



**DIGITALIZATION
OF THE ECONOMY:
HOW TO IMPROVE
THE COUNTRY'S
COMPETITIVENESS**

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DIGITALIZATION OF THE ECONOMY: HOW TO IMPROVE THE COUNTRY'S COMPETITIVENESS

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The monograph investigates the features of information and communication technologies and processes of digitalization of an economy, analyses methodological approaches to monitoring the development and assessing the effectiveness of the digital economy, builds the functions of the dependence of digital costs and final results of economic activity, assesses the transformational potential of emerging economies' digitalization and substantiates recommendations for increasing their competitiveness. For researchers, teachers, post-graduate students, students, all those who are interested in the problems of digitalization of an economy, industrial revolutions and innovative development.

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CONTENTS

INTRODUCTION	7
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1

DIGITALIZATION OF AN ECONOMY AND DEVELOPMENT OF ICT

1.1. Digitalization and modern ICT. Properties of the ICT sector, its structure and infrastructure	15
1.2. Institutional and economic aspects of ICT	22
1.3. Prerequisites for successful development of ICT	29

2

TECHNOLOGIES OF DIGITALIZATION OF AN ECONOMY

2.1. Transfer from traditional to digital business	39
2.2. Factors of digitalization impact on results of economic activity	46
2.3. Development of technologies for an economy's digital transformation (on example of 5G, Big Data and blockchain)	50
2.3.1. 5G of mobile communications	50
2.3.2. Big Data and analytics	57
2.3.3. Blockchain	65
Appendix 2.1	72

3

ENVIRONMENTAL ASPECTS OF DIGITALIZATION OF THE ECONOMY

3.1. Global trends in the ecological and digital transformation of the economy	77
3.2. Analysis of the digitalization impact on sustainable development	85
3.3. Environmental and digital profile of Ukraine	90

4

PROBLEMS OF ASSESSMENT OF DIGITALIZATION PROCESSES AND THEIR IMPACT ON ECONOMIC DEVELOPMENT

4.1. Analysis of methodological approaches to monitoring and assessment of digitalization processes	105
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4.2. Evolution of mathematical models of ICT impact on economic development 111
4.3. Analysis of modern models of ICT impact on economic developmen 115

5

TRANSFORMATION POTENTIAL OF DIGITALIZATION AND WAYS TO INCREASE NATIONAL COMPETITIVENESS

5.1. Construction dependence function of real results and digital costs 129
5.2. Assessment of the transformation potential of the economy's digitalization. 139
5.3. Ways to enhance the transformation potential of the national economy's digitaliza-
tion and competitiveness 148
5.3.1. Vector of technology development 153
5.3.2. Vector of human capital development 155
5.3.3. Vector of institution development 156
CONCLUSIONS 158
REFERENCES 161
LIST OF ACRONIMES 167



INTRODUCTION

The development of the digital economy and ICT-based cyber-physical systems is a priority field for global technical, technological, social, economic and institutional transformations. In recent years, in the leading countries of the world, a transition to a new technological order has occurred known as "Industry 4.0" or "smart industry". A characteristic of these changes is the fast digitalization of the economy, which is rapidly and cardinally changing the production, state, society and individuals.

From the content point of view, the digital economy includes digital equipment and technologies (hardware, software and communication equipment), human skills in employment of these equipment and technologies (digital skills), as well as intermediate digital goods and services, which are used in the production of GDP. In many of the leading countries of the world, its volume, measured by the size of the ICT sector, exceeds 5% of GDP.

The introduction of modern digital technologies, such as mobile Internet, Internet of Things, Big Data, blockchain, etc., in the activities of enterprises and organizations, equipment and technology, production and non-production processes allows us to expand the range of goods and services, improve their quality and meet consumer needs, increase labour productivity and create new chains and networks for the value added. The gross value added generated in all sectors of the global economy with the help of ICTs today amounts for more than 20% of the world's GDP.

However, the efficiency of digitalization processes in national economies differs significantly. It depends, first, on the extent, to which certain countries are ready to introduce the most up-to-date digital technologies. Here, factors such as the degree of development of ICTs and their infrastructure, parameters of accumulation and use of digital capital, digital skills of the population, etc. are important and, second, to what extent

a national economy is ready for modern industrial transformations in general: how high its technical and technological level of manufacturing is, how complex and diverse its products are, how much the national sphere of R&D contributes to current and future industrial development, etc.

It is obvious that digitalization itself is not an economic panacea, since in the conditions of a inelaborate innovation sphere, outdated production technologies, worn-out machinery and equipment, a shortage of STEM personnel, it has poor prospects and can be reduced generally to the replacement of some jobs with others in the service sector.

Numerous researches have been carried out in the world on the problems of digitalization, formation and further development of the digital economy. However, they often pay attention to unlocking the economic potential of new digital technologies, regardless of how this potential is implemented in practice in the special technical, technological, socio-economic and institutional environment of individual countries, whether it really brings reliably measurable positive results, and under what conditions.

