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DIGITAL AND GREEN ECONOMY: COMMON GROUNDS AND CONTRADICTIONS[1]

Introduction. *The processes of digitalization of an economy, associated with the deployment of technologies of the Fourth Industrial Revolution, are multifaceted and have a significant impact, including on the environment, which affects the interests of future generations.*

Problem Statement. *Acceleration of digitalization is accompanied by contradictory positive and negative effects on the environment. In this regard, the identification of these effects at both the global and national levels is an urgent problem.*

Purpose. *The purpose is to identify the relationship between the digital and green economy and to substantiate ways of environmentally safe development of digital technologies in Ukraine.*

Materials and Methods. *Clustering of world countries on the basis of economic, industrial, and digital development; econometric analysis of the relationships between the ICT development index and the environmental performance index in the world countries and their groups (clusters) for 2017—2020.*

Results. *It has been established that at the global level, the introduction of state-of-the-art digital technologies has a generally positive relationship with the state of environment: the higher the level of digitalization, the more environment friendly national economies, other things being equal. It has been found that the environmental performance of digitalization depends on the level of manufacturing (tangible) technologies and the overall economic development. In the clusters of less developed coun-tries, including Ukraine that has significant problems in industry and innovation, the spread of digital technologies has less positive impact on the environment than in the clusters of more advanced econ-omies. Therefore, the long-term positive effects of digitalization for Ukraine are not obvious, while the negative ones may have serious negative consequences.*

[1] The research has been made in the framework of *Long-Term Factors and Trends in National Industry in the Fourth Industrial Revolution* project and *The Impact of Digitalization on Sustainable Development in the Conditions of Global Instability* target research program of the NAS of Ukraine.

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Conclusions. *To minimize the environmental risks of digitalization processes in Ukraine, it is necessary to develop a national academic program for comprehensive assessment of effects of various aspects (abiotic, biotic, anthropogenic) of digital technologies on environment, as well as to harmonize economic digitalization programs with the overall strategy for innovation-driven national manufacture.*

Keywords: digital technologies, digitalization of economy, industry, sustainable development, ecological footprint, and environmental performance.

In long-term strategies of innovation-oriented industrial advanced economies and emerging markets (USA, European Union, Scandinavian countries, Japan, South Korea, etc.), digitalization and greening of economy are considered complementary and such that promote inclusive, socially responsible and sustainable development. In Communication of the EU Commission to the European Parliament [1], the creation of digital green industrial ecosystems and, consequently, the achievement of climate-neutral digital leadership in industry have been identified as priorities for the upcoming decades to maintain the overall competitive advantage and geopolitical influence of the European Union.

The economy digitalization, like any new understudied phenomenon, is associated not only with ample opportunities but also with challenges, including environmental ones, and with qualitative transformations of the ecological footprint structure. On the one hand, according to European experts, provided that the current trends continue, by 2020 the share of the ICT sector in global CO_2 emissions may increase from today's 2% to 14% [2]. On the other hand, the target use of "green" ICTs to decarbonize the world economy may result in reducing greenhouse gas emissions by 15%, i.e. decreasing the man-made burden on the global ecosystem and achieving carbon neutrality of the ICT industry.

In addition, the ever-growing "digital divide" [2] between the innovative leaders and the less technologically developed economies is contributing to the conservation of outdated environmentally dangerous and resource-intensive technological structures, which casts a role for the latter as raw material colony and hazardous waste endpoint. A clear evidence of such an "institutional-environment trap" is the map of e-waste emigration (Fig. 1).

The logistical flows of e-waste shown in the figure indicate certain patterns in the geopolitical distribution of the links of global value chains. Ecologically "clean" and economically prosperous countries with a strict environment legislation and a high cost of legal disposal of electronic waste, prefer to import them to less developed regions with a relatively loyal attitude to environmentally dangerous economic activities and cheap manual labor. An exception is China, which is both the largest producer of digital products and a place for the accumulation of electronic waste.

The connection between ecology and digitalization manifests itself in the fact that high environment requirements in advanced economies have created barriers to spreading digital technologies. Environment standardization of product life cycle increases the transaction costs of quality control, manufacturing and operating conditions, after-sales environment friendly disposal of electronic products and related infrastructure. Failure (technical and/or financial) to meet the established quality standards is one of the most common market barriers in the international and domestic markets. Influential environment lobbies in central and local government [3], as well as protest movements by environment organizations, create a negative image of developers of potentially dangerous innovations, hinder economic

[2] There are 5 key indicators (per capita), for which the digital inequality between countries is the most obvious: (1) coverage of users by mobile broadband networks; (2) the number of IT professionals; (3) investment in ICT versus GDP; (4) the number of downloaded applications; (5) the number of installed Internet of Things (IoT) databases [3].

[3] In France, 68 local authorities, including the mayors of 11 major cities, are demanding that the government ban 5G communications.

