Relationship between the DESI and the SDG index in the European Union with a special focus on the Visegrad Group countries

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Promoting digitalisation and sustainability has been identified to be a key challenge and priority among countries worldwide. Recent phenomena such as Covid-19, extreme weather events and energy and economic crises have received increased interest from academics and practitioners of these two fields. This study contributes to the better understanding of the links between digitalisation and sustainability. As many indicators exist for measuring both fields, it provides a literature review on the critical assessment of these metrics. Accordingly, two composite indices, namely, the European Union (EU)'s digital economy and society index (DESI) and the sustainable development goals index (SDG index), have been selected for examining the links between digitalisation and sustainability at the level of the EU member states, focusing on the Visegrad Group (V4) countries. The statistical methods used are correlation analysis and hierarchical clustering. The novelty value of this study is that the analysis focuses on the composite indices and – considering their complexity – on their sub-indices (4 of the DESI and 17 of the SDG index). The results determine that the V4 countries are rather behind the average in terms of digitalisation and around the average in terms of sustainability based on the indices analysed. Numerous relationships were noted between different dimensions of digitalisation and sustainability. Correlation analysis has shown that these relationships are mostly positive, but there are also negative ones (between different dimensions of digitalisation and

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responsible consumption and production as well as climate action in the field of sustainability). This finding indicates that digitalisation itself cannot be a guarantee to address all sustainability-related issues, thus requiring a more complex approach. The cluster analysis has shown that V4 countries share several similarities related to their performance in digitalisation and sustainability. Regarding the complex relationship between the dimensions of digitalisation and sustainability, a wide range of pathways can be suggested for its development, including policymaking, company initiatives and individual actions. This diversity and the formerly mentioned controversial links between the two indices urge for complex approaches to achieve development in both fields.

Keywords:
digitalisation,
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sustainable development goals index,
European Union,
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Introduction

Digitalisation plays a crucial role in today's globalised world, including within the European Union (EU). It has revolutionised various aspects of our lives, such as communication, commerce and governance. In the EU, digitalisation has enhanced cross-border trade and economic integration, facilitating the free movement of goods, services and data. Moreover, it has spurred innovation, creating opportunities for startups and businesses to scale up and compete in the global market (Almeida et al. 2020, Thrassou et al. 2020) and has fostered collaboration and connectivity among EU member states, enabling efficient coordination of policies, sharing of knowledge and addressing common challenges. Furthermore, the information and communication technology (ICT) sector has shown intensive growth in the last decades, which was followed by an increasing awareness of the sector's potential relation to sustainability. Digital technologies have become part of our everyday lives; in fact, they now play an important role in the global economy, competitiveness and well-being. The Covid-19 pandemic has boosted connectivity, as digital infrastructure and services became essential during the lockdown.

The EU's Digital Decade policy programme (DDPP 2022) aims to accelerate the digital transformation of the european economy and society over the next 10 years, building on the four principles of the EU 2030 Digital Compass (EC 2021). These

include digital skills, secure infrastructure including connectivity, digital transformation of businesses and online public services, which are in line with the EU's digital rights and principles.

Sustainability plays a central and growing role in the global and EU agenda and policies, and the EU has long been committed to promoting sustainable development, recognising that economic goals must go hand in hand with environmental protection and social progress (Baker 2007). The EU and its member states have been active for a long time in setting ambitious goals to tackle climate change and reduce greenhouse gas emissions (e.g. the Kyoto Protocol or the Paris Agreement). The EU's landmark initiative, that is, the European Green Deal, aims to make Europe the first climate-neutral continent by 2050 (Eckert–Kovalevska 2021). Focusing on the social aspects of sustainability, EU policies are aimed at creating inclusive societies and ensuring fair and equitable opportunities for all (Hacker 2019), similar to the European Pillar of Social Rights (Garben 2019). On the economic side, the EU has taken steps to integrate sustainability considerations into its financial system. Furthermore, the EU's Sustainable Finance Action Plan aims to mobilise private capital for sustainable investments and encourage transparency and disclosure of environmental and social risks by financial institutions (Rant 2022). As part of this action plan, the EU Taxonomy aims to help investors, companies and policymakers identify the economic activities that can be considered environmentally sustainable. Beyond voluntary sustainability reporting (Harangozó 2008, Szennay et al. 2019), the Corporate Sustainability Reporting Directive requires large companies and listed small- and medium-sized enterprises (SMEs) to establish a harmonised set of rules for sustainability reporting.

Extensive research exists measuring the complexity and different aspects of digitalisation and sustainability. The links between the two spheres are manifold; however, how digitalisation can contribute to sustainable development remains unclear. Digital technologies are recognised as important tools for achieving the United Nation's sustainable development goals (UN SDGs). The report of the High-level Panel on Digital Cooperation even stated that of the 17 SDGs and 169 targets, not a single one is detached to the impacts and potential of digitalisation. Efficient and affordable digital infrastructure and services help countries to engage in the digital economy, boost their economic competitiveness and enhance social well-being. In addition to its complexity, the lack of harmonised methodologies and standardised metrics makes it challenging to measure the impact of digitalisation on different sectors and countries as well.

This paper intends to contribute to this stream by analysing the links between the digital economy and society index (DESI) of the EU and the sustainable development goals (SDG) index, which are two widely spread indices in the two domains. Research has already been done to determine the statistical relationship between the DESI and the SDG indices; however, these mostly focused on the overall relationship, and

analysis at the level of the sub-indices is mostly disregarded; thus, this research also addresses their deeper relationships. This study analyses the EU member states, with a special focus on the Visegrad Group (V4) countries (Czech Republic, Hungary, Poland and Slovakia, for countries with relatively similar historic and cultural roots). Although both digitalisation and sustainability are of key importance in these countries, this study demonstrated that they perform somewhat below average within the EU, with regard to both the DESI dimensions and the SDG sub-indices. As Ionescu-Feleagă et al. (2023) highlighted, the link between the main indices (DESI and SDG index) is positive but seems to be somewhat weaker in Eastern Europe compared to the western and northern parts of the EU. This consideration also supports the relevance of a deeper analysis between the two indices for the V4 countries, with a special focus on the sub-indices as well.

The rest of the paper is structured as follows. A literature review is provided of the major approaches used to measure digitalisation, sustainability and the link between the two fields, positioning the link between the DESI and SDG index into a broader framework. Then the data sources and the methods are introduced. The next section presents and analyses the results. After this the findings from different perspectives (policy, business and individual level) are discussed. The study ends with the conclusions.

Literature review

Measuring digitalisation

Measuring and monitoring digital development and following the progress of digital economies can be extremely challenging due to the ICT sector's complexity and rapidly changing nature. Digital development can be characterised by a wide range of indicators; however, collecting quality and comparable data and finding the appropriate methodology can be challenging. The digital sector is constantly changing and evolving while new technologies and platforms are emerging. Addressing the arising challenges at policy level requires collaboration among international organisations, governments, researchers and other stakeholders to improve data collection processes and establish harmonised methodologies for measuring and monitoring the impact of digital technologies and services.

According to the Organisation for Economic Co-operation and Development (OECD) paper assessing the national digital strategies and their governance, countries with available data are monitoring progress in implementing their national digital strategies (Gierten–Lesher 2022). Furthermore, several countries use international metrics and scoreboards to measure national progress towards the policy objectives set out in these strategies. However, the metrics used vary, and therefore, the direct comparison can be challenging. To overcome this issue, the OECD paper proposes

a composite index, that is, the national digital strategy comprehensiveness, to assess the national digital strategies.

The International Telecommunication Union's (ITU) (2022) database, also known as the World Telecommunication/ICT indicators database, is a comprehensive collection of telecommunication and ICT statistics. It includes annual time series data (starting from 1975), encompassing over 180 statistics, covering wide range of topics such as fixed telephone networks, mobile cellular telephone subscriptions, quality of service, Internet usage, traffic, staff, prices, revenue, investment and statistics related to ICT access and usage by households and individuals. Moreover, the database includes selected demographic, macroeconomic and broadcasting statistics. However, due to the ITU's reliance on official economy data, the availability of data for different indicators and years may differ.

The issue of the ITU's ICT development index (IDI) shows the complexity of measuring digital economy or digital development among countries. The IDI was published from 2009 to 2017, combining 11 indicators into a single score into a composite score. However, following the shift from 11 to 14 indicators in 2018, countries were facing challenges in terms of collecting and submitting quality data. Furthermore, concerns arose regarding the harmonisation and quality of the data and the methodology used to calculate some of the newly introduced indicators. Consequently, creating a methodologically robust index that accurately described the state of the digital development of countries was not possible. Currently, the ITU is working on adopting a new IDI methodology with the aim to launch the new IDI in 2023, as stated in ITU Resolution 131 (2022).

