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A theory of digital technology advancement to address the grand challenges of sustainable development

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ABSTRACT

Scholarly research has not yet discussed the totality of the 17 sustainable development goals (SDGs) as part of a broader picture of sustainable development. This paper provides a unique analysis of the linkages between institutions, SDGs and digital technologies to establish their exact interdependencies. Factor analysis of the grand challenges of sustainable development has shown only SDG3 and SDG17 might progress through institutions' development in developed countries, while only SDG16 in developing countries. In developed countries, the institutions of human development, globalisation and innovations influence SDG3, and SDG17, which depend on digitised knowledge and the application of digital technologies. Human development and economic freedom, which rely on digital infrastructure and technologies, impacted SDG16 in developing countries. The digital knowledge index and the digital technologies index in developed countries enhance management efficiency, having a maximum impact on SDG3 and SDG17. The findings of this paper contribute to social and economic policy implications on digital technology development for addressing grand challenges.

1. Introduction

Fourth Industrial Revolution is a unique stage in humanity's history as the development of technologies sets the foundations of the social mode and society's progress entirely. This fact emphasises the necessity for studying digital technology's influence on SDGs as the imperatives of modern society's development. There is ongoing scientific discussion in academic circles about the qualitative treatment of the power of digital technology development on SDGs and their prospects. Some scholars critically address the impact of digital technologies on sustainable development and, considering the traditionally high social and ecological costs of economic growth, treat digital change negatively. Digital technologies have been one of the main vectors of economic growth in recent years [1] and will retain this role in the long-term, up to 2030 [2] and, according to specific estimates, even up to 2050 [3].

The existing empirical data show significant differences in economic influence, including digital growth, on sustainable development in developed and developing countries. Developed countries offer a higher level of development of society and economy but a moderate (slower) rate of economic (and digital) growth [4]. The main social costs of digital economic growth in developed countries are connected to educating personnel through digital mass training. This cost increases social tension and competition between sellers in the labour market. Ecological costs are connected to increased energy consumption since automatisation raises production and consumption energy intensity. However, these costs are successfully reduced by using the leading energy-intensive digital technologies, smart grid, and the transition to alternative energy resources [5].

Developing countries are susceptible to the negative consequences of digital economic growth, which is much higher. They suffer social costs that are connected to a higher unemployment rate, reduction of wages and the population's living standards, as well as ecological costs that

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manifest in an increase in the volume of natural resources consumption and accumulation of production waste, which leads to a degraded environment and quality of life [6].

Other experts state that digital technology development has a noticeable positive influence on society in sustainable development. Digital technologies allow companies to increase production abilities and fully satisfy the public demand for goods and services. Digital finances ensure transparency and control of the economy, stimulating de-shadowisation. Digital training is accessible, encouraging the popularisation of lifelong learning. The digital approach to the organisation of added value chains allows for full-scale monitoring and guaranteeing the products' quality and on-time delivery [7].

The advantages of digital technology development are more apparent in developed countries [8]. Social advantages are connected to creating highly efficient, highly paid, knowledge-intensive, and more creative jobs. The ecological benefits to developing countries from eco-responsible digital innovations allow for increased environmental control and environmental effects of production and distribution. Developing countries have social advantages for labour and social mobility, while ecological benefits are poorly manifested.

The ongoing scholarly discourse shows an inadequate elaboration of the quantitative influence of digital technology development on achieving the SDGs. Various aspects of digital technology development contribute differently to the SDGs. Social institutions indirectly mediate this influence. The result of digital technologies does not lead to a decrease in countries' inequality by itself, but through the mediating role of expanding the capabilities and the increase in the transparency of financing, increase in accessibility of digital education, acceleration of innovative development, and stimulation of global competition through stimulation of globalisation.

Based on the extant literature, this paper offers the Hypothesis that digital technologies allow to improve the results (or achievement) of only specific SDGs through their mediating influence with the help of increasing the effectiveness of institutions: investments, human development, economic freedom, globalisation and innovations. Social and economic policy towards SDGs should be oriented to improve the institutional environment through technological development. Since institutional environment differences are one key accepted criterion of the differentiation between developed and developing countries, the influence of digital technologies on institutions and sustainable development is, therefore, country-specific and does not apply across the board, requiring ad hoc management approaches.

This paper aims to study the top 10 developed and the top 10 developing countries, which have shown the best results in implementing the SDGs (see Annex 1) and their digital technology development perspectives for addressing ongoing grand challenges. The uniqueness and originality of this research are around each of the 17 SDGs. It allows for a description of the causal connections between digital technology developments with the likelihood of achieving progress on each goal. The in-depth analysis allows figuring out the differences between achieving different SDGs, identifying the problematic goals, and finding technological support solutions.

The paper offers the following contributions. First, it performs an indirect study of the influence of digital technology development on sustainable development through technological support. This approach is novel. Unlike the strategy that envisages the search for a direct influence (which is not expressed clearly or is absent), this new theoretical and methodological approach allows studying the indirect effect. This allows to prove that the development of digital technologies is suitable for addressing the grand challenges of sustainable development.

Second, this paper forms a systemic view of digital technology advancement to address the grand challenges of sustainable development, which is not limited by either positive or negative influence. This allows for the correct and fullest characterisation of the impact of digital technologies on implementing the SDGs.

Third, this paper elaborates and substantiates the institutional basis of digital technology advancement to address the grand challenges of sustainable development. Progress in implementing the SDGs in developed and developing countries should be explored separately, taking their specifics into account. For each designated category, we offer recommendations for digital technology advancement of institutions to address the grand challenges of sustainable development.

This paper is structured as follows. A literature review of the topic under study and an outline of the theoretical background follow the introduction, including considering digital technology development as a socio-economic category, the scientific concept of the grand challenges of sustainable development and gap analysis. This is followed by this paper's alternative method and its empirical basis for the research. Results include: 1) factor analysis of a response to grand challenges of sustainable development, 2) dependence of sustainable development factors on digital technology development, 3) social and economic policy implications on digital technology development for addressing the grand challenges of sustainable development, 4) a systemic view on the prospects of addressing the grand challenges of sustainable development based on digital technology development. The conclusion sums up the paper's concepts, tools and findings on the topic, describing its limitations and perspectives of future scientific studies on the influence of society's digital technology development in sustainable development.

2. The theory of digital technology advancement and the scientific concept of grand challenges for sustainable development

2.1. Literature review

Socio-economic preconditions and consequences of digital technology advancement are described in the following works. Ghaffari et al. [9] demonstrate a socio-technical analysis of the development of the Internet of Things (IoT) as an interplay of technologies, tasks, structures and actors; the IoT is one of the most critical manifestations of digital technology advancement. Scuotto et al. [10] also consider the IoT as one manifestation of digital technology advancement. According to scholars, it is developing intensively in smart cities.

Another manifestation of digital technology advancement is big data analytics, which, according to Bertello et al. [11], depends on telecommunications infrastructure. Kovaleva and Kanke [12] prove that the development of intelligent technologies takes place during the transition to the digital economy under the influence of state and corporate management.

Thus, the above publications have formed a clear idea of digital technology advancement as a socio-economic category, which is treated as a process of creation and dissemination of the leading technologies of the Fourth technological mode, which include artificial intelligence (AI), big data, the Internet of Things (IoT), blockchain, ubiquitous computing (UC) and robots.