Fig. 1. Map of distribution of countries by income and e-waste emigration, according to [4, 14, 23]

development and R&D progress, and increase investment risks and tax burden on business. At the same time, the environmental consequences of digital innovation may be really difficult to predict. For example, increasing intensity of wave radiation as a result of the development of digital communications provokes growing number of congenital genetic mutations in living species (birds, fish, insects, etc.), changes in their basic behavioral responses (especially in the species characterized by social way of life: ants, wasps, bees, termites, bumblebees and etc.), changes in their migration routes and habitats, which disrupts the established food chains in ecosystems and leads to a reduction in biodiversity and, in some cases, to the collapse of ecosystems [29, 12—13, 18—21]. The mass extinction of bees causes a reduction in the pollination of fruit crops and some plant species, which can fatally affect the range and quantity of food [5].

As the European experience has shown [2, 6], combining the imperatives of Industry 4.0 with the imperatives of climate and environment emergencies requires radical reforms in the transport and energy sectors of industry, and, accordingly, huge capital investments. According to preliminary estimates, the European Union needs an investment of about EUR 3 trillion to achieve the ambitious goals of climate-neutral digital industry leadership. For the period from 2021 to 2027, the main financial burden is expected to be shared between the European Investment Bank (about EUR 600 billion), the private sector (about EUR 300 billion), governments of EU member states (about 100 billion euros), and the EU budget (about EUR 7.5 billion). Because of this, this initiative has been criticized in the context of unjustified tax increase and uncontrolled use of budget resources by officials under the pretext of environment goals.

These examples have shown that digital and green economies have obvious points of contact, which, on the one hand, may give a new impetus to the sustainable development of national economies and, on the other hand, may create new problems associated with unpredictable consequences that are different for different countries. In this regard, the purpose of this research is to identify the relationship between digital economy and green economy and to substantiate the ways of environmentally safe development of digital technologies in Ukraine.

Environment effects of digitalization

The immediate positive environment effect of digitalization is dematerialization. Transition to electronic document control, digital services and products in trade, banking, and administrative spheres, replacement of physical logistics flows by remote means of communication based on digital technologies (e-mail and bulletin boards, video conferencing, electronic exchanges, e-government services, etc.) have caused a reduction in time, financial, and material resources extracted from the natural environment. As a result, the amount of waste generated by enterprises, organizations, and end users decreases, which consequently sig-

Table 1. **Environment Advantages of Digitalization**

Manifestations	Causal-related environment effects		Consequences for ecosystems
Transition to electronic document control Expansion of commercial and administrative digital services Spread of digital remote means of communication Use of "smart" automatic systems in industry and everyday life	Dematerialization of goods and services Reduction of physical logistics flows Flexible response to changes in environment conditions in real time to ensure the most efficient use of resources and to minimize costs Customization of production Improvement of production monitoring systems, reduction of risks associated with equipment failures (due to undetected technical malfunc-tions, human factor, etc.)	Saving of renewable and non-renewable natural resources Reduction of pollutant emissions into the environment (emissions, discharges, waste disposal) Reduction of risks of manmade disasters	Reduction of mancaused load

Table 2. **Environment Disadvantages of Digitalization**

Manifestations	Causal-related environment effects	Consequences for ecosystems
Expansion of the range of devices Increase in the number of devices as a result of growing demand Increase in the duration of use of devices during the day Change / emergence of new technologies of in-formation signal transmission Accelerated change of device generations (early termination of operation) caused by manufacturers' efforts to gain a monopoly quasirent	Increasing energy consumption (industrial and domestic) Increasing greenhouse gas emissions Increasing industrial consumption of rare earth metals Increasing electronic waste, including that containing toxic substances Increasing risk of industrial accidents because of the imperfection of digital technologies and the accumulation of errors and failures in the systems Increasing intensity of wave radiation per unit area Manifestation of understudied adverse ef-fects in the structure of genomes, the opera-tion of reproductive systems and the behavioral reaction of living organisms Growing consumption of natural resources as a result of aggressive advertising and unfair competition (intentional technological incompatibility of software and hardware, industrial espionage, trade wars)	Disruption of the cycle of substances in ecosystems Disruption of food chains and reduction of habitats of organisms, reduction of biodiversity of ecosystems Distortion of the system of social values

nificantly reduces the anthropogenic burden on ecosystems in certain areas of resource consumption and pollutant emissions. On the other hand, expanding range of and growing demand for devices, as well as increasing time of their daily use significantly affect (raise) energy consumption and, therefore, entail growth in greenhouse gas emissions.

A more purposeful and environment friendly effect of digitalization is the "smartness" of automated (robotic) industrial systems, which improves real-time monitoring and control systems, increases the efficiency of business processes and reduces costs. Smart power systems, ventilation and climate control systems in smart buildings, 3D printing, automated product quality control systems, industrial robotics, smart logistics, etc., contribute to the customization of production, resource savings, inventory optimization, timely troubleshooting, prevention of failures and emergencies and, as a consequence, reduction in man-caused load on ecosystems.

The most obvious advantages of digitization are given in Table 1.