The network readiness index (NRI) was developed by the World Economic Forum in collaboration with various partners in 2002 and was redesigned in 2019. It evaluates the performance of 131 countries based on their readiness to use digital technologies for social and economic benefits. The NRI comprises 58 indicators that cover 4 dimensions-technology, people, governance and impact and society. Moreover, it covers various fields in terms of digital development from new technologies, such as artificial intelligence, robotics and internet of things, to the role of digital transformation in achieving the SDGs.

In the EU, the European Commission has been monitoring the digital development of EU member states since 2014. The results of this exercise are published in the DESI annually (EC 2022). The DESI is a comprehensive index that incorporates relevant indicators to reflect the EU digital objectives. Furthermore, it summarises indicators on the EU's digital performance and tracks the progress of EU countries. It includes four key dimensions: (1) Human capital monitors 'Internet user skills' of citizens and 'advanced skills' of specialists and development of enterprises across the EU. (2) Connectivity dimension monitors connectivity by measuring supply and demand sides of fixed and mobile broadband. (3) Integration of digital technology monitors the integration of new technologies in businesses and

e-commerce. (4) Digital public services dimension monitors the indicators of digital public services in the EU to ensure citizens and governments are enjoying the full potential of this technology. Moreover, unlike any other previously mentioned indicator, the DESI aims to monitor the digital development of the EU member states.

Recent literature also examined the structure and consistency of DESI. Tarjáni et al. (2022) analysed the dimensions of I-DESI, which is the international DESI, using multivariate statistical methods and concluded that a close link exists between the dimensions, and the difference between EU and non-EU states is not significant. Bánhidi–Dobos (2020) systematically investigated the DESI dimensions using different statistical methods, and their result revealed that the DESI dimensions are interconnected and contribute together to digital development. Further, they used the DESI dimensions for a different analysis (Bánhidi–Dobos 2021), where they created a subjective ranking method using DEA-type composite indicators and TOPSIS methods, wherein they concluded that Hungary could be considered as a medium performer among the EU member states.

Measuring sustainability

Efforts to measure sustainability have been long on the agenda of both academics and policymakers. There is a labyrinth of indicators available, with the major streams as follows.

One stream of indicators has emerged based on the shortcomings of the GDP as a comprehensive indicator. GDP was developed and proposed by Kuznets (1934) to measure the added value of the economy. For this purpose, this, for many decades, has been a very effective and widely spread indicator. However, it has many well-known shortcomings, especially when decision makers consider it as an overall welfare or even a sustainability indicator (Stiglitz et al. 2009, Csutora et al. 2021) such as disregarding inequality, non-market services, other than economic factors etc. Van den Bergh (2010) criticised GDP for failing to cover climate change impacts of the economy. Stockhammer et al. (1997) specifically highlight that GDP often disregards environmental harms, but the recovery of an environmental accident (most probably not a full restoration of the original state) may even contribute to the growth of GDP. Daly (2013) demonstrates that only monetisable market transactions are considered in GDP, while environmental degradation (or recovery) has rarely such characteristics.

To overcome these deficiencies, several alternative indicators based on the GDP have been developed over time. The net economic welfare (Samuelson 1973) indicator extends GDP with several aspects, such as non-market work activities, the value of free time and the value of the environment. Similar indicators (extended with further factors) are the index of sustainable economic welfare (ISEW) (Daly–Cobb

1989) and the genuine progress indicator (Cobb et al. 1995). The human development index (HDI) (UNDP 1990) initiated by the UN is a composite index and considers the per capita GDP, life expectancy and the level of education. The first three indicators are deemed sophisticated; however, due to their comprehensive data need (not available in most countries), these are not used in practice. The HDI is widely used as an official statistical indicator (including all member states of the V4) but disregards various important aspects of sustainability.

Several further indicators and indices intend to directly address different aspects of sustainability. The Gini coefficient addresses inequality (Gini 1912), whereas the gender empowerment measure (Kerekes 2005) addresses participation and involvement of both genders in the economy and the society. The ecological footprint (EF) (Rees 1992) is a widely spread indicator, which measures natural resource use, intended to quantify the use of natural resources by a population (or other defined territorial unit or even a company or individual) living in a given area. Moreover, it is widely used in practice and the V4 countries. The environmental performance index (Hsu–Zomer 2014) and the related global green economy index were developed by the Yale University and are composite indices containing over hundred different indicators, all based on goals related to international environmental commitments. The indicators in this stream are useful measures; however, they focus on one major aspect and yet to provide a complex view of our efforts towards sustainability (e.g. economic, social and environmental aspects).

Figure 1

The 17 UN sustainable development goals

Source: UN 2015.

A comprehensive approach for measuring sustainability is the SDG index, based on the UN sustainable development goals. In 2015, the UN formulated the 17 SDGs with further targets; they present a widely accepted and comprehensive set of goals covering the main aspects of sustainability (as summarised by Figure 1).

The SDG index (Sachs et al. 2022, Radácsi–Szigeti 2024) is a composite indicator that covers all the 17 SDGs with measurable indicators with available data for most countries. The SDG index is used in the Sustainable Development Report, which has been published by the Sustainable Development Solutions Network since 2016.

The link between digitalisation and sustainability

Considering the diversity of how to measure digitalisation and sustainability, this subsection focuses on the links between the DESI and the SDGs (or more specifically the SDG index). Although both indices are comprehensive and widely used in practice, limited literature exists on their relationship. Imran et al. (2022) investigated the direct impact of DESI dimensions on the SDG index using panel regression modelling, determining that the standard views on the impact of digitalisation are not true in every case and that the impact of the digital technology on sustainable development is not always positive. Furthermore, the results of Ionescu-Feleagă et al. (2023) support a positive relationship between the overall DESI and SDG index in the EU, for the period before and during the Covid-19 pandemic. Their findings indicate a relatively weaker link in the central and eastern parts of the region, adding a special relevance to the more in-depth analysis in the field for the Visegrad countries. Esses et al. (2021) have also examined the relationship between digitalisation and sustainable development in the V4 countries, concluding that a strong relationship exists between sustainability and digitalisation. Jovanovic et al. (2018) investigated the correlation between the DESI and other indices measuring sustainable development and highlighted that digitalisation plays an important role in society's sustainable development. Esses–Szalmáné Csete (2022) examined the relationship between the digital transformation and sustainable transition in the EU capitals and concluded that digitalisation and sustainable development are significantly and positively correlated.

Existing literature seems to focus on the SDG index as one, even comprehensive, index and disregards the heterogeneity of its different sub-indices. Thus, in this study, we aim to contribute to the better understanding on how DESI and its dimensions are related to different sub-indices of the SDG index.

Materials and methods

Data sources

The DESI has a three-level structure, including four dimensions (human capital, connectivity, integration of digital technology and digital public services); altogether,

it has 10 sub-dimensions and 32 indicators. Each indicator is normalised and scaled between 0 and 1 in most cases (there are several exemptions, where the minimum is bigger than 0 or the maximum is smaller than 1) where the minimum is the worst and the maximum is the best. The annual datasets of the DESI are complete and reliable for the 27 member states. Data collection and verification are carried out mainly by the national statistical offices in co-operation with the Eurostat and the Communications Committee (COCOM). The weights of the indicators within the sub-dimensions and the sub-dimensions within the dimensions are different, but the weight of the four dimensions within the whole DESI are deemed equal (EC 2022).

The SDG index is an assessment of each country's overall performance on the 17 UN SDGs. In the 2022 index (Sachs et al. 2022), there are 94 global indicators and 26 further indicators, which are quantified only for OECD countries. Indicators are always scaled between 0 and 100, where 0 is the worst and 100 is the best. The sub-indices along the 17 UN SDGs are calculated as the arithmetic mean of the respective indicators with equal weight for each. The final SDG index results again as the arithmetic mean of the 17 SDG-specific sub-indices (with equal weight also). The data used for the SDG index comes from official statistics (World Bank, WHO, UN, see Sachs et al. 2022) and from non-traditional statistics, including research centres, universities and non-governmental organisations.

Methods

Quantitative methods were applied for the analysis. First, country ranking is presented and analysed based on DESI and SDG index, including their first-tier sub-indices as well, specifically focusing on Hungary and its relationship to peer V4 countries.