Accordingly, all this has stressed on the urgency of the problem of assessing and effectively using the potential of digitalization of national economies, taking into account the specific circumstances of their readiness for digital and production transformations. At the same time, the task is not just to again emphasize the importance of the accelerated development of the digital economy, which is now a global trend, but to assess its real transformational potential in those specific historical conditions that have now developed in specific countries and groups of countries, and to define, what exactly should be done for its further improvement and efficient application.

For this purpose, the monograph analyses the theoretical and practical aspects of digitalization processes in the world and in Ukraine in particular and substantiates ways to enhance their positive impact on the acceleration of the socio-economic development of national economies.

Structurally, the monograph consists of five sections, which consistently reveal a complex set of issues related to the definition, development and effective use of the transformation potential of digitalization.

The first – theoretical – section "Digitalization of economy and development of ICTs" is devoted to the analysis of the relationship between the digitalization of the economy, i.e., the introduction of up-to-date digital technologies in various fields of economic relations, and ICTs themselves, including definition of properties of the ICT sector, their legal and economic aspects, the prerequisites for the successful development of ICTs, etc. Based on the analysis of individual components of the term "information and communication technologies" and modern trends in the development of the digital economy, they are defined as a set of methods and processes for the information production, storage, processing, transmission and perception by a person or special devices, as well as a scientific description of such methods and processes.

The sector of these technologies consists of two related segments: provision of ICT services and production of ICT goods (ICT manufacturing). In the first segment, new technologies are developed and introduced and services are provided for

transfer, receipt, storage of information, etc., and in the other segment — the material and technical base for these technologies is created. As the analysis performed has shown, the leading countries in the ICTs are mainly related to the circle of states with high incomes per capita and, less often, with incomes above the average level. The exceptions are well-known ICT service providers such as India and Indonesia, where incomes of the population are below the average.

In addition, the intense use of ICTs and even the very presence of a related dynamic sector of the national economy do not guarantee the country's successful development. Much depends on the general level of the national economy, its institutional environment, and on how fully it uses the opportunities of new equipment and technologies. Modern ICTs are a good tool for diagnosing the country's problems and finding new ways to solve them, but only if the necessary conditions for their successful application are created including: the national scientific and technical sphere is developing, a high level of computer literacy of the population is ensured, reliable institutions for intellectual property rights protection are created, effective antitrust legislation are functioning, and the like.

In the second — analytical — section "Technologies of digitalization of the economy", the issues of transition from traditional to digital business and management are considered; factors of influence of digitalization processes on the final results of economic activities are identified; opportunities and problems associated with the penetration of new digital technologies, such as hype ones (5G, Big Data and blockchain) in business, public and private life of people are shown.

Mobile communication of the fifth generation — 5G — is a basic technology for the development of digital infrastructure and the further functioning of key innovations in the frame of the digital economy and the Fourth Industrial Revolution, such as the Internet of Things, Big Data, artificial intelligence, smart automation of production, etc. In connection with such an important role of 5G technology in the world, the struggle for leadership in this field is intensifying. Those countries that will be the first to overcome technological and organizational barriers and deploy 5G networks can receive strategic technical and economic advantages in global competition.

Another of the basic technologies, on which the digital transformation of the economy is based, is Big Data. Their use largely defines the future of cyber-physical production and prospects for growth of many industries. In the public sector of the economy, the use of Big Data opens up new opportunities in taxation and social security of the population, fight against corruption, fraud, etc. This is on the one hand. On the other hand, all this is threatening with the well-known problems of the "Big brother". To mitigate them, the world is trying different approaches (European, American, Chinese) to arranging Big Data, which pros and cons require further in-depth analysis.

But, perhaps, the most "hype" technology is blockchain — a distributed database that stores an ordered chain of records (blocks) linked through cryptographic methods. At first, when its use just started (2009, bitcoin), it seemed to be capable of transforming all spheres of the economy, from agriculture to banks and government agencies. However, it soon became clear that there appeared a number of formidable

obstacles on the way of its widespread employment, which cooled the enthusiasm of pioneers. Nevertheless, recently the blockchain has already begun to manifest its potential in practice, and not only in the field of finance and trade (cryptocurrencies, smart contracts), but also in the field of material production. In particular, the monograph substantiates that a promising area of blockchain's industrial application can be its symbiosis with technologies of the Industrial Internet of Things.

In the third — environmental and economic — section "Environmental aspects of digitalization of the economy", it is noted that the introduction of up-to-date digital technologies in various spheres of public life has a deep and versatile impact (both positive and negative) on the environment. The positive environmental effects of the economy digitalization are associated with the dematerialization of goods and services, improvement of production technologies, reduction in physical logistics flows, decrease in pollutant emissions, and the like. Negative ones are associated with an increase in industrial and national energy consumption (and, therefore, with an increase in greenhouse gas emissions), accumulation of electronic wastes, exercising of little-studied negative effects on the functioning of reproductive systems, the structure of genomes, behavioural reactions of living organisms, etc.

