PROBLEMY EKOROZWOJU – PROBLEMS OF SUSTAINABLE DEVELOPMENT
SUBMITTED: 11.04.23, ACCEPTED: 19.04.23, PUBLISHED ON-LINE: 8.01.24
2024, 19(1): 89-103
https://doi.org/10.35784/preko.5413

Digital Transformation in the Context of Sustainable Development of European Countries

Transformacja cyfrowa w kontekście zrównoważonego rozwoju krajów europejskich

Irina Kolupaieva*, Iryna Sheiko, Tetiana Polozova*****

** Kharkiv National University of Radio Electronics, Kharkiv, Ukraine,*
Linkoping University, Linkoping, Sweden,
E-mail: irina.kolupaieva@liu.se, ORCID: 0000-0003-1256-0817
*** Kharkiv National University of Radio Electronics, Kharkiv, Ukraine,*
E-mail: irina.sheiko@nure.ua, ORCID: 0000-0002-5770-3677
****Kharkiv National University of Radio Electronics, Kharkiv, Ukraine,*
E-mail: tetiana.polozova@nure.ua, ORCID: 0000-0001-9956-8816

Abstract
The country's sustainable development is focused on improving the quality of life at the global level, ensuring equal access to education and public goods, and caring for the environment and biodiversity, as well as responsible consumption and production. Digital technologies are among the main drivers of sustainable development. It is very important to develop government strategy and choose correct measures aimed at ensuring sustainable development of the countries in terms of the digitalization processes. The purpose of the research is to investigate the nature of the correlation between indicators of digital development and sustainable development of the European countries, as well as to identify policy directions and measures regarding their digital and sustainable progress. Methods of the research are principal component analysis, geometric aggregation, and cluster analysis. The positive correlation within the digital and sustainable development is observed. Most indicators of digital and sustainable development positively correlate with each other. Based on PCA, it was found that indicators of sustainable development have a stronger intercorrelation than those of digital development. Based on the construction of integral indicators of digital and sustainable development, a cluster analysis was conducted. The main digital tools that contribute to the achievement of each of the 17 goals of sustainable development were determined. The results of the analysis provide a suitable basis for comparing the digital and sustainable development of individual countries and offer opportunities to identify tools and strategy directions for policymakers.

Key words: digitalization, sustainable development, European countries, principal component analysis, cluster analysis

Streszczenie
Zrównoważony rozwój koncentruje się na poprawie jakości życia na poziomie globalnym, zapewnieniu równego dostępu do edukacji i dóbr publicznych oraz dbałości o środowisko i różnorodność biologiczną, a także odpowiedzialną konsumpcję i produkcję. Technologie cyfrowe należą do głównych czynników zrównoważonego rozwoju. Bardzo ważne jest opracowanie strategii rządu i wybór właściwych działań mających na celu zapewnienie zrównoważonego rozwoju krajów w zakresie procesów cyfryzacji. Celem artykułu jest zbadanie charakteru korelacji pomiędzy wskaźnikami rozwoju cyfrowego i zrównoważonego rozwoju krajów w Europie, a także identyfikacja kierunków i mierników polityki w zakresie ich postępu cyfrowego i zrównoważonego. Metody badawcze to analiza głównych składowych, agregacja geometryczna i analiza skupień. Obserwuje się pozytywną korelację w zakresie rozwoju cyfrowego i zrównoważonego. Większość wskaźników rozwoju cyfrowego i zrównoważonego jest ze sobą pozytywnie skorelowana. Na podstawie PCA stwierdzono, że wskaźniki rozwoju zrównoważonego wykazują silniejszą korelację niż wskaźniki rozwoju cyfrowego. W oparciu o konstrukcję integralnych wskaźników

rozwoju cyfrowego i zrównoważonego przeprowadzono analizę skupień. Określono główne narzędzia cyfrowe, które przyczyniają się do osiągnięcia każdego z 17 Celów zrównoważonego rozwoju. Wyniki analizy stanowią odpowiednią podstawę do porównania rozwoju cyfrowego i zrównoważonego poszczególnych krajów oraz dają możliwości identyfikacji narzędzi i kierunków strategii dla decydentów.

Słowa kluczowe: cyfryzacja, zrównoważony rozwój, kraje europejskie, analiza głównych składowych, analiza skupień

1. Introduction

The country's sustainable development is focused on improving the quality of life at the global level, ensuring equal access to education and public goods, caring for the environment and biodiversity, as well as responsible consumption and production. Digital technologies are one of the main drivers of sustainable development. The development of digital technologies is important for the economic well-being and competitiveness of firms, industrial enterprises, countries and regions. The use of advanced technologies has become especially relevant during the COVID-19 pandemic and post-pandemic recovery.

The most common and widely used definition of sustainable development comes from the UN Brundtland Commission: *Development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs* (WCED, 1987). In September 2015, the United Nations (UN) adopted the 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals (SDGs). They gave new impetus to global efforts to achieve the SDGs.

Digitization plays a key role in achieving the Sustainable Development Goals set by the United Nations in 2015 (UN, 2015). The 2030 Agenda for Sustainable Development refers to information technologies directly as a goal under Sustainable Development Goal 9 *Building sustainable infrastructure, promoting inclusive and sustainable industrialization and promoting innovation*. In addition, information technologies are mentioned in goals related to climate change, gender equality and women's empowerment, private sector development, education and health, biodiversity, as well as agribusiness (UN, 2015).

The purpose of the research is to investigate the nature of the correlation between indicators of digital development and sustainable development of the European Union countries, as well as to identify policy directions and measures regarding their digital and sustainable progress.

2. Literature Review

Sustainable development is a fundamental goal of the European Union, which is determined in legal acts and strategies. In 2001, the EU Sustainable Development Strategy (SDS) was adopted. The EU, in coordination with its member states, undertakes to support the implementation of the 2030 Agenda. Accordingly, the set of indicators of the EU Sustainable Development Goals (SDG) replaced the EU sustainable development in 2017.

The European Green Deal and the New Circular Economy Action Plan set out an ambitious agenda for an environmental policy, while the Industrial Strategy sets out actions on innovation, investment, standards, fair competition and efforts to reduce barriers to the single market. Together, these initiatives outline the European Commission's strategy for the so-called twin transition − green and digital.

The overall objective of the EU SDS was to identify and develop measures that would enable the EU to achieve a continuous long-term improvement in the quality of life by creating sustainable communities capable of managing and efficiently using resources, capable of exploiting the environmental and social innovation potential of the economy and ultimately capable of ensuring prosperity, protection environment and social cohesion (European Commission, 2001). Sustainability also plays an important role in the next EU strategy, Europe 2020: A European strategy for smart, sustainable and inclusive growth (European Commission, 2010).

The United Nations publishes annual reports that provide a global overview of the current situation with the Sustainable Development Goals. A previous report noted that the Russian-Ukrainian military conflict has caused food, fuel and fertilizer prices to rise, disrupted supply chains and global trade, and caused a crisis in financial markets. Together with the refugee crisis, the effects of the conflict could lead to a global food crisis and deal a significant blow to progress towards achieving the SDG. It is estimated that the war could reduce global economic growth by 0.9 % in 2022 and have implications for aid flows (United Nations, 2022).

Chambers et al defines sustainability as a state of achieved quality of life and protected natural capital. They present four scenarios through consumption/conservation of natural resources (consumption of natural capital) and consumption of quality of life (acceptable/unacceptable). Sustainability (one of the 4 possible scenarios) consists in the connection of an acceptable quality of life with the preservation of natural resources. Through sustainable development, communities can conserve natural resources and the quality of life remains at an acceptable level (Chambers et al., 2000).

Fischer and Amekudzi define that achievement of sustainable development involves stable buildout along the three pillars of consistent progress: environment, economy and society. Environmental sustainability requires the conservation of natural assets, economic sustainability requires maintaining healthy markets through which finance is raised to produce and maintain capital assets: goods that are consumed as well as more permanent goods such as infrastructure systems. Finally, social sustainable development involves the growth and maintenance of quality of life (QoL) for people and communities. The authors also analyzed the role of quality of life in civil infrastructure decision-making and explained the importance of quality of life for sustainable development. (Fischer and Amekudzi, 2011). Drastikhova and Filtzmoser analyzed EU countries for progress in achieving the SDG. The authors used a hierarchical cluster analysis (HCA) to group the countries of the European Union and Norway in four clusters. According to the results of the analysis, Ireland is rated as the country that has made the most progress towards the SDG. Also, great achievement in sustainable development belongs to Slovakia and Hungary (Drastichová and Filzmoser, 2019). Huttmanová E. studied the problem in the countries of the European Union and, based on cluster analysis, identified groups of countries with similar characteristics (Huttmanová E., 2016).

B. J. M. de Vries and A. C. Petersen presented the conceptual basis of sustainability assessment methodology. The basis of sustainability is the connection of the capabilities of society (natural resources plus available technologies) with the subjective experience of well-being. Based on such approach, the authors introduce worldview as a *linchpin between resources (and their conversion to capabilities) on the one hand and individual and collective behavior (as realized capabilities or operations) on the other hand* (B. J. M. de Vries and A. C. Petersen, 2009). Based on worldviews, the authors propose modeling of narratives, i.e. scenarios for a sustainable future.