Subsequently, correlation analysis was conducted between the main indices and their first-tier sub-indices (the 4 dimensions of the DESI and 17 UN SDG-related sub-indices of the SDG index). The added value of that section is that most analyses carried out earlier (see the literature review section) did not focus on the relationship of the sub-dimensions, although this can underscore important links often overlooked when complex, composite indices are compared. Furthermore, principal component analysis was applied to better understand the interrelationship between variables (sub-indices of both DESI and the SDG index).

Finally, cluster analysis was applied to better understand similarities and differences between the 27 EU countries in terms of the DESI and the SDG index.

Results

The country ranking of EU member countries along the composite DESI and its dimensions is summarised in Table 1.

Table 1

DESI scores and ranking of EU member states in 2022

Rank	DESI overall		Human capital		Connectivity	
1	Finland	69.6	Finland	71.4	Denmark	77.1
2	Denmark	69.3	Netherlands	63.1	Netherlands	70.1
3	Netherlands	67.4	Ireland	62.6	Spain	69.7
4	Sweden	65.2	Sweden	62.0	Germany	67.3
5	Ireland	62.7	Denmark	59.2	France	64.2
6	Malta	60.9	Luxembourg	57.8	Ireland	61,5
7	Spain	60.8	Malta	56.6	Italy	61.2
8	Luxembourg	58.9	Estonia	53.9	Finland	60.5
9	Estonia	56.5	Croatia	51.8	Sweden	60.3
10	Austria	54.7	Spain	51.3	Slovenia	59.9
11	Slovenia	53.4	Austria	51.0	Luxembourg	59.3
12	France	53.3	France	49.9	Cyprus	58.8
13	Germany	52.9	Belgium	48.7	Hungary	57.6
14	Lithuania	52.7	Portugal	45.9	Austria	56.5
15	Portugal	50.8	Czech Republic	45.6	Romania	55.2
16	Belgium	50.3	Germany	45.0	Malta	53.0
17	Latvia	49.7	Slovenia	44.3	Czech Republic	52.7
18	Italy	49.3	Latvia	44.1	Portugal	51.6
19	Czech Republic	49.1	Slovakia	44.1	Bulgaria	50.7
20	Cyprus	48.4	Lithuania	42.5	Latvia	50.1
21	Croatia	47.5	Cyprus	41.8	Slovakia	49.8
22	Hungary	43.8	Greece	40.1	Greece	49.6
23	Slovakia	43.4	Hungary	38.4	Lithuania	49.4
24	Poland	40.5	Poland	37.0	Croatia	48.1
25	Greece	38.9	Italy	36.6	Poland	46.5
26	Bulgaria	37.7	Bulgaria	32.6	Estonia	44.4
27	Romania	30.6	Romania	30.9	Belgium	39.8

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Rank	Integration of digital technology		Digital public services	
1	Finland	59.1	Estonia	91.2
2	Denmark	58.0	Finland	87.4
3	Sweden	56.2	Malta	85.8
4	Netherlands	52.1	Netherlands	84.2
5	Malta	48.1	Spain	83.5
6	Belgium	48.0	Ireland	83.5
7	Ireland	43.3	Luxembourg	83.4
8	Italy	40.7	Denmark	83.1
9	Slovenia	39.8	Sweden	82.4
10	Austria	39.2	Lithuania	81.8
11	Spain	38.5	Latvia	78.8
12	Portugal	37.6	Austria	72.1
13	Lithuania	37.2	Slovenia	69.5
14	Croatia	36.7	Portugal	67.9
15	Estonia	36.5	France	67.4
16	Germany	35.8	Belgium	64.8
17	Cyprus	35.3	Czech Republic	64.5
18	Luxembourg	35.0	Germany	63.4
19	Czech Republic	33.8	Italy	58.5
20	France	31.9	Cyprus	57.5
21	Slovakia	27.8	Hungary	57.4
22	Greece	26.6	Poland	55.8
23	Latvia	25.8	Croatia	53.6
24	Poland	22.9	Slovakia	52.0
25	Hungary	21.6	Bulgaria	51.9
26	Bulgaria	15.5	Greece	39.4
27	Romania	15.2	Romania	21.0

Source: own compilation based on the raw data of the EC 2022.

In terms of the overall DESI, the Nordic countries are the top performers together with the Netherlands. These countries are also ranked high in each dimension of the DESI. Meanwhile, the V4 countries perform below average in the overall DESI (the Czech Republic is ranked 19th, Hungary 22nd, the Slovakia 23rd while Poland 24th). Hungary performs best in the connectivity dimension, (being ranked above the other V4 countries), thanks to the country's relatively developed broadband infrastructure. However, it is among the worst performers in terms of integration of digital technology, as Hungarian businesses have made only a small investment in digital technologies.

Regarding the SDG index measuring countries' efforts and performance towards sustainability, Table 2 provides an overview of the overall index and its sub-indices.

Table 2

The position of the EU member states based on the SDG index and the 17 sub-indices along the respective UN SDGs for 2022

Rank	SDG index score		SDG_1_no poverty		SDG_2_zero hunger	
1	Finland	86.5	Estonia	100.0	Ireland	76.2
2	Denmark	85.6	Poland	99.9	Croatia	75.0
3	Sweden	85.2	Cyprus	99.9	France	73.8
4	Austria	82.3	Slovenia	99.9	Austria	73.7
5	Germany	82.2	Malta	99.8	Hungary	72.7
6	France	81.2	Czech Republic	99.8	Slovakia	72.6
7	Ireland	80.7	Finland	99.8	Germany	72.6
8	Estonia	80.6	Ireland	99.8	Belgium	71.6
9	Poland	80.5	Denmark	99.7	Italy	71.0
10	Czech Republic	80.5	France	99.7	Romania	70.7
11	Latvia	80.3	Belgium	99.7	Poland	68.1
12	Slovenia	80.0	Netherlands	99.6	Netherlands	67.7
13	Spain	79.9	Germany	99.5	Malta	67.2
14	Netherlands	79.9	Luxembourg	99.5	Slovenia	66.9
15	Belgium	79.7	Portugal	99.4	Denmark	66.4
16	Portugal	79.2	Latvia	99.4	Greece	66.4
17	Hungary	79.0	Austria	99.3	Bulgaria	66.3
18	Croatia	78.8	Greece	99.2	Latvia	65.1
19	Slovakia	78.7	Hungary	99.1	Finland	64.2
20	Italy	78.3	Croatia	99.1	Spain	64.0
21	Romania	77.7	Lithuania	99.0	Portugal	64.0
22	Greece	76.8	Slovakia	98.9	Lithuania	63.8
23	Malta	76.8	Sweden	98.9	Estonia	63.6
24	Luxembourg	75.7	Spain	98.5	Sweden	63.4
25	Lithuania	75.4	Bulgaria	98.2	Czech Republic	62.1
26	Bulgaria	74.3	Italy	98.1	Cyprus	60.5
27	Cyprus	74.2	Romania	96.0	Luxembourg	59.7

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Rank	SDG_3_health/well-being		SDG_4_education		SDG_5_gender	
1	Sweden	95.7	Sweden	99.9	Finland	91.1
2	Netherlands	95.6	Ireland	99.8	Sweden	90.9
3	Luxembourg	95.6	France	99.7	France	87.4
4	Denmark	95.4	Luxembourg	99.4	Denmark	86.8
5	Spain	95.0	Poland	98.8	Spain	86.7
6	Finland	94.7	Malta	98.4	Belgium	86.0
7	Ireland	94.5	Cyprus	98.4	Portugal	83.7
8	Italy	94.1	Lithuania	98.4	Austria	82.9
9	Germany	93.8	Netherlands	98.3	Netherlands	82.1
10	Slovenia	93.4	Austria	98.2	Germany	80.5
11	Portugal	92.6	Finland	98.1	Luxembourg	78.7
12	Belgium	92.5	Denmark	97.7	Latvia	78.1
13	Austria	91.9	Latvia	97.5	Estonia	77.2
14	France	91.9	Germany	97.3	Slovenia	77.2
15	Malta	90.8	Croatia	97.1	Ireland	76.4
16	Cyprus	90.8	Greece	96.0	Bulgaria	75.1
17	Greece	90.5	Estonia	96.0	Lithuania	74.4
18	Estonia	90.2	Spain	95.6	Italy	73.4
19	Czech Republic	89.9	Slovenia	95.4	Czech Republic	72.6
20	Croatia	87.6	Portugal	95.0	Poland	72.5
21	Slovakia	87.0	Belgium	94.4	Slovakia	71.9
22	Lithuania	85.0	Italy	94.1	Cyprus	70.6
23	Latvia	84.2	Czech Republic	92.3	Croatia	68.1
24	Hungary	84.0	Hungary	92.0	Greece	64.8
25	Poland	83.8	Romania	83.4	Hungary	64.5
26	Romania	81.1	Slovakia	83.1	Malta	63.8
27	Bulgaria	77.9	Bulgaria	68.5	Romania	57.3