The scientific concept of grand challenges for sustainable development uses a reliable theoretical basis. The issues of sustainable development are found in many works. Singla et al. [13] suggest studying the effectiveness of technology push strategies for achieving sustainable development in manufacturing industries. The scholars emphasise the potential contribution of digital technology advancement to the implementation of the SDGs.

Bebbington and Unerman [14] suggest integrating the SDGs into the practice of accounting to ensure their precise quantitative and comprehensive monitoring around the world. George et al. [15] offer a philosophy of understanding and tackling societal grand challenges through management research. Hassani et al. [16] suggest using SDGs. Huan et al. [17] developed a method for assessing the impacts of an international agreement on regional progress towards SDGs.

At present, two grand challenges for sustainable development are distinguished. The first one is the Fourth Industrial Revolution and the transition to Industry 4.0. Under this influence, changes are taking place in several economic spheres that are related to implementing the SDGs:

– an increase in the resource intensity and energy intensity of the economy and growth of the ecological costs of economic growth, which cause an unfavourable change to the climate, environmental pollution, rapid depletion of natural resources, and decrease of biodiversity;
– Systemic automatisation in all sectors and spheres and business processes radically changes the need for personnel and demand in the labour market, thus complicating the search for a decent job and realising human potential.

The following authors describe this. Fakhar Manesh et al. [18] deem it necessary to manage knowledge in the conditions of the Fourth Industrial Revolution to support sustainable development. Mhlanga [19] substantiates that artificial intelligence in Industry 4.0 has a negative impact and creates challenges for fighting poverty, innovative development, development of infrastructure, and SDG implementation in emerging economies.

Khan et al. [20] present a systemic reflection of the triple result and the prospects of circular economy and sustainable business models, proving that Industry 4.0 changes the rules on implementing the SDGs and complicates their achievement. Chen et al. [21] demonstrate a potential negative influence of technological innovations on energy efficiency in the age of Industry 4.0 and determine the moderate character of the shadow economy in sustainable development.

The second grand challenge for sustainable development is the COVID-19 pandemic and crisis, which also radically changes the conditions for achieving the SDGs, in particular, the following:

– actualisation of healthcare problems due to the global viral threat and the continuing urgency of these problems during 2020–2021 and onward. While prevention (and vaccination) and treatment of COVID-19 become more accessible, public healthcare is in crisis, and other (similarly dangerous and widespread) diseases receive less attention;
– the redirection of investment flows in the healthcare sphere from other spheres, particularly the social and ecological spheres.

These issues have been studied in the following works. Anholon et al. [22] have demonstrated that the COVID-19 pandemic increased the need to train engineers aligned to the SDGs, on which path COVID-19 has become a severe obstacle. Sun et al. [23] prove that COVID-19 has created problems for the healthcare system in China and that the perspectives of a sustainable future are connected to the adaptation to the challenges of the pandemic.

Ranjbari et al. [24] determined three pillars of sustainability in the wake of COVID-19: responsible production, consumption and state management. Based on evidence from Italy, Peluso et al. [25] determined the age-related effects on environmentally sustainable purchases during COVID-19 and explained that responsible consumption reduced due to the pandemic. Oncioiu et al. [26] deem it possible to transform the COVID-19 threat into an opportunity, seeing the pandemic as a stage in the sustainable economy (though this state entails challenges and threats).

The support for implementing the SDGs with the help of digital technology advancement is a less studied sphere of knowledge. Specific issues of this support were considered in some works [27,28].

In summarising the results of the existing studies, it is possible to conclude that digital technology advancement might stimulate the grand challenges of sustainable development. Decreasing or preventing the negative consequences of the Fourth Industrial Revolution's digital technology advancement are possible with the help of:

– dissemination of smart resource- and energy-saving technologies;
– development of distant learning and robotisation of education for the mass training of skilled digital personnel.

These issues are studied in several works [29–33].

Zhang et al. [34] note the contribution of Fintech to sustainable development in the digital age, using the example of the Ant Forest scheme and land restoration in China. He and Bai [35] offer recommendations for developing sustainable intelligent manufacturing based on digital twins. McNaughton et al. [36] consider building smart communities for sustainable development based on community tourism in Treasure Beach, Jamaica. Mirghaderi [37] recommends using an artificial neural network for estimating the sustainable development goals index. The leading technologies will allow the monitoring of progress in the sphere of the SDGs' implementation.

Digital technology advancement also allows (potentially) for an effective response to the COVID-19 pandemic and crisis with the help of the following:

– using the leading technologies (in particular, AI) for the development of telemedicine and an increase in the quality and accessibility of public healthcare services;
– increasing quality of life and environmental protection based on smart economic practices.

Singh et al. [38] provide examples of the successful use of three-dimensional printing in the fight against the novel virus COVID-19, substantiating it as a technology that helps society during an infectious disease pandemic. Wongnaa and Babu [39] demonstrate an increase in resilience to climate change shocks in Ghana's cocoa production and its effect on productivity and incomes.

Allam and Jones [40] demonstrate the advantages of future (post-COVID) digital, smart and sustainable cities in the wake of 6G, offering such concepts as digital twins, immersive realities, and new urban economies. Roesch et al. [41] recommend Green-Lean-Digital as a guiding principle for the sustainable factory of the future. Lepore et al. [42] substantiate (using the example of Italian regions) that Industry 4.0 accelerates sustainable manufacturing in the COVID-19 era.

Based on the review of the literature, existing knowledge on the theory of potential digital technology advancement to address the grand challenges of sustainable development is systematised in Table 1.

Thus, as is shown in Table 1, the current theoretical views on digital technology advancement to address the grand challenges of sustainable development are rather detailed. However, they are at the level of hypotheses, which are not proved or disproved, due to a lack of empirical studies and the underdevelopment of the evidential base.

2.2. Research questions and hypotheses

As a result of the literature review, we conclude that a systemic vision of digital technology's contribution to SDGs is still missing. The first gap is assessing the SDGs as a totality, requiring unique approaches for their achievement. The second gap is the lack of a scientific framework to assess the influence of digital technologies on sustainable development results. It is unclear whether it is expedient to stimulate or restrain the growth of digital technologies in the interests of sustainable development.

Therefore, there is a need to further elaborate digital technology development prospects for addressing the grand challenges of sustainable development. A social and economic policy implemented to achieve the SDGs should be oriented to improve the institutional environment through technological development. Since institutional environment differences are one key accepted criterion of differentiation between developed and developing countries, digital technologies' influence on institutions is country-specific and requires different management approaches.

To fill the above gap, we set the following research questions (RQ):

Table 1
Systematisation of the existing knowledge in the theory's sphere of potential digital technology advancement to address the grand challenges of sustainable development.

Consequences of grand challenges	Grand challenges of sustainable development	
	The Fourth Industrial Revolution and the transition to Industry 4.0.	COVID-19 pandemic and crisis and the general cyclicity of the economy (crises).
Influence on sustainable development without technological support for the SDGs	−increase in the resource- and energy-intensity of the economy, growth of ecological costs of economic growth; −systemic automatisation in all sectors and spheres of activities and business processes.	−actualisation of healthcare problems due to the global viral threat; −redirection of investments flows to the healthcare sphere from other spheres.
	Results: inability to address the grand challenges of sustainable development and slow implementation/regress on the SDGs (problem).	
Support for implementing the SDGs with the help of digital technology advancement	−dissemination of smart resource- and energy-saving technologies; −development of distant learning and robotisation of education for the mass training of skilled digital personnel.	−using the leading technologies (AI) for the development of telemedicine, an increase in the quality and accessibility of public healthcare services; −increase in quality of life and environmental protection based on smart economic practices.
	Alternative result: the ability to address the grand challenges of sustainable development and the accelerated implementation of the SDGs (solving the problem).	