The environment disadvantages of digitalization (Table 2) are caused by growing demand for smart products and digital services, which provokes an increase in energy consumption and greenhouse gas emissions and accumulation of electronic waste. These negative consequences are exacerbated by unfair competition and attempts to maximize monopoly quasi-rent from pseudo-innovation, when marketing policies that stimulate excessive consumption for prestige reason substitute for real research and development. In addition, the risks to the ecosystem increase as a result of the understudy [4] of the impact of digital technologies on flora and fauna [7].

[4] In particular, 5G technology that is critical to the spread of the Internet of Things, including for households [8], because of the peculiarities of signal transmission (millimeter waves and small signal reception / transmission centers), requires a high coverage density (≈ 250 m between cells), which may lead to a critical growth of mutations in some species of birds, as well as to mass death of bees [7], i.e. there is a threat of the destruction of ecosystem food chain and the extinction of species.

Estimate of digitalization effects on environmental performance

The relevance of smart industrial development based on the principles of digitalization and decarbonization of the economy through digital technologies leads to a strong research interest in quantifying the impact of digitalization on the environmental footprint. Depending on the methodology and the approach to forecast, the following estimates have been obtained:

- the share of digital technologies in the total world energy consumption may exceed 3% [9, 10];
- carbon footprint of the ICT industry ranges from 1.1 to 1.4 billion tons of CO_2 equivalent [9, 11, 17, 12, 13, 14, 15];
- potentially possible reduction of global greenhouse gas emissions due to "green" digital technologies varies within 15%—16.5% of the total projected emissions of all sectors [2, 12].

To confirm the hypothesis of the existence of a direct relationship between digitalization and sustainable development (in terms of its environment component), the authors have assessed the strength of the relationship between the ICT Development Index that characterizes the world achievements in terms of ICT development (Table 3) and the Environmental performance Index (EPI) that reflects the combined effect of preserving the quality of the natural environment and natural resource management (Table 4).

For this purpose, different countries that have different level of economic and R&D development, the specifics of national production, and, accordingly, size and structure of man-made load on world ecosystems have been selected. At the same time, to increase the objectivity of the results of the analysis, the countries with a population of less than 1 million people, the countries that are unable to ensure the regular submission of the necessary statistical information, as well as the countries with atypically high revenues from sale of minerals (primarily, hydrocarbons) are ex-

Table 3. **Quality Structure of ICT Development Index**

ICT access sub-index		ICT use sub-index		ICT skills sub-index	
Share in the index composition					
40%		40%		20%	
Fixed telephone lines per 100 inhabitants	20%	Proportion of households with Internet access at home	33%	Adult literacy rate	33%
Mobile cellular telephone subscriptions per 100 inhabitants		Proportion of house-holds with Internet access at home per 100 inhabitants		Secondary gross enrolment ratio	
International Internet bandwidth (bit/s) per Internet user		Mobile broadband subscribers per 100 inhabitants		Tertiary gross enrolment ratio	
Proportion of households with a computer					
Proportion of households with Internet access at home					

cluded from the review. As a result, 106 world economies are included in the final sample [5].

The distribution of the countries by ICT development and environmental performance, as well as the dependence curve are presented in Fig. 2, where Ukraine is ranked 48th among the analyzed countries with the ICT Development Index of 5.62 and the Environmental Performance Index of 49.50.

The coefficient of determination ($R^2 = 0.85$) indicates a significant weight of the positive linear relationship between the ICT development (variable x) and the environmental performance (variable y) of the analyzed countries. The Mean Absolute Percentage Error for the environmental performance is 11%, i.e. the equation may be considered satisfactory. The nonparametric Spearman rank correlation coefficient (0.93) also indicates the presence of a statistically significant relationship between the analyzed phenomena.

Thus, the most advanced and innovation-driven economies (Germany, Denmark, Finland, France, Switzerland, Japan, etc.) with a high level of economy digitalization and, accordingly, a high ICT development index, are generally characterized by the best results in terms of ensuring environmental performance (less anthropogenic burden on ecosystems and more effective environmental policy).

Table 4. **Quality Structure of Environmental Performance Index**

Environmental health		Ecosystem vitality	
Share in the index composition			
40%		40%	
Air quality	20%	Climate change	24%
Sanitation and drinking water	16%	Biodiversity and habitat	15%
		Ecosystem services	6%
Heavy metals		Fisheries	
Waste management	2%	Agriculture	
		Pollution emissions	3%
		Water resources	

[5] Sample composition: Australia, Austria, Albania, Algeria, Argentina, Bangladesh, Belgium, Benin, Belarus, Bulgaria, Bolivia, Bosnia and Herzegovina, Brazil, Burkina Faso, Burundi, Great Britain, Gambia, Guatemala, Guinea, Guinea Georgia, Denmark, Dominican Republic, Ecuador, Estonia, Ethiopia, Egypt, Zambia, Zimbabwe, Israel, India, Indonesia, Ireland, Spain, Italy, Jordan, Kazakhstan, Cambodia, Cameroon, Canada, Kenya, Kyrgyzstan China, Cyprus, Colombia, Costa Rica, Ivory Coast, Laos, Latvia, Lesotho, Lithuania, Lebanon, Myanmar, Mauritius, Madagascar, Macedonia, Malaysia, Morocco, Mexico, Mozambique, Moldova, Mongolia, Namibia, Nepal, Nigeria, Netherlands, Nicaragua, Germany, New Zealand, Norway, Pakistan, Panama, Paraguay, Peru, South Africa, South Korea, Poland, Portugal, Russian Federation, Romania, El Salvador, Senegal, Serbia Slovak Republic, Slovenia, USA, Thailand, Tanzania, Tunisia, Turkey, Uganda, Hungary, Ukraine, Uruguay, Philippines, Finland, France, Croatia, the Czech Republic, Chile, Switzerland, Sweden, Sri Lanka, Jamaica, and Japan.