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Rank	SDG_6_water/ sanitation		SDG_7_affordable/ clean energy		SDG_8_work/ economic growth	
1	Sweden	95.1	Sweden	93.3	Ireland	89.2
2	Finland	93.6	Latvia	89.9	Denmark	88.9
3	Austria	92.4	Finland	89.0	Finland	87.7
4	Denmark	89.8	Denmark	88.1	Netherlands	87.0
5	France	89.7	Austria	85.2	Germany	86.9
6	Latvia	89.5	Portugal	82.6	Slovenia	86.5
7	Germany	88.5	Croatia	80.8	Belgium	84.6
8	Greece	88.3	Slovenia	78.4	Austria	84.0
9	Hungary	87.9	Italy	78.2	Czech Republic	83.9
10	Netherlands	87.6	Romania	77.7	Sweden	83.9
11	Slovenia	87.5	Spain	77.4	Poland	83.7
12	Spain	87.2	Germany	76.6	Latvia	83.6
13	Ireland	85.6	France	76.6	Estonia	83.3
14	Czech Republic	85.3	Slovakia	75.3	Malta	82.3
15	Poland	85.2	Ireland	74.7	France	81.2
16	Croatia	84.0	Estonia	74.5	Slovakia	80.4
17	Estonia	83.8	Czech Republic	74.0	Hungary	80.3
18	Slovakia	83.5	Greece	73.9	Portugal	80.3
19	Italy	82.3	Bulgaria	73.2	Romania	80.0
20	Luxembourg	81.8	Belgium	72.9	Lithuania	78.2
21	Portugal	80.9	Hungary	72.7	Croatia	77.6
22	Lithuania	80.3	Cyprus	72.7	Bulgaria	77.2
23	Romania	79.8	Netherlands	71.5	Cyprus	75.9
24	Belgium	72.8	Malta	71.0	Italy	74.4
25	Cyprus	69.5	Poland	70.2	Spain	74.1
26	Bulgaria	69.1	Lithuania	64.0	Luxembourg	73.9
27	Malta	68.5	Luxembourg	52.6	Greece	63.4

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Rank	SDG_9_industry/ innovation		SDG_10_reduced inequalities		SDG_11_cities/ communities	
1	Sweden	97.3	Belgium	100.0	Luxembourg	97.6
2	Denmark	96.4	Czech Republic	100.0	Netherlands	96.5
3	Austria	95.7	Slovakia	100.0	Denmark	95.1
4	Finland	94.4	Slovenia	100.0	Czech Republic	94.9
5	Germany	93.4	Finland	98.4	Spain	93.1
6	Belgium	92.1	Denmark	98.4	Austria	93.0
7	Netherlands	91.6	Austria	93.8	Finland	92.0
8	France	90.1	Poland	93.4	Sweden	92.0
9	Spain	87.8	Sweden	93.4	Estonia	91.3
10	Luxembourg	87.0	Hungary	93.3	Germany	90.9
11	Ireland	83.3	Netherlands	93.2	France	90.5
12	Italy	83.3	Malta	93.2	Ireland	90.0
13	Czech Republic	79.3	Croatia	90.5	Portugal	89.6
14	Estonia	78.4	Estonia	89.8	Malta	88.7
15	Poland	75.8	Ireland	89.2	Belgium	88.6
16	Portugal	75.7	Germany	89.1	Hungary	88.5
17	Greece	75.7	France	87.5	Latvia	87.9
18	Slovenia	75.2	Greece	84.9	Poland	85.8
19	Hungary	74.9	Portugal	83.4	Slovakia	85.2
20	Cyprus	73.7	Cyprus	83.4	Lithuania	84.0
21	Latvia	72.5	Luxembourg	82.3	Slovenia	84.0
22	Lithuania	69.8	Spain	80.8	Greece	81.1
23	Slovakia	69.1	Italy	76.9	Romania	80.9
24	Malta	68.0	Romania	75.8	Bulgaria	80.4
25	Croatia	65.7	Latvia	74.3	Cyprus	76.9
26	Romania	61.4	Lithuania	70.3	Croatia	75.4
27	Bulgaria	58.4	Bulgaria	49.6	Italy	73.6

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Rank	SDG_12_responsible consumption/production		SDG_13_climate action		SDG_14_life below water	
1	Romania	83.6	Romania	85.4	Romania	85.4
2	Hungary	82.3	Bulgaria	83.1	Estonia	85.2
3	Bulgaria	80.5	Portugal	80.3	Finland	85.1
4	Poland	78.7	Croatia	80.3	Latvia	80.5
5	Italy	75.9	Greece	76.4	Ireland	72.4
6	Slovakia	75.7	Italy	76.3	Denmark	71.3
7	Croatia	75.6	Spain	76.3	Croatia	70.8
8	Spain	72.5	Malta	72.5	Lithuania	68.0
9	Portugal	72.0	Hungary	72.4	Germany	67.6
10	Latvia	71.6	Poland	72.2	Sweden	67.3
11	Finland	70.2	Czech Republic	69.0	Bulgaria	64.7
12	Greece	69.5	France	67.3	Poland	64.2
13	Cyprus	69.4	Cyprus	66.1	France	63.7
14	Czech Republic	68.8	Slovakia	64.4	Malta	62.4
15	Malta	67.5	Latvia	63.2	Greece	59.5
16	Estonia	64.9	Slovenia	60.4	Slovenia	58.5
17	France	63.9	Sweden	60.2	Spain	57.6
18	Sweden	63.1	Finland	60.2	Italy	56.7
19	Slovenia	63.0	Denmark	58.5	Belgium	54.7
20	Lithuania	61.9	Lithuania	58.2	Netherlands	53.1
21	Germany	59.4	Germany	55.6	Cyprus	48.4
22	Ireland	57.4	Ireland	55.4	Portugal	43.0
23	Austria	56.8	Austria	55.3	Austria	
24	Belgium	56.6	Belgium	54.6	Czech Republic	
25	Netherlands	55.0	Estonia	53.5	Hungary	
26	Denmark	54.8	Netherlands	53.2	Luxembourg	
27	Luxembourg	46.7	Luxembourg	44.9	Slovakia	

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Rank	SDG_15_life on land		SDG_16_peace/ justice/institutions		SDG_17_partnership	
1	Latvia	97.9	Finland	94.1	Sweden	87.2
2	Estonia	96.0	Denmark	93.3	Denmark	82.3
3	Lithuania	95.1	Austria	91.2	Germany	82.0
4	Bulgaria	93.7	Luxembourg	90.3	France	73.4
5	Denmark	92.8	Estonia	89.4	Bulgaria	73.2
6	Czech Republic	92.4	Ireland	88.5	Finland	72.9
7	Poland	92.3	Portugal	88.3	Austria	68.7
8	Slovakia	89.2	Sweden	86.6	Luxembourg	67.7
9	Ireland	88.1	Slovenia	86.1	Belgium	66.9
10	Hungary	85.8	Belgium	85.4	Romania	65.7
11	Finland	85.0	Netherlands	85.2	Italy	65.0
12	Croatia	84.4	Germany	84.2	Slovenia	63.3
13	Slovenia	83.5	Czech Republic	83.9	Poland	62.9
14	Belgium	81.5	Spain	83.1	Portugal	62.5
15	Greece	81.2	Latvia	82.4	Spain	62.1
16	Sweden	80.1	Poland	81.5	Netherlands	62.0
17	Italy	79.7	Slovakia	80.8	Greece	58.0
18	Romania	79.5	Cyprus	80.6	Slovakia	56.5
19	Germany	79.1	Malta	79.8	Czech Republic	55.8
20	Malta	78.9	Italy	78.7	Lithuania	53.8
21	Cyprus	78.5	Lithuania	78.0	Estonia	53.3
22	Netherlands	78.3	Romania	77.5	Hungary	52.9
23	Portugal	73.6	Greece	76.8	Malta	52.3
24	Austria	73.5	Croatia	76.7	Ireland	50.7
25	France	69.2	Hungary	76.2	Croatia	50.7
26	Spain	66.6	France	75.5	Latvia	47.2
27	Luxembourg	66.4	Bulgaria	73.8	Cyprus	46.8

Source: data based on Sachs et al. 2022.