George et al. (2021) identified six managerial problems of mitigating climate change and advancing sustainability; they are knowledge, evaluation, communication, coordination and trust, access and reach, and institutions.

Many studies focus on digitization and IT development and relate the future of manufacturing to digital progress (Amuso et al., 2019; Bilichenko et al., 2022; Evangelista et al., 2014; Iavorskyi et al., 2020; Hallward-Driemeier, Nayyar, 2018). The authors (Evangelista et al., 2014) proved that digitalization is important for productivity and GDP growth. Nambisan et al. (2019) investigated three issues related to digital development and innovation in entrepreneurship: openness, accessibility, and generativity. The digital development of the Central and Eastern Europe region was discussed by Novak et al (2018).

Yavorskyi et al. provided an assessment of the benefits Ukraine get by joining the EU single digital market. The authors calculate the Digitization Index for Ukraine and EU countries and note that the current level of digital development in Ukraine lags far behind the average level in the EU (Iavorskyi et al., 2020).

The authors (Basu et al., 2012) identify that digital technologies provide new opportunities and create new challenges for export-oriented manufacturing for a wide range of low- and middle-income countries (Basu, et al., 2012).

The authors of the report (University of Cambridge, 2020) identify four new drivers of industrial digitalization in the post-COVID-19 recovery: supply chain transparency, predictability and flexibility; effective reconfiguration of the workspace and personnel tracking; increase in distance work and training; flexibility of business re-engineering processes.

Besides, many scientists compare different countries in their digital progress by putting them into several different groups (Androniceanu et al., 2019; Bilozubenko et al., 2020; Chakravorty, Chaturvedi, 2017; Chen, Wellman, 2004; Milosevic et al., 2018). Such comparisons allow government institutions to track progress in digital development and determine a further strategy.

The authors (Bilozubenko et al, 2020; Evangelista et al, 2014; Milošević et al, 2018; Novak et al, 2018; Pellényi et al, 2020; Polozova et al, 2021) found the difference in digital, social and economic development between different regions of Europe.

Some scholars combine research on digital and sustainable development and draw conclusions about the future prospects of using the digital transition to ensure sustainable development.

Based on the experience of overcoming the COVID-19 pandemic, the key characteristics of competitiveness such as economic digitization and digital skills, security systems and financial reliability, balance between health policy and economic and social policy are defined as key characteristics in the report of the World Economic Forum (World Economic Forum, 2021). Therefore, digital technologies are assigned the role of one of the main factors of ensuring competitiveness. The rating of readiness for economic transformations of the countries is presented as well. Leaders of the ranking are Finland, Denmark, and Sweden.

M. E. Mondejar, R. Avtar and others have analyzed the opportunities that digitalization can provide for building a sustainable society of the future and achieving the sustainable development goals in various sectors: agriculture, biodiversity assessment, clean water, climate change control, energy consumption (M. E. Mondejar , R. Avtar and others, 2021).

The International Institute for Applied Systems Analysis presents the world in 2050 (TWI2050) initiative and focuses on research into six global transformations: workforce and demographics; consumption and production; decarbonization and energy; food, biosphere and water; smart cities; digital revolution.

There are not only benefits of digital tools for sustainable development, but also point to potential negative consequences such as the digital gap, inequality, dysfunctional and weak international organizations are presented in the report (TWI2050, 2019).

Bohnsack et al. summarized intended and unintended consequences of digitization for sustainable development. They noted the following negative consequences of digitalization: information technologies consumes about 10% of the world's energy; digital technologies also raise social and ethical issues such as data privacy and consumer attachment; the dominance of big technologies (e.g. GAFA – Google, Amazon, Facebook, Apple) concentrates enormous power in the hands of a few (Bohnsack, 2021).

Based on theoretical studies, it can be concluded that digital innovations are very sophisticated to ensure the achievement of 17 sustainable development goals defined in (UN, 2015). However, at the moment there is a lack of research on the nature of the correlation between indicators of digital and sustainable development, which increases the relevance of conducting such research. Besides, it might be very significant to develop government strategy concerning the sustainability as well as very important to choose correct measures to ensure digitalization processes and sustainable development of the countries.

2. Data and Methodology

The approach applied in the conducted analysis is presented in Fig. 1. The principal component analysis, geometric aggregation, and cluster analysis are the main methods of the research.

In accordance with the conceptual scheme of the research, the indicators of digital and sustainable development were determined at the first stage. The analysis of theoretical studies allows us to determine two groups of variables (Fig. 2).

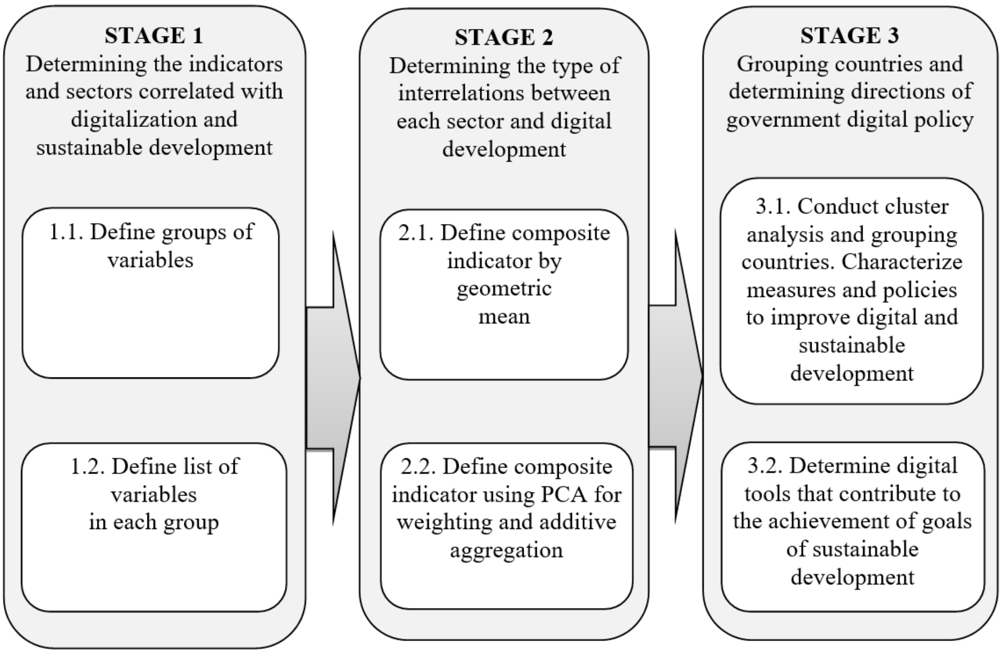


Figure 1. Conceptualization of the research model (designed by the authors)

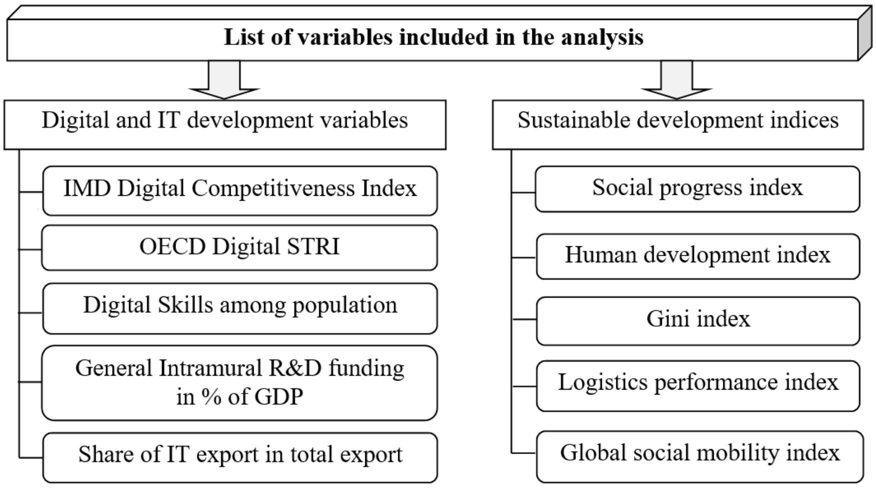


Figure 2. Variables for modeling (designed by the authors)

This study focuses on the following indicators that measure the level of digitalization and development: IMD World Digital Competitiveness Ranking, OECD Digital Services Trade Restrictiveness Index (Digital STRI), Digital Skills Among Population Ranking (World Bank), as well as data on R&D results and the high-tech sector (Eurostat, 2021; State Statistics Service of Ukraine, 2021).

The IMD World Digital Competitiveness Ranking represents the overall ranking of digital development for 2021. Ratings are calculated on the basis of 52 indicators. Ukraine ranks 54th among 64 economies due to the low level of regulatory and legal framework and the low efficiency of the implementation of digital technologies in business processes (IMD, 2021).

The OECD Digital STRI identifies and quantifies constraints and barriers affecting trade in digital services. It provides an evidence-based tool to help identify regulatory bottlenecks, develop policies that promote more competitive and diversified markets for digital commerce, and analyze the impact of policy reforms. For Ukraine, this indicator is higher than for European countries (P. Yavorskyi, S. Taran, etc., 2021).