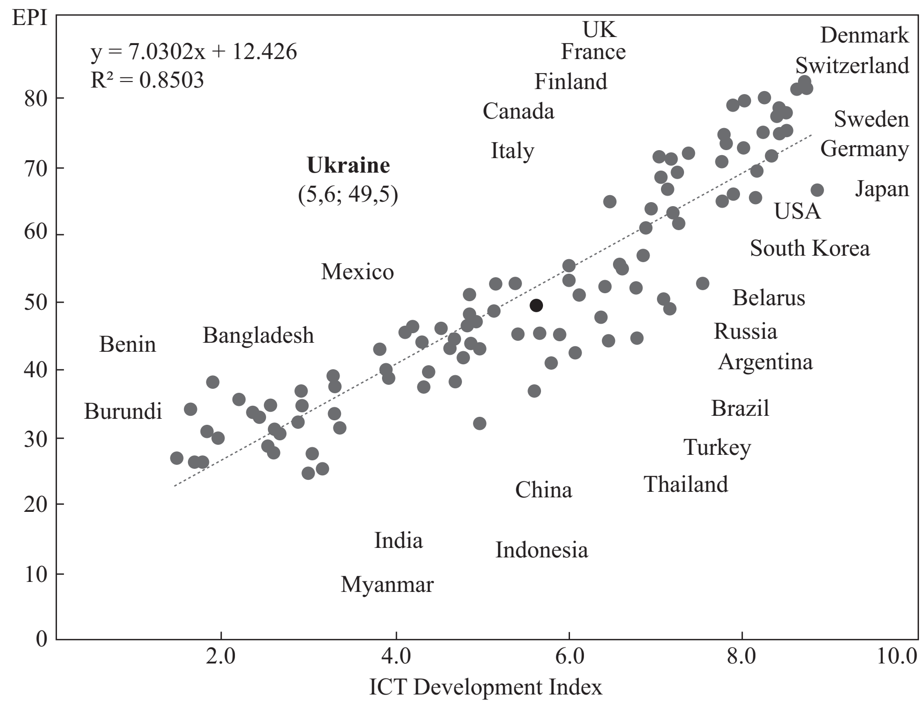

Fig. 2. Relationship between ICT Development Index and EPI (106 world countries, based on data of 2017—2020)
Source: [17, 25].

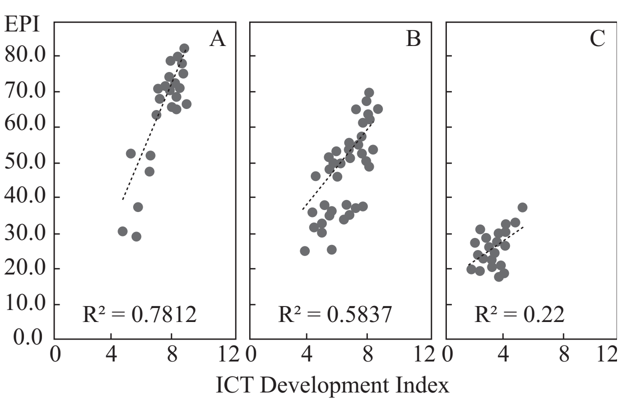

Fig. 3. The relationship between ICT development and environmental performance indices by clusters. A — The "leaders" and the "chasers" (with a high level of digitalization); B — The "catchers" (with a medium level of digitalization); C — The "outsiders" (with a low level of digitalization)

At the same time, from the point of view of economic and environmental policy formation, such global dependence has limited value. The fact is that economic institutions (formal and informal rules and norms of conduct) that operate well in some countries cannot be automatically transferred to other countries. Similarly, the transition from one dominant production technology to a new one that determine, in particular, the level of environmental performance, is not a "smooth" process, but is described in terms of technological gaps between countries [18]. Therefore, it is advisable to divide these countries into relatively homogeneous clusters (groups), within which there are certain general patterns of socio-economic and digital processes, on which environmental processes depend.

The clusters have been formed in STATISTICA[6]. The following variables are used: (1) income per capita; (2) the share of manufacturing industry in GDP; (3) the Human Development Index (HDI); (4) exports of ICT goods and services; (5) the number of fixed broadband subscriptions and mobile subscriptions; and (6) the number of individual users of the Internet. The first three

[6] STATISTICA: Data Mining, data analysis, quality control, forecasting, training, and consulting. *StatSoft Russia*. 2020. URL: http://statsoft.ru/ (last access 01.11.2020).