Regarding the overall SDG index, Hungary and the V4 countries, in general, perform relatively on average (Poland, the Czech Republic, Hungary and Slovakia ranked 9th, 10th, 17th and 19th, respectively, out of the 27 EU member states). The top performers are the Nordic states (i.e. Finland, Denmark, and Sweden) with well-balanced achievement along the 17 sub-indices, while the countries lagging behind at the end of the list do not show any regional focus.

Hungary is among the top five performers along SDG 2 (zero hunger) and SDG 12 (responsible production and consumption) with relatively low per capita pollution and waste-related indicators, outperforming in both cases the other V4 countries.

Hungary performs above average and better than its peer V4 states (ranked in the top 10 of the sample of 27) along the SDG 6 (water and sanitation) due to the relatively good infrastructure and supply of fresh water and SDG 13 (climate action),

based on the per capita carbon emissions coming from fossil fuel combustion and embedded in imports and exports.

Still performing above average, but behind the rest of the V4 countries, Hungary is ranked 10th along SDG 10 (Reduced Inequalities), based on the Gini-coefficient and the Palma ration, and SDG 15 (Life on Land), primarily based on land protection and (de)forestation indicators, where peer V4 countries have better conditions because of bigger proportions being forested.

Beyond several sub-fields where Hungary performs on average (and irrelevant along the SDG 14 (Life Below Water) as inland countries, such as the Czech Republic and Slovakia), there are several fields where Hungary is ranked behind (in the last five). In terms of SDG 3 (Health and Well-being) and SDG 4 (Education), Hungary's position is relatively similar to the peer V4 countries, while related to SDG 5 (Gender Equalities) and SDG 16 (Peace, Justice and Institutions), Hungary lags well behind also of the other countries from the V4.

To reveal potential relationships between the two composite indices (and their respective sub-indices to contribute to the literature – as this missing link was already pointed at the literature review section), correlation analysis has been carried out, as summarised in Table3.

Table 3

The Pearson correlation matrix between the DESI and the SDG index, including also the respective dimensions and sub-indices

		SDG_1_no poverty	SDG_2_ zero hunger	SDG_3_ health/ well-being	SDG_4_ education
1_human capital dimension (weighted score 0 to 100)	Pearson correlation	0.509**	–0.114	0.718**	0.560**
	Sig. (2-tailed)	0.007	0.573	0.000	0.002
	N	27	27	27	27
2_connectivity dimension (weighted score 0 to 100)	Pearson correlation	0.012	0.001	0.553**	0.251
	Sig. (2-tailed)	0.954	0.995	0.003	0.206
	N	27	27	27	27
3_integration of digital technology (weighted score 0 to 100)	Pearson correlation	0.453*	–0.139	0.808**	0.576**
	Sig. (2-tailed)	0.018	0.489	0.000	0.002
	N	27	27	27	27
4_digital public services (weighted score 0 to 100)	Pearson correlation	0.603**	–0.330	0.576**	0.548**
	Sig. (2-tailed)	0.001	0.093	0.002	0.003
	N	27	27	27	27
SDG index score	Pearson correlation	0.265	0.153	0.480*	0.386*
	Sig. (2-tailed)	0.182	0.446	0.011	0.047
	N	27	27	27	27
DESI overall index score	Pearson correlation	0.521**	–0.209	0.787**	0.600**
	Sig. (2-tailed)	0.005	0.295	0.000	0.001
	N	27	27	27	27

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		SDG_5_ gender	SDG_6_ water/ sanitation	SDG_7_ affordable/ clean energy	SDG_8_ work/ economic growth
1_human capital dimension (weighted score 0 to 100)	Pearson correlation	0.607**	0.381*	0.220	0.460*
	Sig. (2-tailed)	0.001	0.050	0.271	0.016
	N	27	27	27	27
2_connectivity dimension (weighted score 0 to 100)	Pearson correlation	0.383*	0.412*	0.205	0.240
	Sig. (2-tailed)	0.049	0.033	0.304	0.228
	N	27	27	27	27
3_integration of digital technology (weighted score 0 to 100)	Pearson correlation	0.634**	0.259	0.329	0.454*
	Sig. (2-tailed)	0.000	0.191	0.093	0.017
	N	27	27	27	27
4_digital public services (weighted score 0 to 100)	Pearson correlation	0.638**	0.240	0.071	0.441*
	Sig. (2-tailed)	0.000	0.228	0.725	0.021
	N	27	27	27	27
SDG index score	Pearson correlation	0.647**	0.765**	0.703**	0.652**
	Sig. (2-tailed)	0.000	0.000	0.000	0.000
	N	27	27	27	27
DESI overall index score	Pearson correlation	0.696**	0.365	0.228	0.490**
	Sig. (2-tailed)	0.000	0.061	0.252	0.009
	N	27	27	27	27

		SDG_9_ industry/ innovation	SDG_10_ reduced inequalities	SDG_11_ cities/ communities	SDG_12_ responsible consump-tion/ production
1_human capital dimension (weighted score 0 to 100)	Pearson correlation	0.640**	0.491**	0.638**	–0.629**
	Sig. (2-tailed)	0.000	0.009	0.000	0.000
	N	27	27	27	27
2_connectivity dimension (weighted score 0 to 100)	Pearson correlation	0.545**	0.114	0.372	–0.331
	Sig. (2-tailed)	0.003	0.572	0.056	0.092
	N	27	27	27	27
3_integration of digital technology (weighted score 0 to 100)	Pearson correlation	0.699**	0.521**	0.423*	–0.612**
	Sig. (2-tailed)	0.000	0.005	0.028	0.001
	N	27	27	27	27
4_digital public services (weighted score 0 to 100)	Pearson correlation	0.530**	0.228	0.649**	–0.623**
	Sig. (2-tailed)	0.004	0.252	0.000	0.001
	N	27	27	27	27
SDG index score	Pearson correlation	0.720**	0.588**	0.525**	–0.249
	Sig. (2-tailed)	0.000	0.001	0.005	0.210
	N	27	27	27	27
DESI overall index score	Pearson correlation	0.714**	0.401*	0.643**	–0.677**
	Sig. (2-tailed)	0.000	0.038	0.000	0.000
	N	27	27	27	27

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		SDG_13_ climate action	SDG_14_ life below water	SDG_15_ life on land	SDG_16_ peace/justice /institutions
1_human capital dimension (weighted score 0 to 100)	Pearson correlation	–0.597**	0.181	–0.175	0.705**
	Sig. (2-tailed)	0.001	0.420	0.383	0.000
	N	27	22	27	27
2_connectivity dimension (weighted score 0 to 100)	Pearson correlation	–0.198	–0.082	–0.380	0.291
	Sig. (2-tailed)	0.322	0.715	0.050	0.142
	N	27	22	27	27
3_integration of digital technology (weighted score 0 to 100)	Pearson correlation	–0.516**	–0.088	–0.155	0.666**
	Sig. (2-tailed)	0.006	0.696	0.439	0.000
	N	27	22	27	27
4_digital public services (weighted score 0 to 100)	Pearson correlation	–0.656**	0.080	0.003	0.633**
	Sig. (2-tailed)	0.000	0.723	0.987	0.000
	N	27	22	27	27
SDG index score	Pearson correlation	–0.331	0.376	0.057	0.634**
	Sig. (2-tailed)	0.092	0.084	0.776	0.000
	N	27	22	27	27
DESI overall index score	Pearson correlation	–0.625**	0.035	–0.172	0.708**
	Sig. (2-tailed)	0.000	0.875	0.390	0.000
	N	27	22	27	27

		SDG_17_ partnership for goals	SDG index score	DESI overall index score
1_human capital dimension (weighted score 0 to 100)	Pearson correlation	0.208	0.585**	0.915**
	Sig. (2-tailed)	0.297	0.001	0.000
	N	27	27	27
2_connectivity dimension (weighted score 0 to 100)	Pearson correlation	0.458*	0.396*	0.566**
	Sig. (2-tailed)	0.016	0.041	0.002
	N	27	27	27
3_integration of digital technology (weighted score 0 to 100)	Pearson correlation	0.327	0.585**	0.896**
	Sig. (2-tailed)	0.096	0.001	0.000
	N	27	27	27
4_digital public services (weighted score 0 to 100)	Pearson correlation	0.066	0.397*	0.894**
	Sig. (2-tailed)	0.744	0.040	0.000
	N	27	27	27
SDG index score	Pearson correlation	0.545**	1	0.577**
	Sig. (2-tailed)	0.003		0.002
	N	27	27	27
DESI overall index score	Pearson correlation	0.278	0.577**	1
	Sig. (2-tailed)	0.160	0.002	
	N	27	27	27

** Correlation is significant at 0.01 level (and the Pearson coefficient is above 0.5, indicated with dark grey).

* Correlation is significant at 0.05 level (and the Pearson coefficient is around 0.4–0.5, indicated with light grey).