Sustainable development can be measured by many indicators. The following indices characterizing sustainable development were selected for the study: social progress index, human development index, global social mobility index, Gini index, logistics performance index

The Social Progress Index (SPI) ranks 168 countries on social progress. 53 indicators are used to calculate the overall score. Currently, the Social Progress Index measures the outcomes related to all 17 goals and reflects 131 of the 169 goals. (SPI, 2020)

The Human Development Index (HDI) is a summary measure of average achievement in key aspects of human development: a long and healthy life, knowledge and a decent standard of living (measured by gross national income per capita). (United Nations Development Program, 2021)

Social mobility can be understood as an upward and downward movement in which people see their circumstances become better or worse than those of their parents or during their lifetime. OECD research has shown that intergenerational social mobility tends to be lower in societies with greater inequality (OECD, 2010).

The Gini index calculates the level of income inequality: the higher the index is, the lower the equality becomes. This index measures the degree to which the distribution of income among individuals or households in an economy deviates from a perfectly equal distribution. It measures the area between the Lorentz curve and the hypothetical line of absolute equality, expressed as a percentage of the maximum area under the line.

To build the model, open statistical data from the European Statistical Service, data from a number of rating agencies and international institutions were obtained. The sample countries include European Union countries (with the exception of Malta due to the absence of key indicators, especially the IMD Digital Competitiveness Ranking), as well as the Great Birtain and Ukraine.

Descriptive statistics of the variables are shown in Table 1.

Table 1. Description of variables and descriptive statistics (designed by the authors)

Name	Description	Valid cases	Mean	Min	Max	STD
IMD_DC	IMD Digital Competitiveness Ranking	28	69.56943	49.75100	95.18900	14.14539
Tech	Technology Factor of IMD_DC	28	60.75111	35.39100	86.15800	13.91450
Know	Knowledge Factor of IMD_DC	28	61.25736	41.85700	86.49000	12.66847
Ready	Future Readiness Factor of IMD_DC	28	60.02986	31.39600	92.93600	18.18856
DigSkills	Value of Digital Skills among Population Ranking (World Bank)	28	4.77321	3.72000	5.83000	0.51772
STRI	OECD Digital Service Trade Restriction Index	28	0.14979	0.08300	0.26300	0.04992
$STRI_{new}$	Index of Digital Trade Openness (1-STRI)	28	0.85021	0.73700	0.91700	0.04992
GERD	Intramural R&D Expenditure (GERD) in % of GDP	28	1.81393	0.40000	3.53000	0.93645
IT	Share of IT Sector Export in total export value of the country	28	16.78679	5.78000	51.28000	9.76585
LPI	Logistics Performance Index	28	3.53679	2.81000	4.20000	0.42357
SPI	Social Progress Index	28	86.08357	75.78000	92.26000	4.21345
HDI	Human Development Index	28	0.89396	0.77900	0.95500	0.04340
Gini	Gini Coefficient (World Bank)	28	30.90000	23.20000	40.30000	3.90821
$GINI_{new}$	Modification of Gini Coefficient	28	68.10000	58.70000	75.80000	3.90821
GSM	Global Social Mobility Index by World Economic Forum	28	72.87500	59.80000	85.20000	7.13394

Based on the collected data for the analyzed 28 countries, it is proposed to calculate integral indicators for each group (I_{dig} and I_{sus}) using geometric aggregation.

However, before aggregation, all indicators should be in the same direction, that is, an increase in a single indicator should reflect progress in digital and sustainable development. Due to this, two indicators that do not meet this requirement (STRI and $Gini_{new}$) need to be transformed.

Therefore, the digital trade restrictions indicator (STRI) was transformed into the $STRI_{new}$ digital trade openness indicator based on the methodological explanations of the authors of the index (Ferencz, 2019).

$$STRI_{new} = 1 - STRI\,. \tag{1}$$

The Gini index is modified in a more complex manner. It is used to calculate income inequality that exists between citizens of a certain territory, usually a country. The value of the Gini index ranges from 0 to 1, where zero is maximum equality (all citizens have the same income) and 1 is maximum inequality (all income belongs to the same citizen). To calculate the Gini coefficient, it is necessary to know the nature of the distribution function of aggregate income for certain parts of the population. If this information is unknown, and only information is available about the share Y_k of the distribution of the quantity Y (aggregate income) for the share X_k of the values with the smallest values of the variable Y, then the Gini coefficient can be approximately calculated using Brown's formula:

$$Gini = 1 - \sum_{k=1}^{n} (X_k - X_{k-1}) \cdot (Y_k + Y_{k-1}), \quad (2)$$

where n – the number of referral groups with approximately the same income level;
X_k – share of the population in the k group;
Y_k – share of total income belonging to the population of the k group.
According to Brown, the Gina index can be converted into an indicator for which an increase will indicate a decrease in inequality:

$$Gini_{new} = 1 - Gini = \sum_{k=1}^{n} (X_k - X_{k-1}) \cdot (Y_k + Y_{k-1}). \quad (3)$$

Each indicator for a given country at a given time is calculated as the ratio of the difference between the raw indicator value and the minimum value divided by the range. This method uses the range rather than the standard deviation. All normalized indicators have identical range (0.1) (EU, OECD, 2019).

$$x'_{ij} = \frac{x_{ij} - \min_j}{\max_j - \min_j}, \quad (4)$$

where x_{ij} – the value of the j indicator for the i country;
max_j – the maximum value of the j indicator among all analyzed countries;
min_j – minimum value of the j indicator (theoretical);
x_{ij} – the normalized value of the j indicator for the i country.
Taking into account the transformations of two indicators, the calculation of integral indicators for each group is proposed to be carried out on the basis of the geometric aggregation:

$$I_{dig} = \left(\prod_{j=1}^{m=7} \left(x'_{ij} \right) \right)^{1/m}, \quad (5)$$

$$I_{sus} = \left(\prod_{j=1}^{m=5} \left(x'_{ij} \right) \right)^{1/m}. \quad (6)$$

However, aggregation based on the geometric mean does not give an idea of the correlation between variables within the same group. To study the relationships between variables within the same group, it is suggested to use the method of principal components (PCA).
This method will reveal the correlation between the indicators. New variables, so-called principal components or factors, are formed on the basis of the correlation between the existing original variables. Principal components are new variables that are constructed as linear combinations or mixtures of the original variables. These combinations are performed in such a way that the new variables (i.e., the principal components) are uncorrelated, and most of the information of the original variables is in the first factors.
Principal Component Analysis (PCA) is often used to reduce the size of large data sets by transforming a large set of variables into a smaller one that still contains most of the information that the initial larger set. (L.I. Smith, p. 12).
PCA can be constructed based on correlation or covariance matrices. The authors (Jolliffe I.T., Cadima J., 2016) suggested using the covariance matrix when the variables have the same scales and the correlation matrix when the scales of the variables differ. Due to the descriptive statistics (table 2) showing different scales for different variables, a correlation matrix was chosen. In addition, PCA results based on the correlation matrix are easier to interpret and to analyze. The analysis using the correlation matrix clearly better reveals the structure of the data and the relationships between the variables.
One important question to be answered in PCA is the number of principal components that can ideally represent the entire set of points (variables or cases). Since each eigenvalue of the correlation or covariance matrix is representative of the variance explained by the principal component, the percentage of cumulative variance (explained) can be attributed to a certain number of factors.
To ensure PCA calculations, all raw data must be standardized before computation. Based on PCA, the number of factors is determined. For each i factor, a generalized indicator for the t country is then calculated:

$$F_{it} = \sum_{j=1}^{n} v_{tj} \cdot r_{ij}, \quad (7)$$

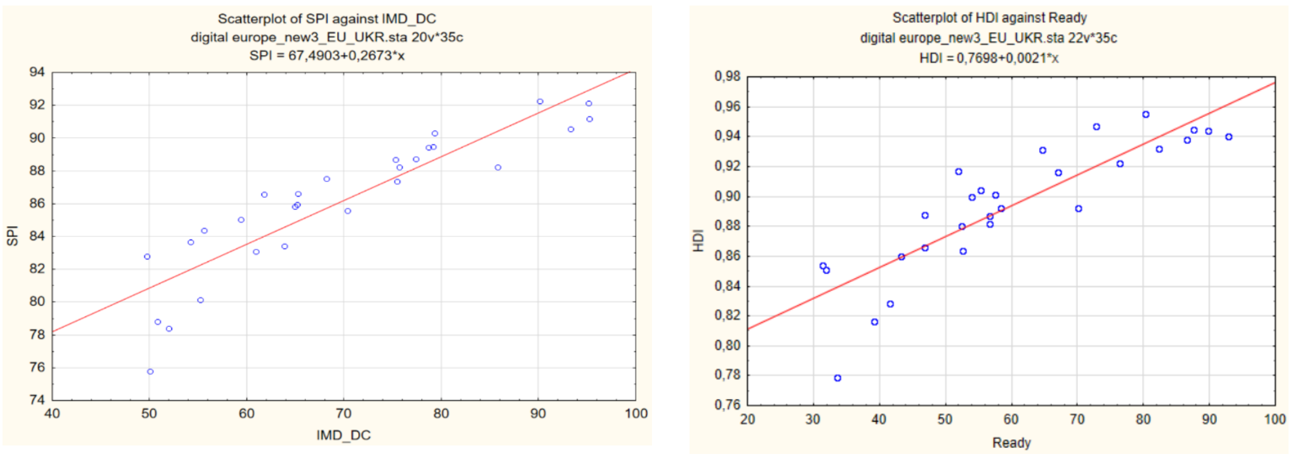
where v_{jt} – the standardized value of the j indicator for the t country;
r_{ij} – the correlation coefficient between the j indicator and the i factor (only those indicators with a correlation coefficient with the factor higher than |0.7| are selected);
n – the number of indicators included in the i factor.
The integral indicator for each group (F_{dig}, F_{sus}) is calculated according to the formula:

$$F_t = \sum_{i=1}^{m} F_{it} \cdot EV_i \quad , \qquad (8)$$

where F_{it} – integral indicator for the t-th country;
EV_i – eigenvalue of the ith factor (eigenvalue).
Given the high quality of available official statistics (Eurostat, OECD, World Bank, World Economic Forum), the prepared sample of data is relevant for analysis. Statistics are prepared systematically, so the methodology can be applied to other periods.
PCA is a popular method in economic research. Drastichová and Filzmoser used PCA to analyze quality of life factors in a sample of 26 EU and OECD countries (Drastichová, Filzmoser 2021). The authors also used PCA in the analysis of EU countries regarding their progress in achieving the SDGs. In the first step, hierarchical cluster analysis was used to create clusters of the analyzed EU countries, after which PCA was applied to determine the prospects of a particular country belonging to a particular cluster, including its progress over time. (Drastichová and Filzmoser, 2019). Mittal P. used PCA to propose an optimal strategy using the analytic hierarchy process for government to improve the delivery of public digital services (Mittal P., 2020).

3. Results

A preliminary analysis of the data of the studied countries proved the existence of a positive correlation between individual indicators characterizing digital and sustainable development (Fig. 3 and Fig. 4).
Thus, there is a significant positive correlation between the index of digital competitiveness (IMD_DC) and the index of social development (SPI). For the analyzed countries, the correlation coefficient comprises 0.89 (Fig. 3a). Indicators of readiness for the future (Ready) and the human development index (HDI) are also positively correlated with a correlation coefficient of 0.86 (Fig. 3b). However, the graphs also show that several countries do not follow the general trend.
Thus, a preliminary analysis of data for 28 European countries (European Union + Ukraine) provides a basis for identifying important conclusions about the existence of correlation between indicators of digital and sustainable development, which should be explored in detail.
Firstly, two integral indicators of digital (I_{dig}) and sustainable development (I_{sus}) were constructed using the data for 28 analyzed countries by the method of geometric aggregation (formulas 4-6) taking into account the transformation of two indicators: STRI (formula 1) and Gini (formula 3) .
The calculation results are shown in Fig. 4.
The integral indicator of sustainable development exceeds the indicator of digital development in all countries. At the same time, the spread of the values of the integral indicator of digital development I_{dig} (from 0.77 to 0.36) is much greater than the spread of the values of the integral indicator of sustainable development I_{sus} (from 0.94 to 0.63). The lower variability of I_{sus} can be explained by the similarity of social policies in the EU countries, which affects the similar level of education, wages, level of rights and freedoms, access to information - components of changes in sustainable development.



a) b)
Figure 3. The correlation between individual indicators of digital development and sustainable development (constructed by authors in Statistica 7.0 software)

For the countries of Northern and Western Europe, the difference between the values of the two integral indicators I_{sus} and I_{dig} is on minimal level, while for the countries of Eastern and Southern Europe, such a difference is quite significant and the largest for the Czech Republic, Poland, and Hungary. As for Ukraine, it has the lowest value of I_{sus} and I_{dig} as Greece has.

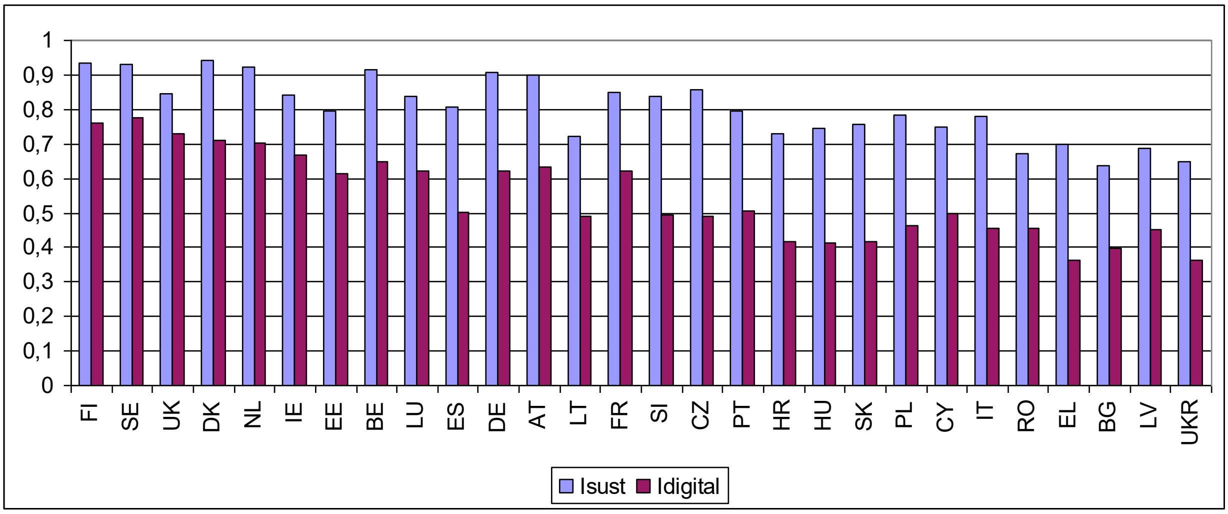


Figure 4. Integrated indicators of digital (I_{dig}) and sustainable development (I_{sus}) based on geometric aggregation (designed by the authors)
Abbreviation used: AU – Austria. BE – Belgium. BG – Bulgaria. HR – Croatia. CY – Republic of Cyprus. CZ – Czech Republic. DK – Denmark. EE – Estonia. FI – Finland. FR – France. DE – Germany. EL – Greece. HU – Hungary. IE – Ireland. IT – Italy. LV – Latvia. LT – Lithuania. LU – Luxembourg. NL – Netherlands. PL – Poland. PT – Portugal. RO – Romania. SK – Slovakia. SL – Slovenia. ES – Spain. SE – Sweden. UK – United Kingdom. UKR – Ukraine.

However, the values of integral indicators do not provide information about the influence of individual indicators on the integral value. In addition, integral indicators do not provide an opportunity to assess the nature of relationships within two groups, and therefore principal component analysis was additionally conducted.
Based on the data (Table 1 and Fig. 2) for 28 European countries (European union + Ukraine), PCA was conducted separately for each group of indicators. Through the PCA procedure, factors (principal components) were identified as combinations of initial variables. It was determined that most indicators are included into the first, most important factor. Table 2 contains the PCA results for the digital and sustainable development indicators separately.

Table 2. Information on factors according to PCA results (calculated by the authors)

Group of variables	Share of total variance, that explained by factor		Eigenvalues of correlation matrix	
	Factor 1	Factor 2	Factor 1	Factor 2
Variables of digital development	62.90	19.14	4.40	1.12
Variables of sustainable development	73.71	16.52	3.68	0.83

One important question to be answered in PCA is the number of principal components that can ideally represent the entire set of initial variables. All factors with eigenvalues greater than 1 were selected. Cumulative variation is an additional parameter. Ideally, it should exceed 80% for all selected factors. Due to the data in Table 2, two factors were selected for the indicators of digital and sustainable development. The share of total variation described by two factors exceeds 82% for two groups of indicators.
In account of the factor loadings (correlations between the indicator and the factor axes), the structure of each factor was determined. The indicators are made out to create determined factors (Table 3).

Table 3. PCA results for two groups of variables (calculated by the authors)

Name	Factor coordinates of variables		Communalities from all factors, based on correlations	Active cases (countries), that provide highest contributions to determining factors (with weighted coefficient in %)	
	Factor1	Factor 2		Factor1	Factor 2
Variables of digital development					
Tech	0.911015	-0.012676	0.830109	Finland (11.9%), Sweden (11.8%), Denmark (11.2%), Netherland (9.9%)	Ireland (21.75%), Luxembourg (17.34%), Austria (12.89%), Slovenia (11.79%)
Know	0.934033	-0.243516	0.931718		
Ready	0.955976	-0.000970	0.913890		
DigSkills	0.882207	0.078822	0.784502		
GERD	0.735841	-0.567116	0.863083		
IT	0.481374	0.640527	0.641995		
$STRI_{new}$	0.484803	0.576245	0.567092		
Variables of sustainable development					
SPI	0.955590	-0.139744	0.932681	Bulgaria (16.6%), Rumania (12.38%), Denmark (8.8%)	Slovakia (29.31%), Slovenia (14.87%), Bulgaria (10.31%)
HDI	0.946114	-0.068071	0.899765		
GSM	0.937507	-0.015551	0.879162		
LPI	0.861634	-0.256826	0.808373		
$Gini_{new}$	0.505825	0.857629	0.991387		

Thus, it was found that most indicators of digital and sustainable development are positively correlated with the Factor 1, having a correlation coefficient close to +1 (Table 3, Fig. 5a). Among the indicators of digital development, five were included in Factor 1, and the export of IT products and the level of openness of digital trade (STRInew) were placed in Factor 2. Among the indicators of sustainable development, only the Gini coefficient determines Factor 2, and the rest of the indicators − Factor 1.