BOX 1

BRIEF DESCRIPTION OF THE CLUSTERS

The first cluster includes traditional world leaders in economic development and such a relatively fresh EU member state and former member of the socialist bloc (as part of Yugoslavia) as Slovenia. Accordingly, the countries of the "leaders" cluster are characterized by the highest average values of the 6 studied indices, except for "exports of ICT goods (% of total exports of goods)".

The second cluster (tentatively called "the outsiders") consists of the countries that demonstrate diametrically opposite results: the average values of all indices are the worst among all clusters. The cluster of "outsiders" mainly includes countries that gained independence from the leading countries of Europe (mostly Britain and France), as late as in the 20th century, and during the Cold War were considered the Third World countries.

The third cluster is the largest one in terms of the number of countries. It includes the countries that are characterized by a high or an upper middle income and fall behind the "leaders" and the "chasers" in terms of the average indices, but exceed the indices of the "outsiders". They are mainly the former countries of the socialist bloc, as well as the countries belonging to the Third World, which have managed to improve their socio-economic situation since the Cold War. Some of them are currently the EU member states (Cyprus, Greece, and Portugal), which during the period under review (2009—2018) either failed to improve the socio-economic situation up to the level of the leading countries, or because of the influence of various external and internal factors (in particular, the global financial crisis) have lost stability. Conventionally, the countries of the third cluster are called the "catchers".

The fourth cluster includes the countries that in terms of 6 indices, in addition to "exports of ICT goods (% of total exports of goods)" are as close as possible to the leading countries (cluster 1), with this index even exceeding that of the leading countries. This cluster includes the countries that have been actively developing national industry for at least the last 30 years (including through offshoring) and some new EU member states that were part of the USSR or the socialist bloc. Conventionally, the countries of this cluster are called the "chasers".

REFERENCE

The "leaders": Switzerland, Ireland, Norway, Denmark, the Netherlands, Sweden, Japan, Germany, Finland, Austria, USA, Great Britain, Belgium, Israel, France, Canada, Australia, Italy, New Zealand, Slovenia, and Spain (21 countries)

The “chasers": South Korea, Czech Republic, Malaysia, Estonia, Slovak Republic, Hungary, China, Philippines, Costa Rica, Thailand, and Mexico (11 countries).

The "catchers": Cyprus, Lithuania, Poland, Latvia, Greece, Portugal, Uruguay, Russia, Croatia, Panama, Argentina, Romania, Chile, Bulgaria, Belarus, Kazakhstan, Mauritius, Brazil, Turkey, Serbia, Tunisia, Georgia, Colombia, Ukraine, Albania, South Africa, Bosnia and Herzegovina, Morocco, Jordan, Peru, Lebanon, Dominican Republic, El Salvador, Ecuador, Jamaica, Moldova, Algeria, Paraguay, Indonesia, Sri Lanka, Egypt Pet, Mongolia, Guatemala, and Kyrgyz Republic (45 countries).

The "outsiders": Namibia, Bolivia, Nicaragua, Honduras, Cambodia, India, Ivory Coast, Laos, Senegal, Lesotho, Gambia, Nepal, Zimbabwe, Bangladesh, Kenya, Nigeria, Zambia, Ben Uganda, Tanzania, Myanmar, Guinea, Burkina Faso, Madagascar, Mozambique, Ethiopia, and Burundi (29 countries).

indices characterize the general level of national economy and industrial sectors development. The rest of them describe the level of development and use of ICT technologies and the Internet. All statistic data on world countries, in terms of digital technologies and digitization indices, are taken from the World Bank website [20].

According to the results of cluster analysis with the use of the method of k-means, there have been formed 4 relatively homogeneous clusters of countries, which are called: “leaders” (typical representatives are the Scandinavian countries, Western EU, and USA), “chasers” (Asian emerging markets such as China, South Korea, etc.), “catchers” (Eastern European and the post-Soviet countries, including Ukraine, etc.), and “outsiders” (underdeveloped African and Asian countries) (Box 1).

As shown by the estimates given in Fig. 3, the global dependencies and trends cannot be directly extrapolated to underdeveloped national economies, as the relationship between ICT development and environmental performance in the catchers and the outsider countries is not strong

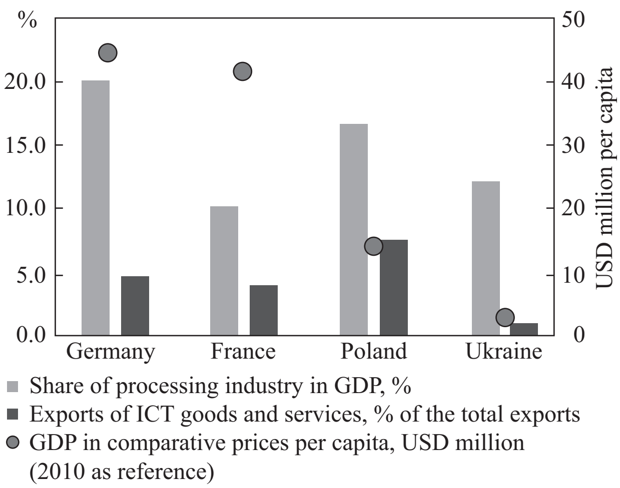

Fig. 4. Comparative estimate of the economic development indices of Ukraine and the reference countries

enough. Moreover, as one can see from Fig. 3 (according to the angle of the trend lines), the digitalization of the economy in these clusters has a much smaller positive impact on the environment. That is, digitalization itself, without reference to the general economic development as a whole and particularly the technologies of the real sector, does not provide environmentally sustainable growth. Therefore, to address the problem it is important to take into account the specifics of national R&D development, as well as its general strategic direction.

