators [51]. According to a research group, digital, technology-driven economies will be the engines of growth [52]. Researchers examined the impact of digitization on the economic growth of the EU. Their main conclusion is that digitalization positively and significantly affects economic growth, even when several control variables are considered. The results confirm the robustness of the relationship, which is supported by the use of DESI as an independent variable. The results of a study examining GDP output show that using DESI as an independent variable confirms the conclusion that digitalization positively influences economic growth [37]. The results of model studies showed that digitalization in the member states of the European Union has a positive effect [53–57] on competition, productivity, and output.

The research carried out in this study contributes to the investigation of a significant problem related to the relationship between digital development and GDP. The conclusion can be drawn from this research that the relationship between the index elements of the international digital economy and society is significant with GDP, which confirms the hypothesis formulated in the introductory part.

The EU's economic growth and digital development are closely linked to the issue of smart cities. Thanks to digitalization technological progress, machines and devices can perform more tasks independently, and more and more intelligent devices help the lives of members of society. The prominence of digitization and automation transforms cities into smart cities, digital technology makes urban life more efficient and comfortable.

Several studies have examined the relationship between digital development, economic growth, and smart cities, mentioning, for example, possible undesirable developments and side effects of digitization. For example, in the study [58], the authors elaborated on the specifics of the digital economy about the existing competition law. Another study draws attention to the fact that to protect the integrity of the legal system and prevent violations, clearer regulations are needed in general and also in connection with developments [59]. Among the many studies on the subject, article [60] should be highlighted, which focuses on the development of smart cities and the importance of digital connectivity in the process of building smart cities. The study [61] tries to show (among other things) how much pressure the EU is currently under in the process of implementing the single market due to the digital revolution. The study [62] examines the extent to which data protection issues influence the attitude and behavior of social media platform (SMP) users regarding social commerce within the framework of continuous digital development.

The European Union is also looking for answers to digitalization and technological challenges, the implementation of which awaits legal regulation. In addition to the definition of the four main directions of the economy, infrastructure, government, and expertise, digital citizenship arises as a central question, i.e., according to which rights and principles digitalization development can be realized. These principles are recognized as rights and become part of the Member States' regulations.

Several studies have examined the relationship between digitization-based commerce and law. For example, a study [63] highlights that nowadays digital content has become the main product and/or service to be delivered in the EU, which phenomenon must be regulated by law by the requirements of the time. Another legal study concluded that orphan works should be negotiated and negotiated at the intergovernmental level since no national or regional level can solve the problem of cross-border relations in the digital space [64]. A legal study found that, in addition to several factors, growing economic output as a result of digital development increased the credit demand of economic actors and the market activity of financial organizations [65]. The following study examined the topic of digital identity. The researchers are convinced that the amendment of the eIDAS regulation, in addition to the proposed European digital identity, will also put into practice the unification of the regulation of trust services, because this is indispensable in a period of high digital development [66]. The growing information needs of EU citizens can be ensured at a higher level by digital development, as it effectively contributes to the consumer's task of obtaining information and processing information. The consumer needs this when general terms and conditions are applied to them during a purchase [67]. Other authors, such as [68], investigated the effectiveness of digital administration within national borders. They concluded that the effectiveness of digitized administration is increasing at a dizzying speed, in addition to the fact that citizens are increasingly using the Internet and other digitalization techniques as a basic means of communication.

6. CONCLUSION

From the results of the correlation calculation, F-statistics, regression calculation, and exponential smoothing used in the study, four conclusions can be drawn about the relationship between the dimensions of the EU international digital economy and society index and GDP. The first conclusion is that the value of the I-DESI index, which represents digital development over the same period, shows a strong positive relationship with the GDP per capita of the same member country (Table 1). So, more digitally developed member countries have a higher GDP per capita.

The second conclusion of the study is that there is also a positive relationship regarding the change of the mentioned indicators from 2015 to 2019. So the increase in digital development was accompanied by the increase in GDP. However, this statement does not apply to 2020. In the first year of the pandemic, not twenty EU member states but seven member states (Austria, Belgium, Cyprus, the Czech Republic, Finland, France, and Greece) saw their GDP per capita decrease. Contrary to the previous finding, the value of the I-DESI index did not decrease in only five countries (Denmark, France, Greece, Germany, and Romania), and the value fell dramatically in the other 22 member countries.