Source: Authors' compilation based on literature review [9–42].

RQ1. What is the influence of digital technologies (in practice) on sustainable development: positive, neutral or negative? What are the consequences for each SDG? Taking into account the results of previous scientific research ([43–45]), the following Hypothesis is formulated:

Hypothesis. **H_1:** Digital technologies allow improved results (or achieving) only specific SDGs through institutions' development. The hypothesis is considered proved if the following conditions are simultaneously observed:

- Not all institutions will show average (arithmetic mean for all SDGs), positive and evident (above 10%) correlation with SDGs with moderate (below 400%) variation;
- Only some of the 17 SDGs will show (simultaneously) positive correlation with all selected institutions;
- Not all digital technology development manifestations will show (simultaneously) a high (above 70%) and a positive correlation with institutions.

To check Hypothesis H_1, we gather detailed values of all 17 SDG results separately (average performance by SDG) based on the 2020 UNDP report [W1]. The institutions that potentially stimulate the implementation of SDGs are:

- Total investment, according to "World economic and financial surveys. World Economic Outlook Database (October 2020)" of the International Monetary Fund [W2];
- Human Development Index, according to the "2019 Human Development Index Ranking" of UNDP [W3];
- Index of Economic Freedom, according to the "2020 Index of Economic Freedom: Promoting Economic Opportunity" of the Heritage Foundation [W4];
- Globalisation Index, according to the "Globalization Index 2019" of KOF Swiss Economic Institute [W5];
- Global Innovation Index, according to the "Global Innovation Index 2020" of WIPO [W6].

The manifestations of digital technology development are knowledge, technology and future readiness.

RQ2. How is it possible to ensure the contribution of digital technology advancement to addressing the grand challenges of sustainable development? Taking into account the results of the previous scientific research ([46,47]), the following Hypothesis is formulated:

Hypothesis. **H_2:** The contribution of digital technology advancement to addressing the grand challenges of sustainable development could be achieved under the condition of proper institutional support. The influence of digital technologies on institutions in developed and developing countries is specific and requires different management approaches. The hypotheses are proved if digital technology development that influences SDG implementation diverges in developed and developing countries (a strong correlation of more than 50%). A positive correlation is identified.

3. Data and methods

The research methodology is based on the method of economic statistics. The correlation (factor) analysis method determines the connection between the studied indicators and selects the indicators with positive and strong connections. The choice of this method is explained by its simplicity and the possibility for quick (rapid) receipt of results with the use of official statistics and the possibility to build an idea on the character (positive or negative) and strength (quantitative value) of the connection between the indicators [48].

The method of variation analysis is used to determine the differences between the correlation coefficients and to find disproportion in the contribution of digital technology advancement to addressing the grand challenges of sustainable development. The method of regression analysis is used to specify the ties between the selected indicators. The advantage of regression analysis is the greater precision and detail of the results, which demonstrate not only the character (positive or negative) and strength (quantitative manifestation) of the connection between indicators but also the direction of the indicators' dependence (depending and dependent variables) [49]. The following research model is used in this paper:

$$SDG = a + \sum_{j=1}^{n} b_j * i_j \quad (1)$$

The research model in Formula (1) is a regression equation, which describes mathematically the dependence of the set result on the SDGs on the selected (with the help of previously performed correlation analysis, i.e., the ones that influence it strongly and positively) n institutions of digital technology advancement. The research model (regression equation) allows checking the hypotheses H_1 and H_2; the regression equation is compiled separately for each SDG in developed and developing countries, allowing a system of equations.

We use the simplex method to determine the prospects of improving the grand challenges of sustainable development based on institutional support (development of the institutions of digital technology advancement) and based on the given research model (1). The advantage of this model is the possibility of automatically obtaining the optimal combinations of the control values of the studied variables, which guarantees the greatest precision of the modelling results [50].

We intend to investigate the relationship between digital technology development and the grand challenges of sustainable development, resorting to correlation, regression and variance analyses. The advantage of correlation analysis lies in the possibility of comparison of many indicators to each other. The advantage of the selected regression analysis lies in the maximum accuracy of results and data analytics.

The data employed for this research include results on implementing 17 SDGs in the selected developed and developing countries in 2020, as well as institutions that potentially influence the implementation of SDGs and manifestations of digital technology development in developed and developing countries in 2020: total investment, human development index, index of economic freedom, globalisation index, global innovation index, knowledge, technology, and future-readiness.

The research includes the top 10 developed (Sweden, Denmark, Finland, Germany, France, Norway, Austria, the Czech Republic, the Netherlands and Estonia) and the top 10 developing (Chile, Thailand, China, Brazil, Russia, Malaysia, Peru, Kazakhstan, Mexico and Turkey) countries. The reason for the selection is because these countries have shown the best results in SDG implementation, according to the UNDP ranking ("Sustainable Development Report 2020" for 2020 [W8] (Fig. 1).

Fig. 1 shows that sustainable development results are more apparent in developed countries (81.74 points on average) than in developing countries (72.58 points on average). Considering the generalised sustainable development index, the differences between these categories of countries are small. To perform more in-depth research, let us consider the detailed results for SDGs in developed (Table 2) and developing (Table 3) countries in 2020. We show institutions that potentially influence SDG implementation and digital technology development in developed countries in Table 4 and developing countries in Table 5.

To model the prospects of achieving a manageable SDG with digital technology development, we solve poly-parametric non-linear optimisation using simplex methods. All calculations are performed automatically with the help of standard functions and Microsoft Excel Analysis Toolpak.

4. Results and discussion

4.1. Factor analysis of response to grand challenges of sustainable development

To determine the influence of institutions on SDGs' results, let us use the correlation analysis results from Tables 1–4 (Tables 6 and 7).

Using variation analysis results to select institutions that show the greatest connection between all SDGs (Fig. 2).

As shown in Fig. 2, the following institutions in developed countries showed (arithmetic mean for all SDGs) positive and clearly expressed (above 10%) correlation with SDGs, with moderate (below 400%) variation: innovations (average correlation: 12.36%, variation coefficient: 274.06%), globalisation (average correlation: 14.25%, variation coefficient: 217.68%) and human development (average correlation: 14.34%, variation coefficient: 186.80%). As shown in Table 6, we observe a simultaneous positive correlation with all selected institutions with SDG2, SDG3, SDG4, SDG5, SDG9, SDG10 and SDG17.

Also shown in Fig. 2, the following institutions in developed countries showed (arithmetic mean for all SDGs) positive and clearly expressed (above 10%) correlation with SDGs, with moderate (below 400%) variation: economic freedom (average correlation: 10.47%, variation coefficient: 368.56%) and human development (average correlation: 8.30%, variation coefficient: 698.56%). Table 7 reflects a simultaneous positive correlation with all selected institutions observed with SDG3, SDG3, SDG4, SDG6, SDG7, SDG8, SDG10, SDG11 and SDG16. We show the regression output for developed countries in Table 8 and developing countries in Table 9.