Based on the analysis of Factor coordinates of variables, the following meaningful interpretation can be given to the factors of digital and sustainable development:

a) digital development:

– Factor 1: digital readiness and funding of science (Digital readiness & research funding);

– Factor 2: IT development and openness of trade and services (IT development & trade and service openness).

b) sustainable development:

– Factor 1: social development and logistics (social development and logistics);

– Factor 2: income equality.

In PCA, the community of the indicator (communality) shows what proportion of the variance of the indicator is described by the action of the selected factors (Field, 2013). Table 3 shows that communality is the smallest in the indicators that make up the second factor of digital development: IT and STRI_new: a significant part of the variance of these variables is unique and not related to the action of the first and second factors. For the rest of the variables, the communality indicator exceeds 80%, which indicates that the main part of the variance of the variables is explained by the action of Factor 1 and Factor 2.

Among the analyzed countries, Finland, Sweden, Denmark, and the Netherlands made the largest contribution to the construction of Factor 1 by indicators of digital development, and Ireland worked for Factor 2 (as the country with the highest share of IT products in total exports). According to indicators of sustainable development, the most contribution to the definition of the Factor 1 has been made by Bulgaria, Romania, and Denmark. Slovakia, Slovenia, and have more contribution to Factor 2 (which is fully determined by the transformed $Gini_{new}$ coefficient). Therefore, in the analysis of digital development, the Scandinavian countries acquire special importance, and in the analysis of sustainable development special importance has the countries of Eastern and Central Europe.

The projection of indicators onto factor axes allows presenting the nature of the correlation between individual indicators (Fig. 5). Therefore, indicators of sustainable development (Fig. 5b) have a stronger intercorrelation than indicators of digital development (Fig. 5a). It means that progress on one of the indicators of sustainable development (for example, human capital, quality of logistics processes, social progress, and mobility) is able to significantly increase the level of other indicators. Indicators of sustainable development determining the Factor 1 (GSM, HDI, SPI, and LPI) create a data cloud with a separate position of the $Gini_{new}$ indicator.

Regarding indicators of digital development, the two components of the digital competitiveness index (Tech and Ready) and the level of digital skills (DigSkills) are highly correlated. The Know component and the volume of R&D funding (in % of GDP) of GERD occupy a separate position. The share of exports of the IT sector (IT) and the level of openness of the digital economy (STRInew) occupy a separate position and determine the 2nd factor.

The projection of the analyzed countries on the factor axes provides information on the progress of individual countries in digital and sustainable development (Fig. 6). Thus, the leaders of digital development according to the Factor 1 are the countries of Northern Europe and Great Britain, and according to the Factor 2 - Ireland and Luxembourg (Fig. 6a). Also, the Scandinavian countries lead in the Factor 1 of sustainable development indicators, while Slovakia and Ukraine lead in the Factor 2 (Fig. 6b).

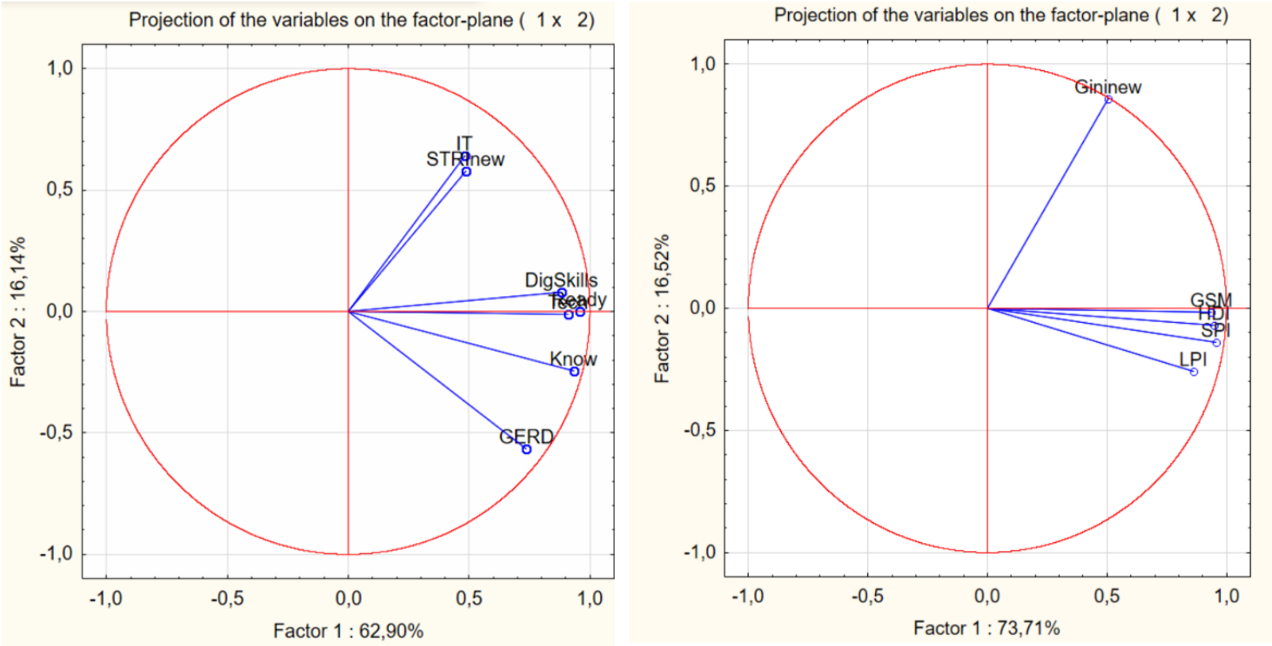
Ukraine is located next to Eastern European countries in terms of digital development, and occupies an isolated position in terms of sustainable development. According to Factor 1 of both groups of indicators, Ukraine has the worst position and lags behind EU countries in the level of digital indices and those of sustainable development. The level of export of IT services of Ukraine Factor 2 corresponds to the average value among EU countries (almost on the coordinate axis). However, according to Factor 2 of sustainable development indicators, Ukraine and Slovakia are leading among EU countries.

Based on PCA, correlation coefficients of individual digital and sustainable development indicators with factor axes were determined (table 3). These data were used as weighting factors for aggregation of indicators within each factor (formula 7) for each country.

At the second stage, the generalized indicators for each of the factors (Factor 1 and Factor 2) are combined into a single integral indicator, respectively, of digital (F_{dig}) and sustainable development (F_{sus}) of the country (Formula 8). Eigenvalues of correlation matrix (eigenvalues of correlation matrix) were used as weighting factors (Table 2). Due to the fact that the integral indicators of F_{dig} and F_{sus} are built on the basis of standardized variable values (as required by the PCA technique), individual values for each country show deviations from the average European level in the direction of increase or decrease.

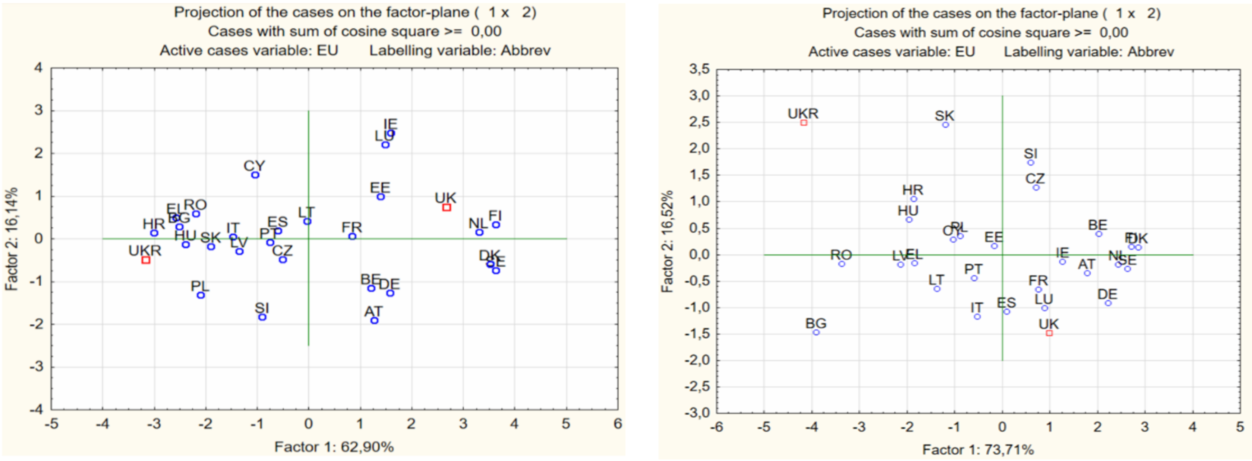
The results of calculating F_{dig} and F_{sus} for the analyzed countries based on PCA results are presented in the Fig. 7.