In particular, with regard to Ukraine, given its strategic geo-economic priorities, individual EU members, similar in size, climate, and population, can be used as references for justifying national policies in the field of environment friendly digitalization. These criteria are met by Germany and France (the “leaders”), as well as by Poland (the “catchers”).

As shown by the example presented in Table 5 and in Fig. 4, the largest gap between Ukraine and these countries is observed in terms of GDP per capita: the share of the economies of Germany and France (in comparative prices) exceeds Ukraine almost 15 times. The gap with Poland is slightly lower, 4.7 times. To correctly understand

Table 5. **Digitalization and Environmental Performance Indices of Ukraine and the Reference Countries (averaged for 2009–2018)**

Cluster type	Rank in the internal clus-ter rating in terms of digita-lization	Country	GDP (in compara-tive prices) per capita, USD million (2010 as reference	Share of pro-cessing industry in GDP, %	HDI *, points	Export of ICT goods and servi-ces, % of total exports of goods	Fixed telephone line subscribers (per 100 inhabitants)	Mobile subscribers (per 100 inhabitants)	Individual users of Internet (% of popu-lation)	EPI **, points
			Indices							
Leaders	8	Germany	44.4	20.0	0.93	4.7	36.1	121.7	84.1	77.2
	15	France	41.7	10.3	0.88	4.1	39.2	100.1	79.4	80.0
Catchers	3	Poland	14.1	16.7	0.85	7.6	17.8	136.1	67.0	60.9
	25	**Ukraine**	**3.0**	**12.2**	**0.74**	**1.0**	**9.3**	**130.7**	**41.6**	**49.5**
Ukraine, difference in the indices as compared with the reference countries										
Leaders	8	Germany	–41.4	–7.8	–0.19	–3,7	–26,8	+9.0	–42,5	–27,7
	15	France	–38.7	+2.1	–0.14	–3,1	–29,9	+30.6	–37,8	–30,5
Catchers	3	Poland	–11.1	–4.5	+0.11	–6,6	–8,5	–5.4	–25,4	–11,5
Average difference			**–30.4**	**–3.4**	**–0.07**	**–4.5**	**–21.7**	**+11.4**	**–35.2**	**–23.2**
Ukraine, % of averaged indices			**9.0%**	**77.9%**	**83.5%**	**18.3%**	**30.0%**	**109.6%**	**54.1%**	**68.1%**

* HDI is Human Development Index; ** EPI is Environmental Performance Index.
Source: [19].

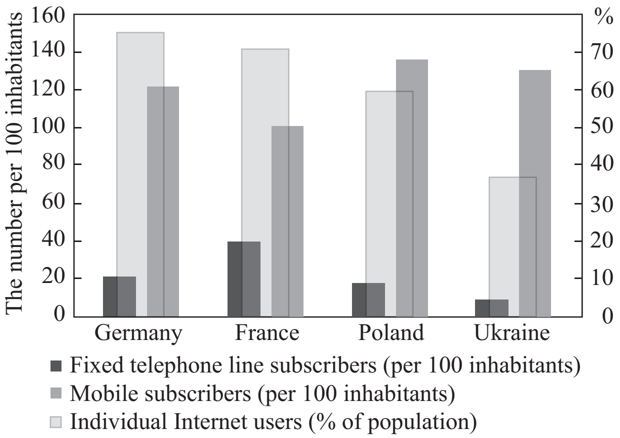

Fig. 5. Comparative estimate of the digitalization indices of Ukraine and the reference countries
Source: [19].

the situation, it is also important to take into account a large gap, especially from the "leaders" cluster, in terms of the share of ICT exports, which well characterizes national technological level (Fig. 5). At the same time, in terms of the number of mobile subscriptions per 100 inhabitants, Ukraine is ahead of Germany and France, which is typical for low-income countries, where population actively uses mobile communications, equipment, and technologies of more advanced economies. As a consequence, there is a significant gap between Ukraine and the countries under review in terms of EPI.

If we analyze environmental indices more thoroughly (Table 6), it can be noted that Ukraine has the worst air and water quality, including because of poor development of wastewater treatment infrastructure, and the best ecological purity of agriculture, due to a relatively low use of mineral fertilizers [20].