As seen in Table 8, in developed countries, regression equations are statistically significant at the significance level 0.05 only for SDG3 and SDG17. An increase in the human development index by 1 fraction of 1 leads to an increase of SDG3 by 108.24 points. An increase in the globalisation index by 1 point leads to the growth of SDG3 by 1.01 points. An increase in the innovation index by 1 point leads to the growth of SDG3 by 0.02 points. Significance F is 0.0334 (below 0.05), and multiple correlation, 86.18% (high).

Similarly, an increase in the human development index by one fraction of 1 leads to the growth of SDG17 by 646.52 points. An increase in the globalisation index by 1 point leads to a reduction of SDG17 by 3.05 points. An increase in the innovations index by 1 point leads to the growth of SDG17 by 0.82 points. Significance F constitutes 0.0436 (below 0.05), and multiple correlation, 84.73 (high).

As shown in Table 9, only for SDG16, we have a regression equation that is statistically significant at the significance level of 0.05 in developing countries. An increase in the human development index by one fraction of 1 leads to the growth of SDG16 by 43.44 points. An increase of the economic freedom index by 1 point leads to a growth of SDG16 by 0.99 points. Significance F is 0.0484 (below 0.05), and multiple correlation, 76.09% (high).

In developed countries, only SDG3 and SDG17 could be managed with the help of institutions; in developing countries, only SDG16. We shall dwell on these SDGs. The findings better explain the essence of a sustainable development concept, determined by the institutions' development.

4.2. Dependence of sustainable development factors on digital technology development

To determine the dependence of sustainable development factors on digital technology development, consider correlation coefficients (Fig. 3).

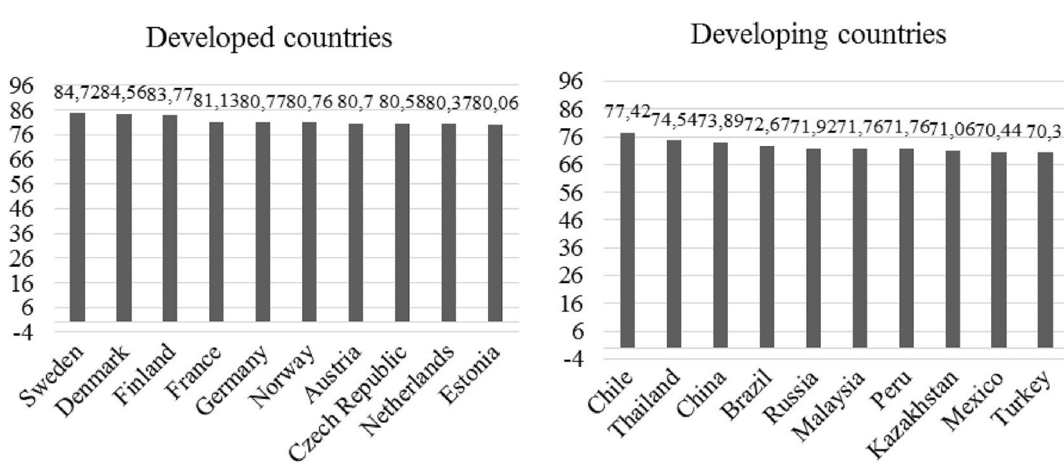

Fig. 1. Sustainable Development Index in the selected countries in 2020, points 1–100.
Source: Built by the authors based on [W1]

Table 2
Results in implementing 17 SDGs in the selected developed countries in 2020, points 1–100.

Country	SDG1	SDG2	SDG3	SDG4	SDG5	SDG6	SDG7	SDG8	SDG9	SDG10	SDG11	SDG12	SDG13	SDG14	SDG15	SDG16	SDG17
Sweden	99	69	97	100	90	96	99	80	98	96	94	59	70	52	79	82	90
Denmark	99	73	96	99	80	85	94	80	98	98	93	47	60	58	96	96	80
Finland	100	60	92	98	90	92	97	80	88	97	80	53	65	66	80	95	70
France	100	68	94	100	80	80	97	77	85	84	86	55	75	66	67	75	70
Germany	100	69	95	99	76	80	95	81	92	80	89	52	60	51	77	79	78
Norway	99	60	97	99	88	78	99	79	90	100	85	76	23	70	72	83	100
Austria	100	73	91	99	78	90	96	79	92	89	90	48	53	100	69	97	63
Czech Republic	100	63	90	98	68	84	91	80	78	96	94	71	71	100	95	81	50
Netherlands	100	70	97	100	78	80	82	79	80	97	95	48	57	51	79	80	60
Estonia	99	60	81	97	75	88	89	88	75	77	94	57	55	79	97	86	45

Source: Compiled by the authors based on [W1]

Table 3
Results in implementing 17 SDGs in the selected developing countries in 2020, points 1–100.

Country	SDG1	SDG2	SDG3	SDG4	SDG5	SDG6	SDG7	SDG8	SDG9	SDG10	SDG11	SDG12	SDG13	SDG14	SDG15	SDG16	SDG17
Chile	99	70	79	98	68	96	95	78	60	31	79	78	83	69	55	75	81
Thailand	100	62	76	84	70	76	79	78	52	61	80	77	84	66	68	72	58
China	98	75	78	96	75	70	71	83	73	62	75	85	86	50	55	58	45
Brazil	83	71	77	80	72	82	94	68	55	25	78	78	97	73	54	53	75
Russia	100	50	76	98	68	74	89	78	68	52	80	77	76	50	69	50	71
Malaysia	100	53	77	88	53	76	90	79	73	55	80	76	77	54	40	73	52
Peru	87	60	77	97	70	78	80	75	34	37	75	83	96	79	54	55	54
Kazakhstan	99	53	76	88	76	78	81	76	42	60	80	75	71	100	55	73	50
Mexico	84	54	79	100	76	77	81	74	48	23	79	79	83	75	47	52	62
Turkey	100	57	78	99	47	75	83	71	56	37	72	79	84	48	52	68	73

Source: Compiled by the authors based on [W1]

Table 4
Institutions that potentially influence the implementation of SDGs, and manifestations of digital technology development in developed countries in 2020, points 1–100.

Country	Total investment, % of GDP	Human development index, fractions of 1	Index of economic freedom, points 1–100	Globalisation index, points 1–100	Global innovation index, score 0–100	Knowledge, points 1–100	Technology, points 1–100	Future Readiness, points 1–100
	i_1	i_2	i_3	i_4	i_5	i_6	i_7	i_8
Sweden	24.491	0.937	74.9	89.93	62.47	89.199	88.348	92.393
Denmark	21.232	0.930	78.3	88.26	57.53	86.145	86.394	100.00
Finland	24.567	0.925	75.7	87.70	57.02	80.438	86.270	91.184
France	22.729	0.891	66.0	87.25	53.66	71.021	80.046	64.384
Germany	21.382	0.939	73.5	88.60	56.55	81.028	67.851	78.809
Norway	26.744	0.954	73.4	86.17	49.29	78.196	89.874	92.943
Austria	26.181	0.914	73.3	88.85	50.13	81.821	70.113	81.948
Czech Republic	25.895	0.891	74.9	85.60	48.34	60.941	64.740	61.197
Netherlands	20.935	0.933	77.0	90.71	58.76	80.839	87.618	93.745
Estonia	25.237	0.882	77.7	83.77	48.28	69.565	72.565	76.461

Source: Compiled by the authors based on [W2, W3, W4, W5, W6, W7]

Table 5
Institutions that potentially influence the implementation of SDG, and manifestations of digital technology development in developing countries in 2020, points 1–100.