Northern and Western European countries have indicators of digital and sustainable development above the European average, while the vast majority of Eastern and Southern European countries are below the European average. Some countries (Estonia, Spain, the Czech Republic and Slovakia) have one indicator above the average level and the other one below the average.



a) b)

Figure 5. Projections of variables for (a) digital development and (b) sustainable development on factor axes (designed by the authors)



a) b)

Figure 6. Projections of the analyzed countries on the factor axes of indicators of (a) digital development and (b) sustainable development (designed by the authors)

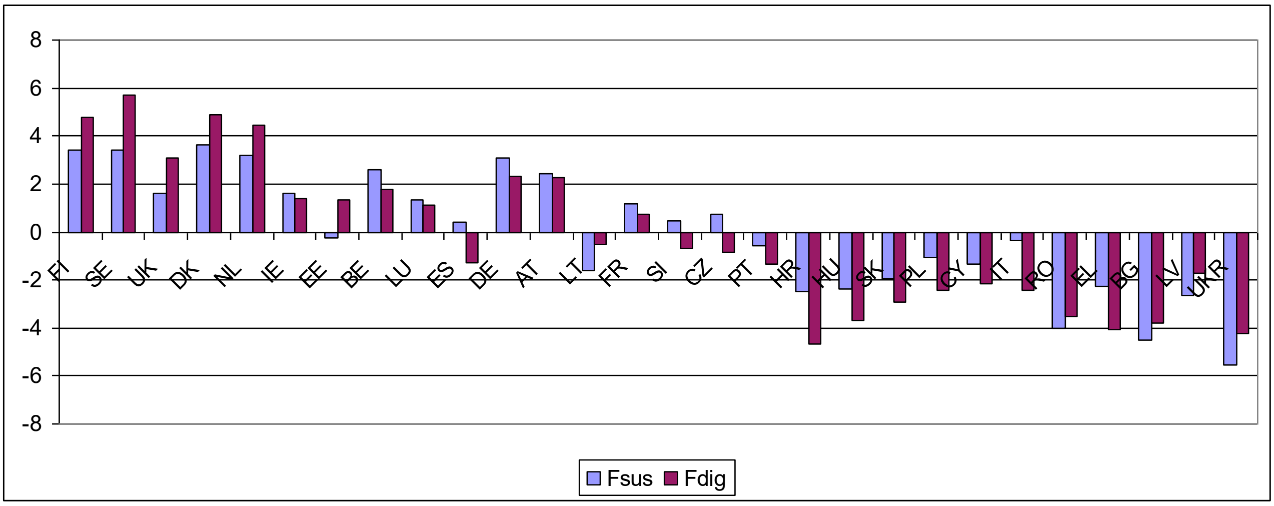
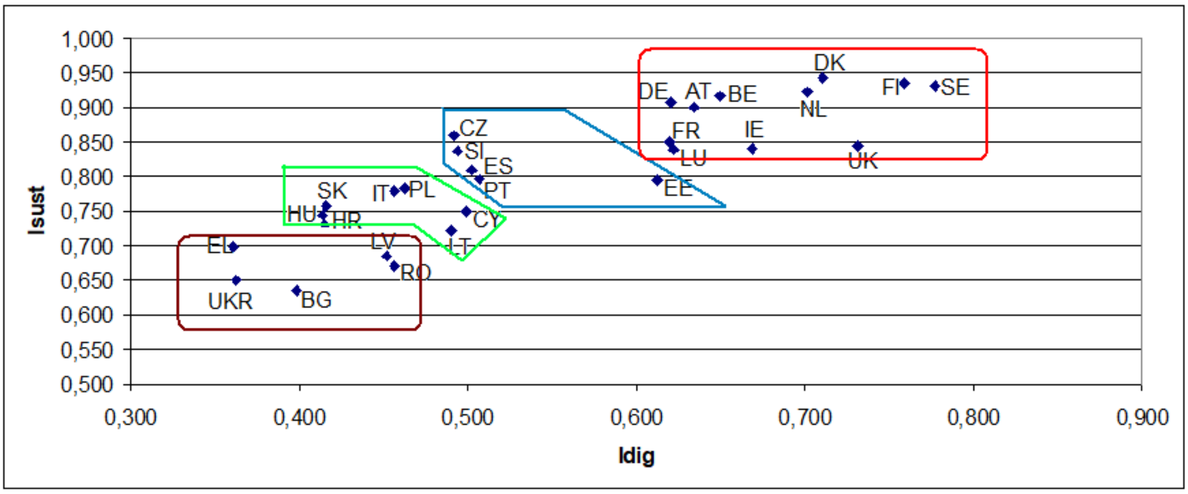


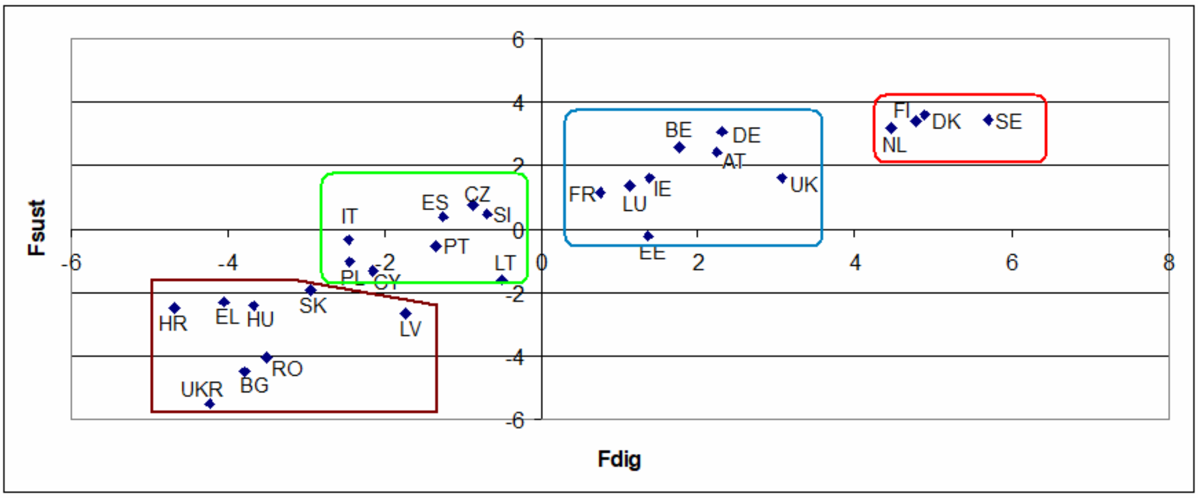
Figure 7. Integrated indicators of digital F_{dig} and sustainable $Fsus$ development based on PCA results (designed by the authors)

The use of PCA made it possible to outline the difference between European countries in terms of digital and sustainable development. Ireland, Estonia, France, Luxembourg, which had high values of indicators of digital and sustainable development (I_{dig}, I_{sus}) based on geometric aggregation (Fig. 4), significantly reduced the levels of indicators when using

PCA (Fig. 7). The indicators for Ireland fell lower than others, because the country's only strong indicator, the share of IT product exports in total exports, was assigned to Factor 2 in the PCA, and Factor 2 has a much lower weight due to a lower eigenvalue.
The results of the formation of integral indicators based on PCA for Ukraine worsened the overall picture and increased the lag behind the EU countries, because the strong indicators, IT and $Gini_{new}$ Index, were included in Factor 2 of a less weight. If the integrated indicator of Ukraine F_{dig} corresponds to the level of most Eastern European countries in terms of the level of digital development, then the indicator of sustainable development for the country F_{sus} is the worst.
Based on the comparison of the calculation results of two pairs of integral indicators of digital (I_{dig}, I_{sus}, Fig. 4) and sustainable development (F_{dig}, F_{sus}, Fig. 7), conclusions can be drawn: the results of the calculation based on PCA are worse than obtained using the geometric aggregation. An analysis of the results of the construction of F_{dig} and F_{sus} shows that for most countries, the negative value of the integral indicator of digital development of F_{dig} does not allow the country to achieve significant progress in the direction of sustainable development. Therefore, the use of PCA made it possible to notice such features of digital and sustainable development in European countries that were not visible when calculating integral indicators based on geometric aggregation.
A cluster analysis (k-means clustering) was performed on the basis of two pairs of integral indicators. Four clusters are identified, within which countries have approximately the same level of indicators of digital and sustainable development (Fig. 8). According to the aggregation based on the geometric mean (Fig. 8a), two clusters-leaders and two clusters that have a significant gap with the leaders are formed. Based on the PCA results (Fig. 8b), two groups of countries with positive values of both indicators and two groups with negative values were formed.
According to the data on Fig. 9, the content of each cluster, according to the two methods of determining integral indicators, coincides with the only exception of Great Britain, according to the second method (using PCA), did not get into the leadership cluster. The leading cluster was formed by the countries of Northern Europe, while the second cluster was sharpened by the countries of Northern and Western Europe. The third and fourth clusters are formed mainly by the countries of Eastern and Southern Europe (as well as Latvia and Lithuania). Ukraine is in the same cluster with Latvia, Romania, Bulgaria, Hungary, Greece, Croatia, and Slovakia.



a)



b)

Figure 8. Cluster analysis results (a) by aggregation based on geometric mean and (b) based on PCA results (designed by the authors)

4. Discussion

The results of constructing integral indicators of digital and sustainable development using two methods and carrying out a cluster analysis made it possible to form 4 clusters of countries with a similar level of digital and sustainable development. The formation of clusters allows defining policies, formulating methodological recommendations to improve the level of indicators in the two defined levels. This will allow policymakers to be oriented around the development of new strategies aimed at the digitalization of society and the economy in the context of sustainable development (Table 4).