The two composite indices are positively and significantly correlated to each other (Pearson coefficient: 0.577, $p = 0.002$) for the EU countries, mostly in line with earlier findings presented in the literature review on the global scale (Jovanovic et al. 2018).

The DESI is internally consistent in the sense that its dimensions are strongly and positively correlated to the composite index (in line with the findings of Bánhidi–Dobos [2020], for earlier years). The SDG index is less consistent in this regard; many sub-indices are not significantly correlated to the composite index (and in the case of two sub-indices, the SDG 12 Responsible Consumption and Production and the SDG 13 Climate Action, the correlation coefficients are even negative). These findings can be explained by the DESI dimensions overlapping more with each other in content, while the sub-dimensions of the SDG index are more diverse, intending to address different aspects of sustainability.

When one of the two main indices are decomposed, it can be seen that two dimensions of the DESI (human capital and integration of digital technology) are strongly correlated, while the other two DESI components (connectivity and digital public services) are moderately correlated to the overall SDG index (all correlations are positive). On the contrary, the overall DESI has been determined to be strongly correlated to 10 out of the 17 sub-indices of the SDG index. However, it is important to note that SDGs 12 and 13 are again negatively (and in this case strongly) correlated to the DESI.

If the rest of the correlation matrix is concerned (the links between the respective sub-indices of the two composite indices), various relationships can be detected, with many positive and strong correlations (while again the Responsible Consumption and Production and the Climate Action SDG sub-indices are negatively correlated with different DESI dimensions, this negative correlation is discussed later).

The relationships shown in Table 3 are not always straightforward to interpret. Correlations show the strength, but do not indicate the direction of the relationship.

In many cases, however, it makes sense to assume that digitalisation and the (dimensions of) DESI have a positive impact on the respective SDG index sub-dimensions. Different dimensions of digitalisation may lead to better health and higher well-being (SDG 3), reduced inequalities (SDG 10) or better public transport services (SDG 11).

In some other cases, positive correlation between different dimensions of digitalisation and sustainability may be interpreted as a mutual impact. Different aspects of digitalisation support the reduction of poverty (SDG 1), but decreasing poverty can also have a positive impact on digitalisation. Digitalisation can improve education (SDG 4), but high level of education is also needed to support the human capital dimension of the DESI. Digitalisation supports part time and home office working opportunities to decrease gender imbalance (SDG 5), as the inclusion of talented females into the economy can have a positive impact on digital services. Similarly, digitalisation has a positive impact on industry development and innovation (SDG 9) and institutions (SDG 16), but these fields may also support several aspects of the DESI.

One further interesting finding was that among the strong relationships, SDG 12 (Responsible Production and Consumption) and SDG 13 (Climate Action) are the ones that are always in the negative correlation with DESI and its dimensions. It seems that top DESI performer countries underperform along pollution, waste and carbon release indicators. Thus, it can be concluded that high levels of digitalisation do not lead to the reduction of pollution (the other direction does not seem to make sense). It means that other types of policy and technological and individual solutions are needed to address pollution, carbon emissions and overconsumption. To exploit the enabling potentials of digital technologies, which can help address issues such as carbon emissions and increasing energy consumption in various sectors, targeted measures and policies are necessary.

To address the links between both the SDG sub-indices and DESI dimensions (within the groups), the internal correlation matrices are also presented in Internet Appendix and Table A1 in Appendix. Results show that at some points, there is moderate correlation between SDG sub-indices (with Pearson coefficients between 0.4 and 0.5), while there are several stronger ones between DESI dimensions (Pearson coefficients between 0.6 and 0.7, this latter in line with Bánhidi–Dobos [2020]). These correlations also raise multicollinearity issues within the main indices. To test this, principal component analysis was applied. The KMO values (0.659 for the SDG sub-indices and 0.761 for the DESI dimensions) and the results of the Bartlett's test ($p < 0.001$ in both cases) indicated that the data are adequate for the principal component analysis.

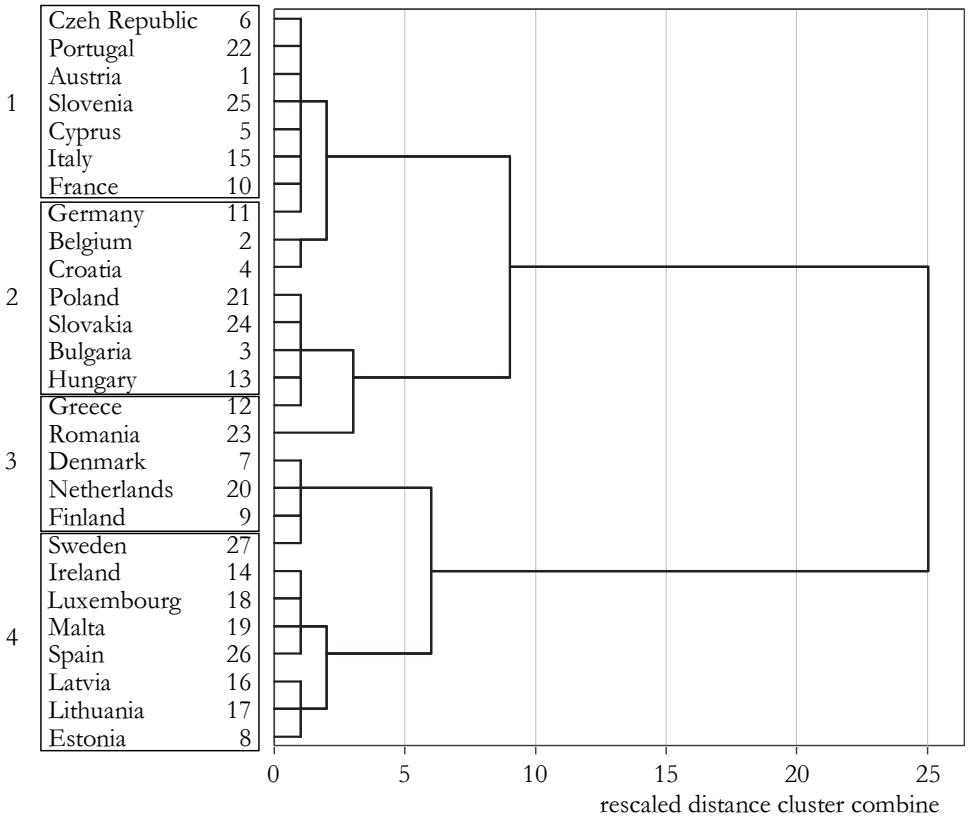
Components were obtained by looking for eigenvalues over 1, resulting in five components for the SDG sub-indices (explaining 79.19% of the total variance), while for the DESI dimensions, one component covered all the four dimensions (explaining 69.30% of the total variance). Table A2 and A3 in Appendix present the summary tables – eigenvalues, total variance explained and (rotated) component matrices. Out of the five components emerging from the SDG sub-indices, the first one is an inclusive component (loadings over 0.5 with nine sub-indices); the second represents social aspects of the SDG index (no poverty, education and reduced inequalities); the third relates to access to infrastructure (water, sanitation and energy); the fourth covers nature conservation (life below water and on land); and the fifth is linked to a single sub-index (zero hunger).

As sub-indices and dimensions of the main indices can be suppressed into several latent factors, there seems to be a certain level of multicollinearity. However, the Pearson correlation coefficients between the DESI component and the five SDG components are −0.673, $p = 0.000$; 0.488, $p = 0.002$; 0.381, $p = 0.046$, respectively for the first three components (explaining 59.1% of the total variance of the SDG sub-indices). Meanwhile, there is no significant correlation with the remaining two SDG components (explaining only three out of the 17 SDG sub-indices) still show correlation between the sub-indices of the two main indices.

To classify the EU member countries according to the indices focused on, cluster analysis was conducted to unveil similarities and differences within the sample. Considering the relatively small sample size (27 EU member states), hierarchical clustering was applied (instead of K-means clustering), using Ward's linkage and the squared Euclidean distance as the distance measure. In case of the DESI, four dimensions (i.e. human capital, connectivity, integration of digital technology and digital public services) were used as the basis of the clustering. The results are summarised in Figure 2.