Country	Total investment, % of GDP	Human development index, fractions of 1	Index of Economic Freedom, points 1–100	Globalisation Index, points 1–100	Global innovation index, score 0–100	Knowledge, points 1–100	Technology, points 1–100	Future Readiness, points 1–100
	i_1	i_2	i_3	i_4	i_5	i_6	i_7	i_8
Chile	22.085	0.847	76.8	77.74	33.86	49.501	60.318	59.236
Thailand	24.019	0.765	69.4	72.44	36.68	54.193	73.168	49.936
China	43.922	0.758	59.5	65.08	53.28	85.105	71.706	80.004
Brazil	14.653	0.761	53.7	60.52	31.94	44.349	44.818	51.618
Russia	22.865	0.824	61.0	72.45	35.63	67.891	51.653	44.807
Malaysia	21.581	0.804	74.7	81.49	42.42	73.636	74.771	64.048
Peru	19.234	0.759	67.9	70.35	28.79	46.924	44.739	43.198
Kazakhstan	28.302	0.817	69.6	64.45	28.56	62.942	57.292	63.839
Mexico	19.260	0.767	66.0	72.56	33.60	48.874	45.179	44.976
Turkey	28.174	0.806	64.4	71.58	34.90	46.294	54.402	63.274

Source: Compiled by the authors based on [W2, W3, W4, W5, W6, W7]

As shown in Fig. 3, the institution of human development in developed countries has a high correlation with digital knowledge (75.16%) and digital technologies (77.16%); the institution of globalisation, only with digital knowledge (74.15%); the institution of innovations, only with digital knowledge (74.92%). Fig. 3 shows no high correlation in developing countries; more detailed characteristics of the connection between these indicators are presented in Table 10. These results mean digital technologies contribute poorly to the development of institutions and, through them, to SDG implementation. We can consider the most prominent (though statistically insignificant) connections between the institutions of human development and digital infrastructure (9.94%) and digital technologies (11.71%) and between the institutions of economic freedom and digital infrastructure (40.86%) (Table 11).

An increase in the digital knowledge level by 1 point in developed countries leads to the growth of the human development index by 0.1% (Table 10). An increase in digital technology application activity by 1 point leads to the growth of the human development index by 0.09%. Significance F equals 0.0305 (less than 0.05), and multiple correlations are high, 79.44%. An increase in the digital knowledge level by 1 point leads to the growth of the human development index by 18%. Significance F equals 0.0141 (less than 0.05), and the correlation is high, 74.15%. An increase in the digital knowledge level by 1 point leads to the growth of the human development index by 44%. Significance F equals 0.0126 (less than 0.05), and the correlation is high, 74.92%.

There is no multicollinearity since the cross-correlation of factor variables (digital knowledge index and digital technology index) is 84.22%. The White test does not find heteroscedasticity at a 5% significance level Fact < Ftab. P-probability of acceptance of the heteroscedasticity Hypothesis equals 0.0305, 0.0141 and 0.0126 (Significance F for all three regression models), below 0.05.

As shown in Table 11, an increase in developing countries' digital infrastructure development by 1 point leads to the growth of the human development index by 0.0001 fractions of 1. An increase in digital technology application activity by 1 point leads to the growth of the human development index by 0.0003 fractions of 1. Significance F equals 0.9492 (over 0.05), and multiple correlations are low, 12.16%. An increase in digital infrastructure development by 1 point leads to the growth of the economic freedom index by 0.24 fractions of 1. Significance F equals 0.2411 (over 0.05), and the correlation is moderate, 40.86%.

There is no multicollinearity since the cross-correlation of factor variables (digital knowledge index and digital technologies index) is 63.05%; the results of the White test show heteroscedasticity at 5% significance level Fact < Ftab. The P-probability of acceptance of the heteroscedasticity Hypothesis equals 0.9492 and 0.2411 (Significance F for the two regression models), above 0.05.

The increase in efficiency in SDG3 and SDG17 in developed countries implies human development, globalisation and innovations by mastering digital knowledge and increased digital activity technologies. In developing countries, the possibilities of the development of institutions based on digital technologies are minimal. The results provide a better explanation of digital technology's essence as an economic category, reflecting its contribution to implementing SDGs through assistance in developing institutions (i.e., human development, globalisation, innovation and economic freedom).

Table 6
Correlation between the results on SDGs and the institutions in developed countries, %.

Correlation, %	SDG1	SDG2	SDG3	SDG4	SDG5	SDG6	SDG7	SDG8	SDG9	SDG10	SDG11	SDG12	SDG13	SDG14	SDG15	SDG16	SDG17
Total investment	−19.06	−55.55	−40.49	−44.96	11.39	31.69	38.93	16.37	−16.41	11.28	−21.11	66.17	−36.41	73.08	−5.96	20.66	−2.83
Human development	−21.89	**18.56**	**78.55**	**46.49**	**60.76**	−11.02	27.04	−37,58	**66.35**	**53.34**	−21.00	2.45	−51.36	−57.79	−34.26	9.35	**82.10**
Economic freedom	−39.77	−6.94	−19.60	−43.85	−5.44	31.15	−46.06	54.99	−3.69	27.40	43.86	−15.36	−19.28	−8.19	72.78	49.16	−18.59
Globalisation	26.98	**72.60**	**74.64**	**79.21**	**32.32**	12.44	−4.90	−58.41	**55.00**	**35.35**	10.80	−54.88	18.88	−52.83	−43.88	3.35	**35.53**
Innovations	−3.27	**46.20**	**62.95**	**60.84**	**50.41**	29.86	4.35	−29.85	**55.65**	**28.00**	6.65	−49.57	38.26	−81.66	−12.78	−3.69	**41.42**

Source: Compiled by the authors

Table 7
Correlation between the results on SDGs and the institutions in developing countries, %.

Correlation, %	SDG1	SDG2	SDG3	SDG4	SDG5	SDG6	SDG7	SDG8	SDG9	SDG10	SDG11	SDG12	SDG13	SDG14	SDG15	SDG16	SDG17
Total investment	52.91	30.00	7.64	25.31	5.64	−45.97	−69.98	63.30	39.62	63.13	−36.89	47.32	−27.40	−31.90	9.80	15.90	−51.27
Human development	**60.58**	−31.92	**4.00**	**27.13**	−33.46	**50.13**	**55.50**	**14.30**	25.00	**5.61**	**27.63**	−56.17	−65.37	−4.45	5.47	**48.95**	45.05
Economic freedom	**43.51**	−27.34	**14.52**	**16.87**	−24.42	**44.91**	**15.36**	**38.50**	−9.01	**14.93**	**31.64**	−34.04	−44.28	19.34	−26.01	**75.15**	−8.59
Globalisation	41.05	−37.87	23.53	34.46	−53.03	24.02	29.96	36.61	30.41	2.29	23.94	−26.39	−35.86	−36.16	−25.18	41.99	12.41
Innovations	36.90	38.94	18.89	8.28	−9.42	−43.82	−39.78	66.78	79.72	48.25	−16.06	44.87	−8.53	−67.79	−10.47	1.17	−40.32

Source: Compiled by the authors.