Table 4. Cluster analysis results and possible measures to improve digital and sustainable development (designed by authors)

Cluster	Countries included in the cluster		Possible measures / policies to improve digital and sustainable development
	based on geometric aggregation	based on PCA results	
Cluster of Leaders	Sweden, Denmark, Finland, Great Britain, Belgium, Netherlands, Ireland, Austria, France, Germany, Luxembourg	Sweden, Denmark, Finland, The Netherlands	Continuation of the integration of sustainable development plans into technological digital transformation plans Monitoring of the implementation of a double (digital and green) transition (digital and green transition) Support of the existing level of digital skills of the population and a high level of implementation of digital technologies in business
Perspective cluster	Czech Republic, Slovenia, Spain, Portugal, Estonia	Great Britain, Belgium, Ireland, Austria, France, Germany, Luxembourg	Priority of digital sustainability (digital sustainability): implementation of projects on the integration of digital and sustainable development Motivating staff to improve digital education
Follower cluster	Slovakia, Hungary, Croatia, Italy, Poland, Cyprus, Lithuania	Italy, Poland, Cyprus, Lithuania, Spain, Portugal, Czech Republic, Slovenia	Expansion of digital services for business and population. Measures to activate digital entrepreneurship (funding programs, grants, staff training)
Transiting cluster	Greece, Romania, Latvia, Bulgaria, Ukraine	Slovakia, Hungary, Croatia, Greece, Romania, Latvia, Bulgaria, Ukraine	Development and implementation of technological re-equipment projects taking into account the goals of sustainable development Networking with a digital skills company Involvement of broad segments of the population in acquiring digital skills

Table 5. Digital Innovations to Address Sustainable Development Goals (SDGs) (designed by authors based on UN, 2015)

SDG	Digital Innovations to address SDG
1. No poverty	Support of Big Data for SMEs, online education tools, distance learning, new jobs due to e-commerce, increase of digital skills and entrepreneur potential
2. Zero hunger	Remote sensing, robotics, AI, GIS technologies, genomics, bioinformatics, climate smart agriculture, open data and big data
3. Good health and well-being	Online consulting, genomics, bioinformatics, big data and AI, digital monitoring, electronic patient record, e-health.
4. Education quality	Online and distance learning, lifelong learning, web-based sharing, social media networking
5. Gender equality	Eliminating gender digital divide, online safety and confidence, cybersecurity, digital public services, remote work
6. Clean water and sanitation	AI and data mining in water treatment systems, water quality sensing, smart water infrastructure, treatment and delivery
7. Affordable and clean energy	Renewable energy sources management, smart grid integration, digital twin for measuring energy consumption, energy efficiency in industry and transportation, AI in networks fault detection, autonomous control systems.
8. Decent work and economic growth	Remote work, lifelong learning, e-commerce, e-banking, changing of working hours due to automatization, transition of working power from manufacturing to services.
9. Industry, innovation and infrastructure	Industry 4, robotics, cobots, additive manufacturing, smart factory, cyber-physical systems, cloud computing, open and big data, data mining, AI
10. Reduced inequalities	Equal access to digital carrier, mobile Internet connection, online distance learning, social medial, distance learning, lifelong learning, e-banking
11. Sustainable cities and communities	Smart urban mobility, electric and hybrid transport, digital control of roads, smart homes, smart and energy-saved construction and renovation, building energy management systems, 3D printing
12. Responsible consumption and production	Green energy, digital control of water utilization and recycled production, digital ecological control
13. Climate action	Global biodiversity assessment, Digital Earth observation data, big and open data of greenhouse gases, social media to promote climate actions
14. Life below water	Big and open data to monitor biodiversity, automated observation of subsurface temperature, hydro-acoustic and optical sensors, autonomous underwater vehicles
15. Life on land	AI, data mining, cloud computing, big data in estimating of climate changing effects, IoT and sensors, Life monitoring of Earth surface, geospatial information
16. Peace and justice strong institutions	Network governance, cybersecurity, digital public services, digital public procurement tenders, AI and data minima in tax regulation, open data and big data in public services
17. Partnerships for the goals	Network governance, e-government, e-voting, building transforming alliances from local to global level, multi-scalar governance

The results of the cluster analysis also indicate a stable connection between the indicators of digital and sustainable development. All flagships of digital development are also leaders in indicators of sustainable development.
Based on the analysis of theoretical approaches, we identified the main digitalization tools that contribute to the achievement of each of the 17 Sustainable development goals (Table 5).

5. Conclusions

Based on the empirical study, we have come to the following conclusions:

1. Positive correlation is observed within the two groups of indicators of digital and sustainable development. Most indicators of digital and sustainable development are positively correlated with each other. Countries with a high level of digital development have high values of indicators of sustainable development.
2. On the basis of PCA, it was found that indicators of sustainable development have a closer correlation with each other than indicators of digital development. The analysis based on the construction of integral indicators of digital and sustainable development allows conducting a cluster analysis of the countries. Based on the results of the cluster analysis, it is possible to take into account experience of more developed countries in how they have achieved better results and progress in the field of digital and sustainable development.
3. The main digital tools that contribute to the achievement of each of the 17 goals of sustainable development were identified. The experience of the countries of the European Union also provides a suitable platform for comparing these tools, their selection and implementation in the context of digital and sustainable development of Ukraine in the post-war period. The results of the analysis provide a suitable basis for comparing the digital and sustainable development of individual countries and offer opportunities to identify tools that can ensure further improvement.

Further research would be appropriate to conduct additional time series and cover a wider geography.

Acknowledgments

This paper is an outcome of (i) research *Project Ukraine-EU: Digital Innovations making connections 4 changes* 101047751 – EUDI4C (Erasmus Jean Monnet) of the National University of Radio Electronics, Ukraine; (ii) research grant funded by European Federation of Academies of Sciences and Humanities (ALLEA), Linkoping University of Sweden.

References

1. AMUSO V., POLETTI G., MONTIBELLO D., 2019, The Digital Economy: Opportunities and Challenges, *Global Policy*, 11(1): 124-127, https://doi.org/10.1111/1758-5899.12745.
2. ANDRONICEANU A., GEORGESCU I., & KINNUNEN J., 2019, Digitalization Clusters within the European Union, *IBIMA, 33rd IBIMA Conference*. Granada, Spain, 10-11 April: 1321-1331.
3. BASU S., PASCALI L., SCHIANTARELLI F., & SERVEN L., 2012, Productivity and the Welfare of Nations, *NBER Working Paper*, No. 17971, https://doi.org/10.3386/w17971.
4. BENZ S., GONZALES F., 2019, Intra-EEA STRI Database: Methodology and Results, *OECD Trade Policy Papers*, No. 223, https://doi.org/10.1787/2aac6d21- en.
5. BILOZUBENKO V., YATCHUK O., WOLANIN E., SEREDIUK T., KORNEYEV M., 2020, Comparison of the digital economy development parameters in the EU countries in the context of bridging the digital divide, *Problems and Perspectives in Management*, 18(2): 206-218, https://doi.org/10.21511/ppm.18(2).2020.18.
6. BOHNSACK R., BIDMON C.M., & PINKSE J., 2022, Sustainability in the digital age: Intended and unintended consequences of digital technologies for sustainable development, *Business Strategy Environment*, 31: 599-602,
7. https://doi.org/10.1002/bse.2938.
8. CAMBRIDGE UNIVERSITY, 2020, *The role of industrial digitalisation in post-Covid-19 manufacturing recovery diversification and resilience*, https://www.ciip.group.cam.ac.uk/reports-and-articles/role-industrial-digitalisation-post-covid-19-manuf/download/2020-10-08-DigitalBR.pdf (10.02.2023).
9. CHAKRAVORTI B., CHATURVEDI R. S., 2017, *Digital planet: how competitiveness and trust in digital economies vary across the world*, Tufts University, https://sites.tufts.edu/digitalplanet/files/2020/03/Digital_Planet_2017_FINAL.pdf (04.02.2023).
10. CHAMBERS N., SIMMONS C., WACKERNAGEL M., 2000, *Sharing nature's interest. Ecological footprints as an indicator of sustainability*, Earthscan, London.
11. CHEN W., WELLMAN B., 2004, The Global Digital Divide – Within and Between Countries. *IT & Society,* 1(7): 39-45, http://citeseerx.ist.psu.edu/viewdoc/summary. (25.01.2023).
12. COLGLAZIER E.W., 2018, The sustainable development goals: Roadmaps to progress. *Science and Diplomacy* 7(1), March 2018, http://www.sciencediplomacy.org/editorial/2018/sdg-roadmaps (22.01.2023).
13. DRASTICHOVÁ M., FILZMOSER P., 2019, Assessment of Sustainable Development Using Cluster Analysis and Principal Component Analysis, *Problemy Ekorozwoju/ Problems of Sustainable Development*, 14/2: 7-24.
14. DRASTICHOVÁ M., FILZMOSER P., 2021, Factors of quality of life in a group of selected European Union and OECD countries, *Problemy Ekorozwoju/ Problems of Sustainable Development*, 16/2: 75-93, https://doi.org/10.35784/pe.2021.2.09.
15. EVANGELISTA R., GUERRIERI P., MELICIANI V., 2014, The economic impact of digital technologies in Europe. *Economics of Innovation and New Technology,* November, https://doi.org/10.1080/10438599.2014.918438.
16. EUROPEAN COMMISSION, 2010, *Europe 2020: A European strategy for smart, sustainable and inclusive growth,* https://ec.europa.eu/eu2020/pdf/COMPLET%20EN%20BARROSO%20%20%20007%20-%20Europe%202020%20-%20EN%20version.pdf (07.02.2023).