The third conclusion is that the strong positive relationship between period indicators and indices showing changes remains, at least between 2015 and 2019. In other words, digitalization and GDP development increased dynamically in more digitally developed countries than in less developed member countries. Therefore, the lag behind the less developed is increasing and not catching up. This contradicts the widespread belief that the higher a country's digital development or GDP production, the more difficult it is to progress in both digital development and macroeconomic output. However, this statement is a very simplified classification of the correlation between digitalization development and GDP. It cannot be clearly stated that the statement that further economic development and growth are more difficult for a country with high digital development and high GDP is true in all cases. Economic development and growth depend on several factors, and digital development is just one of them. Several macroeconomic factors can have a strong positive effect on economic growth. For example, these factors are the level of training and workforce; innovations; national market and trade openness; economic policy; infrastructure status, etc.

The fourth conclusion is that, based on the results of the exponential smoothing calculation, it can be seen that the growth of annual changes in GDP and the I-DESI index in the analyzed EU member states shows a slowing trend between 2015 and 2020. This result suggests that the intense growth experienced in previous years in the European Union's economic growth and digital development has decreased in this period.

The study's results confirm that digital development positively affects GDP, but this alone is not a sufficient tool for economic growth; something else is needed. After the results of the study and the processing of the literature, it can be concluded that digitization cannot be successful in any way without a suitably qualified user base. Electronic (public) services can only be used by digitally literate citizens. However, the digitization of workplaces cannot be imagined without workers who can use computers and software skillfully. Digital education and training must be prioritized to achieve a successful digital transformation, primarily in EU member states lagging in the digital transition.

The success of digital transformation in lagging countries will also require a robust increase in trust. Based on the results of this study and the conclusions of the referenced articles, it can also be stated that the success of the current industrial revolution, digitalization, depends not only on the rapid development of technologies but also on the openness of societies to change. In connection with the focus of this paper (and in general) it can be stated that the digital transition will be effective if it can be interpreted in a social context, is transparent to the stakeholders, and is actively shaped by the participants. A positive social change in connection with digitization is inclusive, strengthens social equality, and results in sustainable GDP growth.

Several limitations of this research should be acknowledged. Since the explanatory variables in the models represent the preferences of the experts, the results of the study are mostly limited by the bias of the variables not examined. The fact that there are always gaps in the indicators means that the results of this study should be interpreted with reservations, but there are also some robust results. In addition, the model takes into account only the most important factors related to digitization, which are important for the economic growth of the EU but does not include all variables. It would be an interesting study if, in the course of subsequent research, researchers would assess the digital development of other regions (OECD, BRICS, etc.) and compare the results with the results of EU member states.

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Appendix A: European Union countries

The European Union (EU) consists of 27 countries:

Sweden (SE), Spain (ES), Slovenia (SI), Slovakia (SK), Romania (RO), Portugal (PT), Poland (PL), Netherlands (NL), Malta (MT), Luxemburg (LU), Lithuania (LT), Latvia (LV), Italy (IT), Ireland (IE), Hungary (HU), Greece (EL), Germany (DE), France (FR), Finland (FI), Estonia (EE), Denmark (DK), Czech Republic (CZ), Cyprus (CY), Croatia (HR), Bulgaria (BG), Belgium (BE), Austria (AU):

Appendix B: The structure of the I-DESI indexes

I-DESI structure

Dimension	Subdimension	Indicators
1 Connectivity	1a Fixed Broadband	1.1.1. Fixed BB Coverage
		1.1.2. Fixed BB Subscription
		1.1.3. Mobile BB Subscription
	1.2. Mobile Broadband	1.2.1. Mobile BB Subscriptions
		1.2.2. 3G Coverage
	1.3. Speed	1.3.1. Average Connection Speed
		1.3.2. Fast BB Subscription
	1.4. Affordability	1.4.1. Fixed BB Subscription Charge
2. Human Capital	2.1. Basic Skills and Usage	2.1.1. Daly Internet Users
		2.1.2. Regular Internet Users
	2.2. Advanced Skills and Development	2.2.1. ICT Specialist
		2.2.2. STEM Graduates
3. Use of the Internet	3.1. Content	3.1.1. Reading News Online
		3.1.2. Music, Videos, and Games
		3.1.3. Video and Demand
	3.2 Communication	3.2.1. Social Network
	3.3. Transactions	3.3.1. Online Banking
		3.3.2. Purchase Online Products
4. Integration of Digital Technology	4.1. Business Digitization	4.1.1. Electronic Information Sharing
		4.1.2. RFID
		4.1.3. Social Media
		4.1.4. Online Presence
		4.1.5. Cloud Services
	4.2. eCommerce	4.2.1. SMEs Selling Online
		4.2.2. eCommerce Turnover
5. Digital Public Services	5.1. eGovernment	5.1.1 eGovernment Users
		5.1.2. Transactional Services
		5.1.3. Connected Services
		5.1.4. Open Data