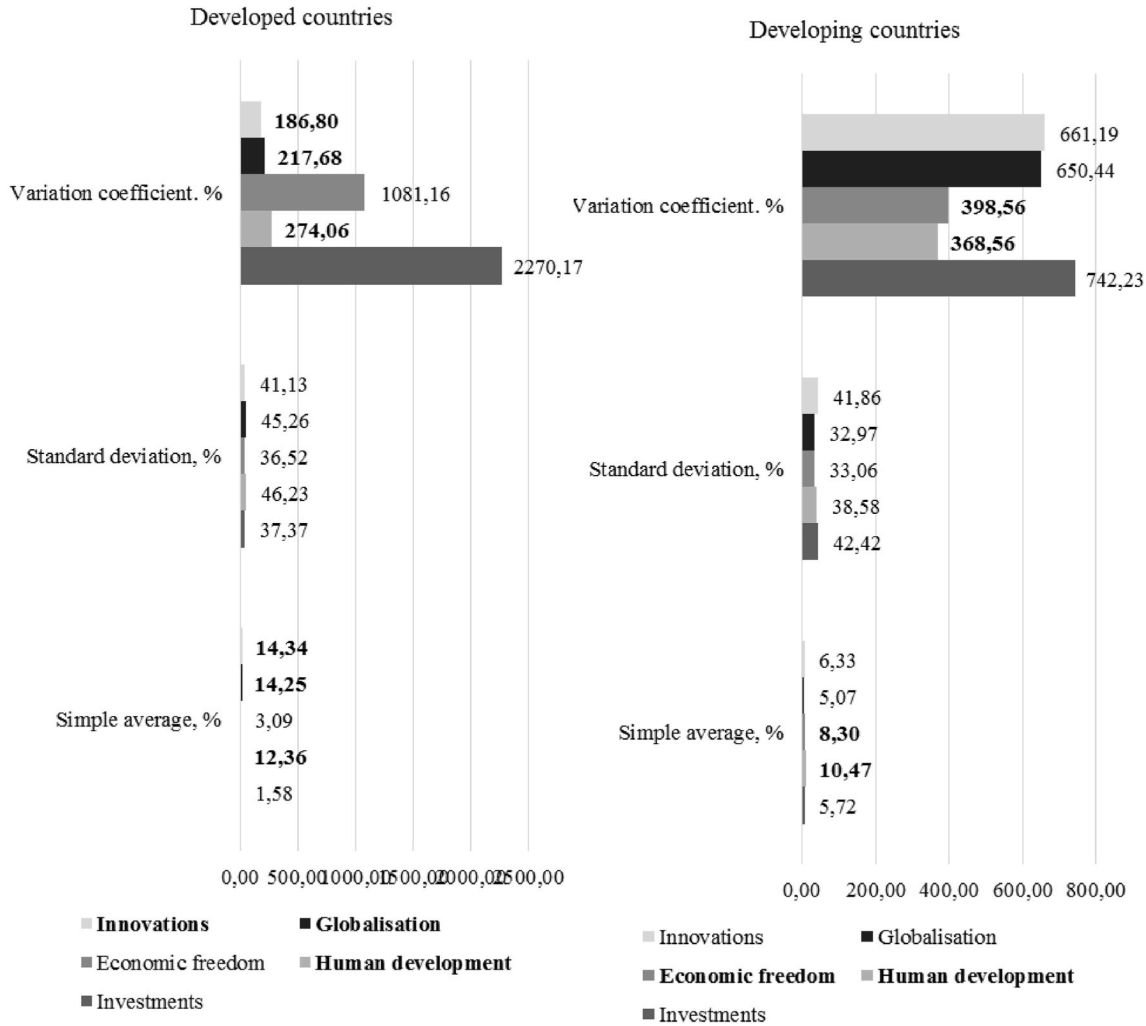

Fig. 2. Analysis of variation of correlation coefficients and selection of the statistically significant connections and indicators (SDGs and their factors), %.
Source: Calculated and compiled by the authors

Table 8
Regression statistics of the dependence of the results on manageable SDGs on developed countries' selected factors.

Regression statistics	SDG2	SDG3	SDG4	SDG5	SDG9	SDG10	SDG17
Multiple R	0.8018	0.8618	0.7934	0.7076	0.7097	0.5378	0.8473
F table	3.5995	5.7746	3.3973	2.0059	2.0298	0.8139	5.0883
Significance F	0.0852	**0.0334**	0.0945	0.2147	0.2113	0.2113	**0.0436**
Y-intercept	−105.99	−95.87	63.84	25.71	−104.74	−104.74	−301.20
Human development index, fractions of 1	−74.34	108.24	0.37	174.21	165.79	165.79	646.52
Globalisation index, points 1-100	2.94	1.01	0.41	−1.74	0.20	0.20	−3.05
Global innovation index, points 0-100	−0.31	0.02	−0.01	0.86	0.41	0.41	0.82

Source: Calculated and compiled by the authors

Table 9
Regression statistics of the dependence of the results for manageable SDGs on developing countries' selected factors.

Regression statistics	SDG1	SDG3	SDG4	SDG6	SDG7	SDG8	SDG10	SDG11	SDG16
Multiple R	0.6225	0.1507	0.2734	0.5485	0.5761	0.3904	0.1513	0.3429	0.7609
F table	2.2146	0.0814	0.2827	1.5064	1.7387	0.6293	0.0820	0.4664	4.8139
Significance F	0.1798	0.9227	0.7620	0.2857	0.2438	0.5606	0.9222	0.6454	**0.0484**
Y-intercept	−7.56	76.77	46.61	−1.14	−21.19	66.67	31.02	60.91	−36.88
Human development index, fractions of 1	115.19	−1.69	55.04	78.64	149.65	−9.88	−13.37	13.35	43.44
Index of economic freedom, points 1-100	0.17	0.03	0.04	0.26	−0.19	0.26	0.36	0.10	0.99

Source: Calculated and compiled by the authors

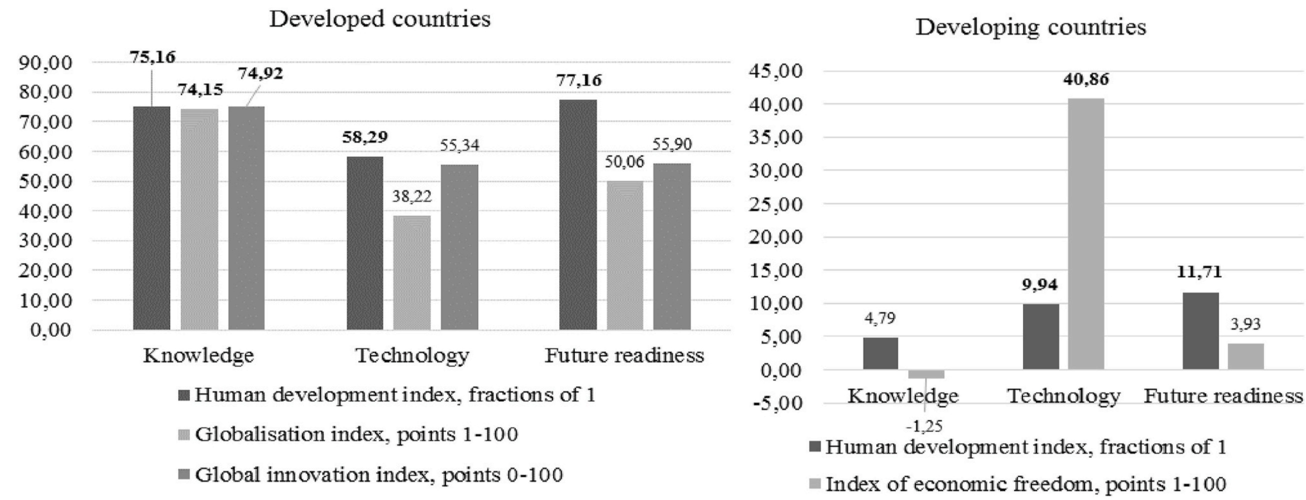

Fig. 3. Correlation coefficients and selection of the statistically significant connections and indicators (factors and digital technologies), %.
Source: Calculated and compiled by the authors

Table 10
Regression statistics of the dependence of the selected factors on digital technology development in developed countries.