17. EUROPEAN COMMISSION, 2001, *A Sustainable Europe for a Better World: A European Union Strategy for Sustainable Development* (Commission's proposal to the Gothenburg European Council), https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52001DC0264 (07.02.2023).
18. EUROPEAN COMMISSION, OECD, 2019, *Handbook of construction of composite indicators: methodology and users guide*, https://www.oecd.org/sdd/42495745.pdf (25.01.2023).
19. EUROSTAT, 2021, *EU: key economic indicators,* https://ec.europa.eu/eurostat/web/main/data/database (12.02.2023).
20. FERENCZ, J., 2019, The OECD Digital Services Trade Restrictiveness Index, *OECD Trade Policy Papers*, No. 221, https://dx.doi.org/10.1787/16ed2d78-en.
21. FISCHER J. M., ADJO A., 2011, Quality of life, sustainable civil Infrastructure, and sustainable development: Strategically expanding choice, *Journal of Urban Planning and Development*, 137(1): 39-48, https://doi.org/10.1061/(ASCE)UP.1943-5444.0000039.
22. GEORGE G., MERRILL R. K., SCHILLEBEECKX, S. J., 2021, Digital sustainability and entrepreneurship: How digital innovations are helping tackle climate change and sustainable development. *Entrepreneurship Theory and Practice*, *45*(5): 999-1027, https://doi.org/10.1177/1042258719899425.
23. HALLWARD-DRIEMEIER M., NAYYAR G., 2017, *Trouble in the Making?: The Future of Manufacturing-Led Development*. Washington, DC: World Bank. https://openknowledge.worldbank.org/handle/10986/27946. (16.02.2023).
24. HOLLAND S. M., 2019, *Principal Component Analysis* (PCA), http://strata.uga.edu/8370/handouts/pcaTutorial.pdf (18.02.2023).
25. HUTTMANOVÁ E., 2016, Sustainable Development and Sustainability Management in the European Union Countries, *European Journal of Sustainable Development* 5(4): 475-482, https://doi.org/10.14207/ejsd.2016.v5n4p475.
26. IAVORSKYI P., TARAN S., SHEPOTYLO O., HAMANIUK O., 2020, Ukraine's Integration into the EU's digital single market: potential economic benefits. Analytical report, *Ministry of Digital Transformation of Ukraine,* https://ucep.org.ua/wp-content/uploads/2021/02/dig_ukraine_eu_ENG-_2_WEB.pdf (11.02.2023).
27. IMD WORLD COMPETITIVENESS CENTER, 2022, *World Digital Competitiveness Ranking,* December, 2022, https://www.imd.org/centers/world-competitiveness-center/rankings/world-digital-competitiveness/ (15.02.2023).
28. JOLLIFFE I. T., CADIMA J., 2016, Principal component analysis: a review and recent developments, *Philisophical Transactions of the Royal Society A,* 374(2065), https://doi.org/10.1098/rsta.2015.0202.
29. KOLUPAIEVA I. V., GAVKALOVA N. L., BARKA Z., 2017, Analysis of leverages' efficiency in the context of state regulatory policy implementation, *Economic Annals-XXI*, 165(5-6): 41-46, https://doi.org/10.21003/ea.V165-09.
30. MONDEJAR M. E., AVTAR R., DIAZ H. L. B., DUBEY R. K., ESTEBAN J., GOMEZ-MORALES A., HALLAM B., MBUNGU N. T., OKOLO C. C., PRASAD K. A., SHE Q., GARCIA-SEGURA S., 2021, Digitalization to achieve sustainable development goals: Steps towards a Smart Green Planet, *Science of The Total Environment*, 794: 148539, https://doi.org/10.1016/j.scitotenv.2021.148539.
31. MILOŠEVIĆ N., DOBROTA M., BARJAKTAROVIC-RAKOCEVIC S., 2018, Digital economy in Europe: Evaluation of countries' performances. *Zbornik Radova Ekonomskog Fakultet au Rijeci*, 36(2): 861-880, https://doi.org/10.18045/zbefri.2018.2.861.
32. MITTAL P., 2020, A multi-criterion decision analysis based on PCA for analyzing the digital technology skills in the effectiveness of government services, *2020 International Conference on Decision Aid Sciences and Application (DASA)*, 2020: 490-494, https://doi.org/10.1109/DASA51403.2020.9317241.
33. NAMBISAN S., WRIGHT M., FELDMAN M., 2019, The digital transformation of innovation and entrepreneurship: Progress, challenges and key themes. *Research Policy*, 48(8): 1-9, https://doi.org/10.1016/j.respol.2019.03.018.
34. NOVAK J., PURTA M., MARCINIAK M., IGNATOWICZ K., ROZENBAUM K., YEARWOOD K., 2018, *The rise of Digital Challengers – how digitization can become the next growth engine for Central and Eastern Europe*. McKinsey & Company, https://digitalchallengers.mckinsey.com/ (22.02.2023).
35. OECD, 2022, *Digital Services Trade Restrictiveness Index*, https://stats.oecd.org/Index.aspx?DataSetCode=STRI_DIGITAL (25.02.2023)
36. PELLÉNYI G. M., 2020, The Role of Central & Eastern Europe in Global Value Chains: Evidence from Occupation-Level Employment Data, *European Economy Economic Brief,* 062, https://ec.europa.eu/info/publications/economic-and-financial-affairs-publications_en. (18.02.2023).
37. POLOZOVA T., KOLUPAIEVA I., SHEIKO I., 2021, Digital Gap in EU Countries and its Impact on Labour Productivity and Global Competitiveness., *Hradec Economic Days*, University of Hradec, Králové. part 1, 2021: 569-570,
38. https://doi.org/10.36689/uhk/hed/2021-01-065.
39. POLOZOVA T., KUTSENKO YU., KANOVA O., 2022, Formation of Sustainable Investment Attractiveness of Regions Under the Conditions of COVID-19, *Problemy Ekorozwoju/ Problems of Sustainable Development*, 17(1): 16-22,
40. https://doi.org/10.35784/pe.2022.1.03.
41. SMITH L. I., *A tutorial on Principal Components Analysis,* http://www.iro.umontreal.ca/~pift6080/H09/documents/papers/pca_tutorial.pdf (12.02.2023).
42. SOCIAL PROGRESS IMPERATIVE, 2021, *Social Progress Index*, https://www.socialprogress.org/index/global/results (05.03.2023).
43. SOCIAL PROGRESS IMPERATIVE, 2021, *The Contribution of Social Progress Index to the 2030 Agenda,* https://www.socialprogress.org/about-us/sdgs (05.03.2023).
44. TWI2050 – The World in 2050, 2019, *The Digital Revolution and Sustainable Development: Opportunities and Challenges*. Report prepared by The World in 2050 initiative. International Institute for Applied Systems Analysis (IIASA), Luxembourg, Austria, https://www.idos-research.de/uploads/media/TWI2050-for-web.pdf (11.02.2023).
45. UNITED NATIONS, 2015, *Transforming our world: the 2030 Agenda for Sustainability Development,* https://sustainabledevelopment.un.org/content/documents/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf (12.01.2023).
46. UNITED NATIONS DEVELOPMENT PROGRAMME, 2021, *Human Development Index,* https://hdr.undp.org/data-center/human-development-index?utm_source=EN&utm_medium=GSR&utm_content=US_UNDP_PaidSearch_Brand_English&utm_campaign=CENTRAL&c_src=CENTRAL&c_src2=GSR&gclid=CjwKCAjwlqOXBhBqEiwA-hhitKBUKD6xDDo4eeU10R6dFztGJCd6nsafa7jwd_8M_9MDHijpHUEMKxoCah0QAvD_BwE#/indicies/HDI (06.03.2023).

47. UNITED NATIONS, 2022, *Economic and Social Council Progress towards the Sustainable Development Goals*, Advance unedited version (Working paper), https://sustainabledevelopment.un.org/content/documents/29858SG_SDG_Progress_Report_2022.pdf (12.02.2023).
48. de VRIES B., PETERSON A., 2009, Conceptualizing sustainable development: An assessment methodology connecting values, knowledge, worldviews and scenarios, *Ecological Economics*, 68: 106-1019, https://doi.org/10.1016/j.ecolecon.2008.11.015.
49. WORLD BANK, 2018, *Aggregated Logistic Performance Index* [Data set]. Retrieved December 01, 2021, https://lpi.worldbank.org/international/aggregated-ranking. (04.03.2023).
50. WORLD ECONOMIC FORUM (WEF), 2021, *Digital skills among population ranking (in Global Competitiveness index),* https://tcdata360.worldbank.org/indicators/hb0649ed2?country=BRA&indicator=41400&countries=NLD&viz=line_chart&years=2017,2019. (23.02.2023).
51. WORLD ECONOMIC FORUM, 2020, *Global Social mobility report 2020: equality, opportunity and a new economic imperative*, https://www3.weforum.org/docs/Global_Social_Mobility_Report.pdf (26.02.2023).