Consequences for Ukraine

In general, as the analysis has shown, the economy digitalization cannot yet be considered as a

Table 6. **EPIs of Ukraine and the Reference Countries, in 2020**

Indices/ sub-indices	"Leaders"		"Catchers"		Ukraine, difference in the indices as compared with the reference countries				Ukraine, % of averaged indices
	Germany	France	Poland	Ukraine	Germany	France	Poland	Averaged difference	
EPI. points	**77.2**	**80.0**	**60.9**	**49.5**	**–27.7**	**–30.5**	**–11.4**	**–23.2**	**68.1**
Environmental health	**89.6**	**91.5**	**58.9**	**49**	**–40.6**	**–42.5**	**–9.9**	**–31.0**	**61.3**
Air quality	81.1	88.1	44.7	39.8	–41.3	–48.3	–4.9	–31.5	55.8
Sanitation and drinking water	99	96.2	71.7	55.1	–43.9	–41.1	–16.6	–33.9	61.9
Heavy metals	90.7	84.0	65.3	69.3	–21.4	–14.7	+4.0	–10.7	86.6
Управління відходами	97.9	94.8	91.1	73.1	–24.8	–21.7	-18.0	–21.5	77.3
Ecosystem vitality	**68.9**	**72.3**	**62.3**	**49.9**	**–19.0**	**–22.4**	**–12.4**	**–17.9**	**73.6**
Biodiversity and habitat	88.8	88.3	89	37.7	–51.1	–50.6	-51.3	–51.0	42.5
Ecosystem services	39.7	36.1	27.1	30.2	–9.5	–5.9	+3.1	–4.1	88.0
Fisheries (condition of reserves, trophic index, environmental friendliness of fishing methods)	14	12.1	8	12.4	–1.6	+0.3	+4.4	+1.0	109.1
Climate change (preventive measures)	71.5	81.9	65.4	69.2	–2.3	–12.7	+3.8	–3.7	94.9
Pollution emissions (preventive measures)	96	100.0	89.6	76.6	–19.4	–23.4	–13.0	–18.6	80.5
Agriculture (ecological purity)	61.9	65.2	57.4	79.5	+17.6	+14.3	+22.1	+18.0	129.3
Water resources (waste water treatment)	97	88.0	60.9	14.1	–82.9	–73.9	–46.8	–67.9	17.2

Source: [17].

reliable means of solving environmental problems in Ukraine. First, digitalization itself has limited transformational potential, unless in the country there is innovation-driven development of national production, with modern production processes and products designed and implemented [21].

Second, the possible environmental consequences of economy digitalization need further in-depth analysis, as the long-term positive effects of national economy digitalization are not obvious (as for many countries in the "catchers" cluster), while the adverse ones can have a significant impact. Ukraine, as part of Eastern Europe, has been already part of the region that receives e-waste [30, 14]. In addition, the introduction of new digital technologies, including 5G (a critical technology for the development of the Internet of Things), may have negative consequences not only for the advanced economies that have strict environmental standards, but also for Ukraine, given its present-day institutional realities (high corruption risks, significant gaps in the field of legal regulation of intellectual property, environmental protection) and relevant infrastructure [22, 69—72]).

While solving this problem, one cannot rely solely on private business, as it is subjectively motivated to maximize profits. In view of this, there is a need for a special national academic program to assess various aspects of the impact (abiotic, biotic, man-made, anthropogenic) of the advanced digital technologies on the environment.

Its important element can be the formation of a representative database on the status and parameters of digitalization of Ukraine's economy, including: the intensity of R&D in the digital sector, the density of digital technologies in industry, their productivity, environmental impact (energy balance and energy saving), carbonization or decarbonization, dynamics of accumulation, movement, and utilization of electronic waste, etc. It is also appropriate to take into account the existing approaches to assessing the economy digitalization, in particular, the EU's Digital Economy and Society Index (DESI)7[7] that integrates several different indicators of digital Europe and monitors the evolution of EU member states in terms of their digital competitiveness.

Third, it is important to form a digitalization program as part of the overall strategy of innovation-driven sustainable development of national production, which involves the formation of strong development institutions, similar to those already used successfully in other emerging markets [24].

In addition, it is necessary to adapt the European public-private partnership practices that have proven viability and to finance projects that are important to the national economy on a long-term basis. According to [26], more than EUR 20 billion are expected to be invested in the EU's single digital market by 2020. The current EU public-private partnership projects cover such important areas as: cybersecurity of energy and power engineering, transport, financial, and health sectors; high-performance computing; robotics; fifth generation mobile communication (5G); development of electronic components and firmware. It should be emphasized that their strategic goal is to help European industry meet the growing global consumer demand for greener, more individualized and better products by ensuring the necessary transition to demand-oriented industries with less waste and better use of resources [26]. Obviously, Ukraine's industry also needs similar support.