Regression statistics	Human development index, fractions of 1	Globalisation index, points 1–100	Global innovation index, points 0–100
Multiple R	0.7944	0.7415	0.7492
F	5.9857	9.7736	10.2388
Significance F	0.0305	0.0141	0.0126
Y-intercept	0.77	73.45	19.67
Knowledge, points 1–100	0.0010	0.18	0.44
Future readiness, points 1–100	0.0009	–	–

Source: Calculated and compiled by the authors

Table 11
Regression statistics of the dependence of the selected factors on digital technology development in developed countries.

Regression statistics	Human development index, fractions of 1 1	Index of economic freedom, points 0–100
Multiple R	0.1216	0.4086
F	0.0526	1.6033
Significance F	0.9492	0.2411
Y-intercept	0.7698	52.3979
Technology, points 1–100	0.0001	0.24
Future readiness, points 1–100	0.0003	–

Source: Calculated and compiled by the authors

4.3. Implications for digital technology development for addressing the grand challenges of sustainable development

To determine the prospects of digital technology development for addressing the grand challenges of sustainable development, let us plan and solve polycriterial optimisation, which condition is maximising the results of SDG3 and SDG17 in developed countries through the development of institutions (not exceeding the maximum allowable values) and through the development of digital technologies (not exceeding the maximum permissible values). We show the solution to this task in Fig. 4.

Fig. 4 shows an increase of the level of digital knowledge in developed countries up to a maximum of 100 points (+28.34% as compared to 2020) and application of digital technologies up to a maximum of 100 points (+20.04%) leads to the growth of the institution of human development up to 0.96 (+4.01%), the institution of globalisation, up to 91.72 points (+4.60%), and the institution of innovations, up to 63.99 points (+18.06%). The result on SDG3 grows up to 100 points (+8.84%), and the result on SDG17 up to 90.18 points (+27.73%). For developing countries, a similar task of optimisation for SDG16 is formulated. We show its solution in Fig. 5.

Fig. 5 reflects the development of digital infrastructure in developing countries up to a maximum of 100 points (+73% as compared to 2020). The activity of digital technologies application up to a maximum of 100 points (+77.01%) leads to the growth of the institution of human development up to 0.81 (+2.01%), and the institution of economic freedom up to76.45 points (+15.31%). As a result, SDG16 reaches 73.60 points (+17.02%).

4.4. A systemic view of addressing the grand challenges of sustainable development based on digital technology development

To form a systemic view of addressing the grand challenges of sustainable development based on digital technology development, we perform a quantitative and qualitative analysis (Table 12).

The SDGs (with low or moderate values) in developed countries are the following ones: SDG2 (moderate value: 66.50 points), SDG12 (low value: 56.60 points), SDG13 (low value: 58.90 points) and SDG14 (moderate value: 69.30 points). The results could be significantly improved only for two of them by developing institutions based on digital technologies: SDG3 (moderate value: 66.50 points, could be increased up to 100 points) and SDG17 (moderate value: 70.60 points, could be increased up to 90.18 points). For the remaining SDGs, the results are high or very high in developed countries.

In developing countries, the problem SDGs (with low or moderate values) are the following ones: SDG 2 (moderate value: 60.50 points), SDG5 (moderate value: 67.50 points), SDG9 (low value: 56.10 points), SDG10 (low value: 44.30 points), SDG14 (moderate value: 66.40 points), SDG15 (low value: 54.90 points) and SDG17 (low value: 62.10 points). Only for one SDG the results could significantly improve through the development of institutions based on digital technologies: SDG16 (low value: 62.90 points could be increased up to 73.60 points), given the low probability of achieving the positive effect.

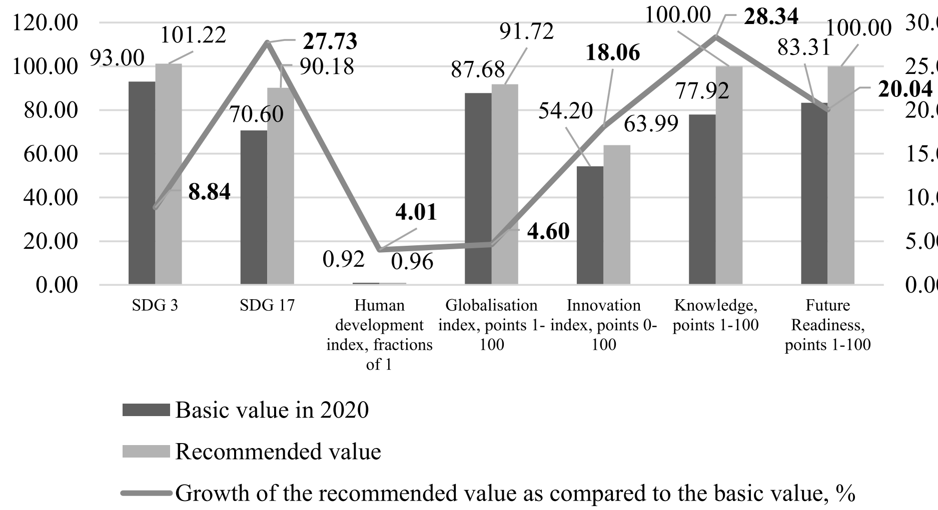

Fig. 4. Strategy milestones of managing digital technology development for addressing the grand challenges of sustainable development in developed countries. Source: Calculated and compiled by the authors

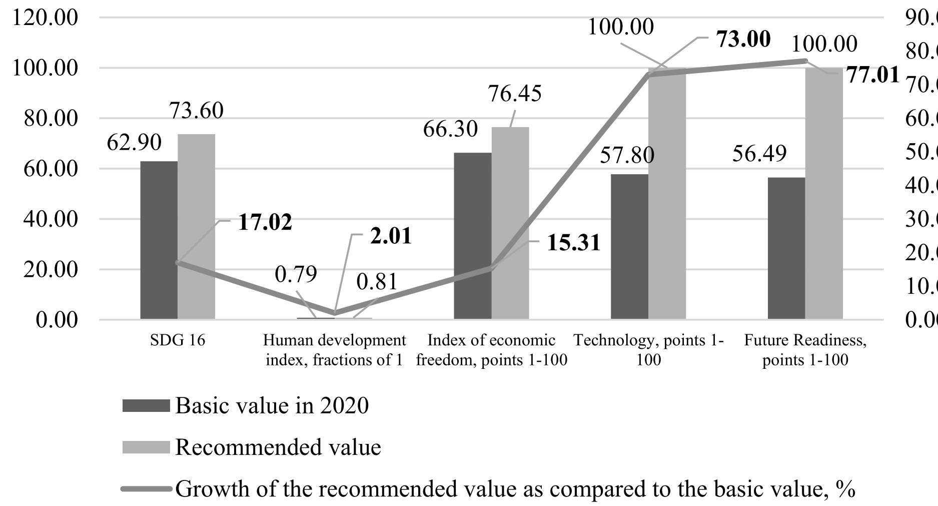

Fig. 5. Strategic milestones of managing digital technology development for addressing the grand challenges of sustainable development in developing countries. Source: Calculated and compiled by the authors

4.5. Discussion

This paper's findings answer the two research questions.