Figure 2

Dendrogram summarising the clustering of the sample along the dimensions of the DESI



Based on the dendrogram (and the scree plot as an additional tool), the four-cluster solution is recommended, as indicated also in the figure. In this case, Hungary is in the same cluster with two peer V4 countries, namely, Poland and Slovakia (together with Bulgaria, Greece and Romania), while the Czech Republic falls into another cluster, but still on the same branch of the dendrogram. These similarities

can be the consequence of similar level of development and maybe similar policies to promote digitalisation.

To examine the characteristics of the different clusters, analysis of variance (ANOVA) has been conducted along the DESI and its dimensions. As a precondition of the ANOVA, the homogeneity of variance between groups was tested. The outcomes of the Levene-tests for the five variables (DESI and its four dimensions, $p = 0.190$, 0.478, 0.320, 0.615, 0.220, respectively) indicated that the dataset is appropriate to proceed with the ANOVA. Meanwhile, the ANOVA showed ($p < 0.01$, < 0.01, 0.033; < 0.01; < 0.01 respectively) that clusters differ significantly along the variables analysed. Table 4 presents the result of the ANOVA, where the clusters (in the columns) are characterised by their averages along the DESI and its dimensions (in the rows).

Table 4

Characteristics of the clusters along the DESI and its dimensions

Clusters	Connectivity and integration focused	Digital laggards	Digital champions	Digital public service providers
N (total = 27)	10	6	4	7
DESI (overall)	50.96	39.15	67.89	57.45
1_human capital	46.04	37.20	63.92	52.70
2_connectivity	56.00	51.57	67.00	55.34
3_integration	37.90	21.60	56.35	37.48
4_digital public services	63.91	46.24	84.26	84.00

'Digital champions' perform the best along DESI, as well as along each dimension, while 'digital laggards' (including Hungary, Poland and Slovakia from the V4) were noted to have the biggest need to develop. 'Digital public service providers' are about the same level along the respective dimension with the champions but underperform, as compared to the others. 'Connectivity and integration focused' perform relatively well in the respective categories.

The cluster means along the different dimensions follow a relatively similar patterns (clusters perform better in one dimension and tend to perform better in others, as well); this can be the result of the high correlation of the dimensions (that means an overlap in content of the four dimensions; see also Bánhidi–Dobos 2020).

The clusters emerging due to the classification were also analysed along the SDG index-related variables, as summarised in Table 5 (again with clusters in the columns and relevant SDG sub-index means in the rows). Only those SDG sub-indices were considered as relevant and included in the rows, where the preconditions of the ANOVA (homogeneity of variance, Levene-test, $p > 0.05$ and means differ significantly; $p < 0.05$) were satisfied.

The SDG index-related variables strongly overlap with those that showed significant correlation with the DESI and its dimensions (Table 3). As a general tendency, 'digital champions' tend to overperform in the sustainability field; however,

a discrepancy has emerged earlier that they perform the worst in terms of responsible consumption and production as well as in climate action. Regarding the other three clusters, however, there is no general tendency; they perform relatively evenly regarding the SDG index, related to the different sub-indices.

Table 5

Characteristics of the clusters along the SDG index and its sub-indices

Clusters	Connectivity and integration focused	Digital laggards	Digital champions	Digital public service providers
N (total = 27)	10	6	4	7
SDG index	79.64	77.84	84.30	78.48
4_education	96.20	86.96	98.50	97.89
5_gender equality	78.24	67.69	87.72	76.45
7_affordable/clean energy	77.81	73.82	85.49	72.01
9_industry and innovation	82.42	69.21	94.94	78.13
11_sustainable cities/ communities	85.75	83.64	93.92	90.36
12_responsible consumption/production	66.15	78.39	60.80	63.23
13_climate action	66.52	75.67	58.04	60.57
16_peace/justice	83.04	77.78	89.79	84.49

As an additional step of the analysis, clustering was also run along the 17 sub-dimensions of the SDG index. Figure A1 in Appendix shows the dendrogram (similarly based on the Ward's method and squared Euclidean distances). Several cluster options can be considered, but V4 countries seem to have similar features, as Hungary falls into the same cluster with Poland and Slovakia anyway, and the Czech Republic is again on the same major branch of the dendrogram. These similarities along the SDG index can be the result of not only the similar level of development and history, but also of the similar geographical location (neighbouring countries in Central Europe and all but Poland are isolated from seas).

Discussion

Pathways to promote digitalisation and sustainability

Improving the performance of the EU and the V4 in the special fields of digitalisation and sustainability is a very complex challenge. Based on the results of this paper, it seems that two major pathways can be highlighted.

The first is to enhance digitalisation directly (through policymaking, corporate or individual actions). This can have a positive impact on different aspects of sustainability, and this can be expected mostly in the fields where significant and positive correlation could have been detected with the DESI or its dimensions. (It

has to be stressed again that a positive correlation coefficient cannot predict the direction of the relationship, but, in some cases, common sense suggests that digitalisation has a positive impact on the respective aspect of sustainability – the other way is more complex).

As there was a significant and negative relationship between components of digitalisation and two key aspects of sustainability (responsible consumption and production; climate action) and it is against common sense that the decline of digitalisation would be the optimal way to promote sustainability, the second pathway can be the direct development of these two aspects of sustainability.

Without being able to provide a fully comprehensive solution, several streams have been suggested to foster development in the above-mentioned fields, as summarised by Table 6.

Table 6

Potential pathways towards the improvement of digitalisation and sustainability in the European Union

	Policymaking	Business initiatives	Individual actions
1. Digitalisation-focused strategies	EU DDPP EU 2030 Digital Compass Path to the Digital Decade	Digitalisation of products and services Digitalisation of processes Developing business models on digitalisation	Self-education of digital skills Preferring digital products and services
2. Sustainability-focused strategies (with a special focus on sustainable consumption and climate action)	Carbon emission regulation Energy efficiency and saving targets Waste prevention and management Enhancing product durability	Energy efficiency and low-carbon strategies Energy-efficient and low-carbon products Develop business models to promote product durability Fair communication practices	Individual level consciousness in energy use Openness to low-carbon and low-waste lifestyles Do-it-yourself practices to prolong product usability

Tools shown in the table are complex and manifold, and there exist further interrelated and horizontal tasks (such as raising awareness and communication). The following passages intend to highlight few examples with a special focus on the V4 countries, supported with relevant literature.

As discussed in the previous sections, EU's policies are extensive and ambitious to promote digitalisation, mostly with targets to be achieved by 2030. Similar tendencies are present in the V4; national digitalisation strategies and digital competence development programmes have been established to follow suit (CRDI, 2019 in the Czech Republic, Ministry of Innovation and Technology, 2021 in Hungary, Ministry of Digitalization, 2020 in Poland and Digital Slovakia, 2022 in Slovakia).

Digitalisation of products, services, processes and new business models is on the rise already, but this phenomenon accelerated rapidly during the Covid-19 pandemic. Among many other indicators, the share of e-commerce within the turnover of enterprises has increased rapidly. Based on Eurostat (2023), for EU-27, it increased from 13.8% (2012) to 17.6%. For the V4, the shares are more impressive in most cases, with developments between 2012 and 2022: from 24.3% to 29.9% in the Czech Republic, from 18.5% to 19.5% in Hungary, from 10.1% to 16.8% in Poland and from 11.6% to 22.7% in Slovakia.

Consumers tend to be more open for digital solutions and developing their digital skills, which is underpinned by empirical data for Hungary (Buda et al. 2019) and Poland (Alaeddin et al. 2018).

Regarding the other stream of policy actions (where digitalisation is insufficient to promote sustainability, these were the cases of responsible consumption and production and climate action), specific policies on the sustainability domain are deemed necessary. The major areas (Table 6) are diverse and are far beyond the scope of this study, although these areas are well developed both at the EU and V4 level. However, the major challenge here is the effective fulfilment of the targets set in these policies.

Business-related solutions presented in the table are also diverse. One successful innovation from practice that also exist in all V4 countries is the shared mobility concept (both regarding passenger cars and bicycles); see, for example, Szabó–Gupta (2020) for car sharing in Hungary or Kubalak et al. (2022) for bicycle sharing in Slovakia.

Individual approaches in this field from the Visegrad Region include voluntary simplicity movements in the Czech Republic (Kala et al. 2017), energy-saving consumer behaviour in Hungary (Vadovics 2019) that also contribute to the reduction of consumption based ecological footprint (Harangozó et al. 2019) or do-it-yourself and prosumer-related consumer activities to save energy in Poland (Trebska et al. 2021). Individual actions are highly needed, as household-level energy consumption increased due to the Covid-19 pandemic in the region (Rokicki et al. 2022, Csutora et al. 2022).