Conclusions

1. The introduction of state-of-the-art digital technologies in various spheres of public life has a profound and diverse impact (both positive and negative) on the surrounding environment. The

[7] DESI was first calculated in 2014; in 2018, in addition to the 28 EU member states, DESI was temporarily extended to 17 non-European countries (within the Interstate Index of Digital Economy and Society, I-DESI), including the United States, Canada, China, Japan, and Brazil., South Korea, Turkey, and Russia.

positive environmental effects of economy digitalization are associated with dematerialization of goods and services, improvement of production technologies, decrease in physical logistics flows, reduction of pollutant emissions, etc. The adverse effects are growing industrial and household energy consumption (and, consequently, increasing greenhouse gas emissions), accumulating electronic waste, understudied negative effects on the reproductive systems, genome structure, behavioral responses of living organisms, and so on.

2. The studies made by influential international organizations (OECD, European Commission, Asian Development Bank, etc.) have confirmed the growing changes in the size and structure of the ecological footprint caused by the introduction of digital technologies. In their assessments, digitalization is a generally positive phenomenon, as it may reduce global greenhouse gas emissions, among others. At the same time, it should be borne in mind that most of the estimates are predictive. Despite the world's prevailing desire to ensure climate neutrality and environmental loyalty of digital innovations, as a result of the lack of representative observations and because of delayed effects of technological interference in the functioning of ecosystems, the real environmental consequences of digitalization may be underestimated.

3. The empirical estimates presented in the research based on the economic analysis of ICT development and environmental performance indices in 106 countries have also showed a generally positive relationship between the introduction of digital technologies and the state of the environment: the higher the level of digitalization, the cleaner the economy. At the same time, from the point of view of substantiation of national policy, this general relationship is rather limited. This is because of the fact that the environmental performance of digitalization processes is determined by local economic development and production technologies, which in different countries (groups of countries) are characterized by their own characteristics rather than by global patterns.

4. To identify the local relationship between environmental performance and digitization, the analyzed countries have been divided into the four relatively homogeneous clusters (groups). Their analysis has showed that in clusters of less developed countries (including Ukraine), the relationship between ICT implementation and environmental performance is not strong, and the development of digital technologies has a much smaller positive impact on the environment than in the groups with advanced economies.

5. Based on this, the possible environmental consequences of digitalization of Ukraine's economy require further analysis, as its long-term positive effects in the specific conditions of the national economy are not obvious, while the negative ones can have a significant impact. Ukraine, as part of Eastern Europe, has been already part of the region that hosts e-waste. In addition, the introduction of new digital technologies may have undesirable consequences in the context of biology, the risks of man-made disasters, and so on. Therefore, there is a need to develop and to implement a national academic program to assess various aspects (abiotic, biotic, man-made, anthropogenic) of the impact of new digital technologies on the environment. In addition, it is critical to incorporate the digitalization of the economy into the overall strategy of innovation-driven sustainable development of national production, because being separated from the real sector, digitalization loses its effectiveness. Consequently, this requires the formation of national development institutions similar to those already used successfully in other emerging markets and the adaptation of best European practices in public-private partnerships for the selection and funding of the most important digital projects on a long-term basis.

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ЦИФРОВА І ЗЕЛЕНА ЕКОНОМІКИ: ТОЧКИ ДОТИКУ Й СУПЕРЕЧНОСТІ

Вступ. Процеси цифровізації економіки, пов'язані з розгортанням технологій Четвертої промислової революції, є багатоаспектними й чинять суттєвий вплив, зокрема й на навколишнє середовище, що зачіпає інтереси майбутніх поколінь.

Проблематика. Прискорення цифровізації супроводжується суперечливими позитивними і негативними ефектами для довкілля. Зважаючи на це, актуальною проблемою є визначення цих ефектів як на глобальному, так і на національному рівнях.

Мета. Виявити взаємозв'язки цифрової та зеленої економіки й обґрунтувати шляхи екологічно безпечного розвитку цифрових технологій в Україні.

Матеріали й методи. Кластеризація країн світу за ознаками економічного, промислового й цифрового розвитку; економетричний аналіз залежностей між показниками розвитку інформаційно-комунікаційних технологій і екологічної ефективності в країнах світу та їх групах (кластерах) за 2017—2020 рр.

Результати. Встановлено, що на глобальному рівні впровадження сучасних цифрових технологій має загалом позитивний зв'язок зі станом довкілля: чим вищим є рівень цифровізації, тим більш екологічно чистими, за інших рівних умов, є національні економіки. З'ясовано, що екологічна ефективність цифровізації залежить від рівня виробничих (фізичних) технологій та загального економічного розвитку держави. У кластерах менш розвинених країн, зокрема й в Україні, яка має суттєві проблеми у сферах промисловості й інновацій, поширення цифрових технологій має менший позитивний вплив на екологію, ніж у кластерах більш розвинених країн. Тому довгострокові позитивні ефекти цифровізації для України не є очевидними, а негативні можуть бути серйозними.

Висновки. Для мінімізації екологічних ризиків цифровізації в Україні потрібно розробити національну академічну програму комплексної оцінки різних аспектів (абіотичних, біотичних, техногенних, антропогенних) впливу новітніх цифрових технологій на довкілля, а також узгодити програми цифровізації економіки із загальною стратегією розвитку національного виробництва на інноваційній основі.

Ключові слова: цифрові технології, цифровізація економіки, промисловість, сталий розвиток, екологічний слід, екологічна ефективність.