RQ1: digital technology development's quantitative influence on implementing SDGs is positive. This allows using digital technologies as an advanced tool for SDGs, although various aspects of digital technology development contribute differently to implementing SDGs. The institution of human development in developed countries has a high correlation with digital knowledge (75.16%) and digital technologies (77.16%), the institution of globalisation, only with digital knowledge (74.15%) just like the institution of innovations (74.92%). In developing countries, digital technologies contribute poorly to the development of institutions and, through them, to SDG implementation. One can observe the most prominent (though statistically insignificant) connections between the institutions of human development and digital infrastructure (9.94%) and digital technologies (11.71%) and between the institutions of economic freedom and digital infrastructure (40.86%).

RQ2: contributes indirectly to digital technology development in implementing SDGs, a contribution mediated by social institutions. The increase of efficiency in SDG3 and SDG17 in developed countries envisages human development, globalisation and innovations by mastering digital knowledge and increased digital activity technologies. In developing countries, institutions based on digital technologies are limited (beneficial effect of implementation can be reduced by 50–70% due to weak correlation of indicators and inadequate reliability of models (heteroscedasticity test and F-test fail).

Thus, compared to the previous key studies, this paper shows that the influence of digital technologies on sustainable development is ambiguous – it is positive for some SDGs and harmful for others. Unlike the existing publications, this paper demonstrates the experience of studying not the direct but the indirect influence of digital technologies on sustainable development, which institutions mediate. On the example of a large sample of developed and developing countries, the new methodological approach allows to determine the indirect ties between all results of the SDGs and the development of digital technologies.

The contribution of this paper to the literature resides in the development of a new theoretical and methodological approach to studying the influence of digital technologies on sustainable development, formation of the systemic view on digital technology advancement to address the grand challenges of sustainable development and the scientific elaboration of the institutional basis of digital technology advancement to address the grand challenges of sustainable

Table 12
Quantitative and qualitative analysis of the prospects of addressing the grand challenges of sustainable development based on digital technology development.

Sustainable development goals	Developed countries		Developing countries	
	The average value in 2020, points	Treatment and prospects of growth based on digital technologies	The average value in 2020, points	Treatment and prospects of growth based on digital technologies
SDG1	99.60	The goal is achieved	95.00	Very high value
SDG2	66.50	**Moderate value**	60.50	**Moderate value**
SDG3	93.00	**High value. The goal could be achieved (up to 100 points) based on digital technologies**	77.30	High value
SDG4	98.90	Very high value	92.80	Very high value
SDG5	80.30	High value	67.50	**Moderate value**
SDG6	85.30	High value	78.20	High value
SDG7	93.90	Very high value	84.30	High value
SDG8	80.30	High value	76.00	High value
SDG9	87.60	High value	56.10	**Low value**
SDG10	91.40	Very high value	44.30	**Low value**
SDG11	90.00	Very high value	77.80	High value
SDG12	56.60	**Low value**	78.70	High value
SDG13	58.90	**Low value**	83.70	High value
SDG14	69.30	**Moderate value**	66.40	**Moderate value**
SDG15	81.10	High value	54.90	**Low value**
SDG16	85.40	High value	62.90	**Low value could be increased up to 73.60 points based on digital technologies.**
SDG17	70.60	**Moderate value. It could be increased up to 90.18 points based on digital technologies.**	62.10	**Low value**

Source: Calculated and compiled by the authors

development and substantiation of the specifics of developed and developing countries.

5. Conclusions

The paper has built social and economic policy implications on digital technology development for addressing the grand challenges of sustainable development. This paper contains valuable information based on analysing the top 10 developed and the top 10 developing countries. It shows that the development of digital technologies is suitable for addressing the grand challenges of sustainable development.

The policy implication for developed countries comprises maximising (bringing up to 100 points) the digital knowledge index and digital technologies index in developed countries to enhance the efficiency on SDG3 to 100 points (+8.84%) and SDG17 up to 90.18 points (+27.73%). It is hard to guarantee sustainable development results for the insufficient statistical significance of regression connections in developing countries. Social and economic policy on digitalisation should maximise the digital technologies application's digital infrastructure and activity. This may ensure—with moderate probability—the increase of results in the sphere of SDG16, up to 73.60 points (+17.02%).

Factor analysis of the grand challenges of sustainable development revealed that only two SDGs in developed countries (SDG3 and SDG17) might show progress based on the development of institutions (i.e., human development, globalisation, innovation, human development, and economic freedom). In developing countries, it is only SDG16. Institutions in developed countries contribute to the development of healthcare and international economic cooperation and partnership, and in developing countries, to improve justice (i.e., SDG16).

Institutions in developed and developing countries must accept divergent directions (i.e., human development, globalisation and innovation in developed countries; human development and economic freedom in developing countries). Sustainable development factors have revealed a conflicting dependence on digital technology development. In developed countries, the institutions of human development, globalisation and innovations influence SDG3 and SDG17, which depend on digital knowledge and the application of digital technologies. In developing countries, the institutions of human development and economic freedom, which rely on digital infrastructure and digital technologies, affected the results of SDG16.

Addressing the grand challenges of sustainable development, based on digital technology development, has shown many problematic SDGs in developed and developing countries (SDG3 and SDG17 in developed countries and SDG16 in developing countries). We could improve only a minor part of them via simple digital technology development. This indicates that the development of digital technology exercises a negative or neutral influence on SDGs (SDG1–2, 4–15). The policy implication for developing countries is that developing digital infrastructure in developing countries increased +73% compared to 2020 and the activity of digital technologies application up to +77.01%.

Prospective studies could figure out alternate SDGs based on other mechanisms beyond the development of digital technology. Management consequences are related to the need for broader digital technologies in implementing SDGs since it allows remarkable results, especially in developed countries. It involves future research with the methodological consideration of the prospects for developing "smart" cities and, more generally, digital ecosystems to improve SDGs, observing this paper's findings [51–53].

Author statement

All authors contributed equally to this paper.

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Annex 1

Sustainable Development Goals (SDGs) or Global Goals are a collection of 17 interlinked global goals designed to be a blueprint to achieve a better and more sustainable future for all. The SDGs were set in 2015 by the United Nations General Assembly and are intended to be achieved by the year 2030. They are included in a UN Resolution called the 2030 Agenda or what is colloquially known as Agenda 2030.

SDG 1–17 include:

Goal 1: No poverty.
Goal 2: Zero hunger.
Goal 3: Good health and well-being.
Goal 4: Quality education.
Goal 5: Gender equality.
Goal 6: Clean water and sanitation.
Goal 7: Affordable and clean energy.
Goal 8: Decent work and economic growth.
Goal 9: Industry, innovation, and infrastructure.
Goal 10: Reducing inequalities.
Goal 11: Sustainable cities and communities.
Goal 12: Responsible consumption and production.
Goal 13: Climate action.
Goal 14: Life below water.
Goal 15: Life on land.
Goal 16: Peace, justice and strong institutions.
Goal 17: Partnership for the goals.

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