The diversity of these few examples of current and future directions underpins the complexity of the development of digitalisation and sustainability, thus urging for multiple approaches for further development.

Limitations

There are certain limitations related to the data used in the analysis. Although data were available for all countries and indicators for the EU sample (despite deficiencies in the availability of several indicators within the SDG index in the global context), as a consequence of delays in reporting systems, several core indicators have a time

delay (in case of the SDG index for 2022, many indicators are based on data from 2021 or 2020). However, this common with complex indicators and the latest data available for the widely used EF is from 2018 (GFN 2023).

A further limitation is that in several cases, causal relationships between certain sub-dimensions of the DESI and the SDG index were assumed to improve interpretability, even though correlations prove only the relationship. However, in these cases, this limitation was always mentioned.

Summary

This study intended to offer a better understanding of the link between the development of digitalisation and sustainability in the EU, focusing on the V4 countries. Hence, the DESI and the SDG indices and their sub-indices have been analysed, providing new additions to literature in the latter field.

The results determined that the V4 countries are relatively behind the average in terms of digitalisation and around the average in terms of sustainability based on the indices analysed. There are various relationships between different dimensions of digitalisation and sustainability. Correlation analysis has demonstrated that these relationships are mostly positive, but there are also negative ones (between different dimensions of digitalisation and responsible consumption and production as well as climate action in the field of sustainability). This finding indicated that digitalisation itself cannot be a guarantee to address all sustainability-related issues, and an increasingly complex approach is thus needed. The cluster analysis has shown that V4 countries share many similarities related to their performance in terms of digitalisation and sustainability.

Regarding the complex relationship between the dimensions of digitalisation and sustainability, a wide range of pathways can be suggested for its development, including policymaking, company initiatives and individual actions, as presented in the discussion section. This diversity and the formerly mentioned controversial links between the two indices urge for complex approaches to achieve a development in both fields. As further region-specific recommendations, in terms of digitalisation along the DESI dimensions, all of the four fields shall be developed (i.e. human capital, connectivity, integration and digital public services). Moreover, related to sustainability (measured by the SDG sub-indices), health and well-being, education (even if Poland does not underperform in this field) and clean energy should be key areas of development.

As potential future research directions, further options can be considered. Increasingly refined spatial analysis of the DESI dimensions and SDG sub-indices is possible, if respective data would be available at the sub-national and regional levels. Panel data analysis can offer deeper understanding between the composite indices and their sub-indices. However, a limitation thus far is the ongoing modification of the main indices (primarily in case of the DESI).

Appendix

Table A1

Correlations between DESI dimensions

		1_human capital dimension (weighted score 0 to 100)	2_ connectivity dimension (weighted score 0 to 100)	3_ integration of digital technology (weighted score 0 to 100)	4_digital public services (weighted score 0 to 100)
1_human capital dimension (weighted score 0 to 100)	Pearson correlation	1			
	Sig. (2-tailed)				
	N	27			
2_connectivity dimension (weighted score 0 to 100)	Pearson correlation	0.382*	1		
	Sig. (2-tailed)	0.049			
	N	27	27		
3_integration of digital technology (weighted score 0 to 100)	Pearson correlation	0.635**	0.416*	1	
	Sig. (2-tailed)	0.000	0.031		
	N	27	27	27	
4_digital public services (weighted score 0 to 100)	Pearson correlation	0.679**	0.300	0.689**	1
	Sig. (2-tailed)	0.000	0.129	0.000	
	N	27	27	27	27

** Correlation is significant at 0.01 level.
* Correlation is significant at 0.05 level.

Table A2

Summary of the principal component analysis (SDG sub-indices)

Eigenvalues and total variance explained

Component	Initial eigenvalues			Rotation sums of squared loadings		
	total	% of variance	cumulative %	total	% of variance	cumulative %
1	6.753	29.721	39.721	4.946	20.093	29.093
2	2.350	13.822	53.543	2.597	15.275	44.367
3	1.918	11.280	64.823	2.501	14.713	59.080
4	1.421	8.361	73.184	2.149	12.639	71.719
5	1.022	6.011	79.194	1.271	7.475	79.194

Rotated component matrix (Varimax rotation) (for easier readability and interpretability, only values over 0.5 are presented in the table).

	Component				
	1	2	3	4	5
SDG_1_no poverty		0.768			
SDG_2_zero hunger					0.944
SDG_3_health/well-being	0.577				
SDG_4_education		0.748			
SDG_5_gender	0.690				
SDG_6_water/sanitation			0.715		
SDG_7_affordable/clean energy			0.907		
SDG_8_work/economic growth	0.508				
SDG_9_industry/innovation	0.741				
SDG_10_reduced inequalities		0.693			
SDG_11_cities/communities	0.793				
SDG_12_responsible consumption/ production	–0.850				
SDG_13_climate action	–0.837				
SDG_14_life below water				0.742	
SDG_15_life on land				0.876	
SDG_16_peace/justice/institutions	0.723				
SDG_17_partnership for goals	0.549				

Table A3

Summary of the principal component analysis (DESI dimensions)

Eigenvalues and total variance explained

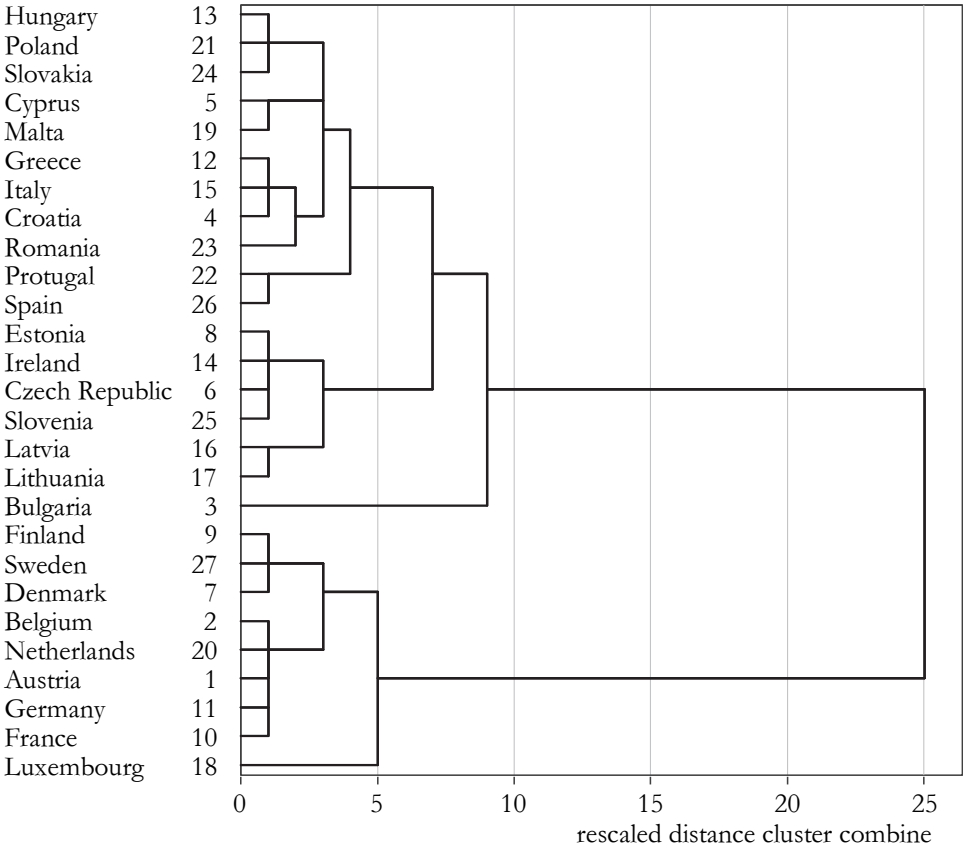
Component	Initial eigenvalues			Rotation sums of squared loadings		
	total	% of variance	cumulative %	total	% of variance	cumulative %
1	2.772	69.298	69.298	2.772	69.298	69.298

Component matrix

	Component 1
1_human capital dimension (weighted score 0 to 100)	0.933
2_connectivity dimension (weighted score 0 to 100)	0.562
3_integration of digital technology (weighted score 0 to 100)	0.914
4_digital public services (weighted score 0 to 100)	0.866

Figure A1

Hierarchical clustering based on the 17 sub-indices of the SDG index



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