The monograph's authors have carried out clustering of the world countries on the basis of their economic, industrial and digital development and econometric analysis of the relationships between the indicators of ICTs' development and the environmental effectiveness of digitalization. As a result, it was found that at the global level, the introduction of modern digital technologies leads to generally positive consequences: the higher the level of digitalization, the more environmentally friendly (other things being equal) national economy is. The environmental effectiveness of digitalization was established to depend on the level of manufacturing (physical) technologies and the general economic development of the state. In clusters of less developed countries, including Ukraine, which has significant problems in fields of industry and innovations, the spread of digital technologies has clearly less positive impact on the environment than in clusters of more developed countries. Therefore, the long-term positive effects of digitalization for Ukraine are not obvious, whereas the negative ones can be serious.

Based on the results of the analysis performed, it is substantiated that in order to minimize the environmental risks of digitalization processes in Ukraine, it is necessary to develop a national academic program for a comprehensive assessment of various aspects (abiotic, biotic, anthropogenic) of the impact of the newest digital technologies on the environment, as well as to coordinate programs on digitalization of the economy with a general strategy for the development of national production on the innovative basis.

In the fourth — scientific and methodological — section "Problems of assessment of digitalization processes and their impact on economic development", the current scientific and methodological approaches and economic-mathematical models used to define the impact of digitalization processes on the real economies have been analysed.

As known, this is a problem with a long history. Back in the late 90s of XX century Nobel laureate R. Solow wrote in a small note in the New York Times: "You

can see the computer age everywhere but in the productivity statistics". These words can be interpreted in such a way that the widespread growth of investments in ICTs (economically viable in a rational world) may ultimately be economically meaningless, i.e., irrational. Since then, lots of things have changed and progress has stepped forward, but the problem of assessing the effectiveness of ICTs remains urgent. Significant difficulties remain in this field of research. In particular, a disadvantage of many methods for calculating indicators of the digital economy development, known from the economic literature, is that they often do not sufficiently take into account the socio-economic, demographic and institutional characteristics of the countries, and therefore require further development and clarification.

The analysis of economic and mathematical models has shown that to assess the impact of ICTs on the results of economic activities, modifications of the Cobb-Douglas production function are mainly used, including those proposed by R. Solow. Their disadvantages are frequently insufficient consideration of the factors of ICTs depreciation, as well as the dynamic aspect of the problem — the phases of technological cycles (inception, maturity, decline), which affects the reliability of the results obtained. In addition, assessments are often carried out within the same country, which reduces their explanatory potential.

Proceeding from this, it is substantiated in the monograph that it is advisable to perform modelling of the ICTs' influence on the growth of a particular national economy in comparison with other countries, taking into account the peculiarities of their evolution in time and space, as well as the phases of the life cycle of dominant technologies, described by S-like technological curves, which gives the problem a deeper meaning.

In turn, solving this problem requires the development of a set of models, within which it is possible to establish the factors, on which the ICTs' development depends, to distribute countries into relatively homogeneous groups depending on the presence of these factors in them, to define the influence of ICTs on production and labour productivity in each of the selected groups separately.

In the fifth — economic and mathematical — section "Transformation potential of digitalization and ways to increase national competitiveness", general principles of assessment were established, new scientific and methodological approaches to modelling the transformational potential of the digital economy were developed and ways to increase it were substantiated.

Based on the results of the previous analysis, the work suggests, firstly, to apply methods of cluster analysis to identify groups (clusters) of countries that are similar in digital and production characteristics and interpreting them as countries of Industry 4.0, Industry 3.0+, Industry 3.0 and Industry 2.0.

Second, the work suggests building functions of the dependence of GDP per capita on the traditional factors (capital, labour) and the size of the digital economy for each of these groups. The analysis of such functions showed that the positive impact of digitalization can be noticeable even in those states that belong to Industry 3.0 group (including Ukraine), but it is significantly weaker than in those countries that

have reached a high level of development of industrial technologies and high quality of public institutions.

Third, it is advisable to employ a new understanding of technological gaps between countries, based on the concept of the technologies' life cycle. For this, a scientific and methodological approach to assessing these gaps has been developed, which involves construction of logistic functions that define the relationship between labour productivity and the capital-to-labour ratio, taking into account the interconnection of physical and digital capital. As a result, it was established that due to the development of digital technologies at the same level of capital-labour ratio, labour productivity in Ukraine can be: in comparison with the Czech Republic — about 5 times smaller (that is, the gap is about \$ 30 thousand per unit of labour and, in comparison with Germany — about 10 times smaller (the gap is about \$ 65 thousand per person).

On the basis of the abovementioned, it is substantiated that the economic effects of digitalization in the form of GDP growth and labour productivity are not automatically ensured. The calculation results should be interpreted with taking into account the specific circumstances of place and time. For this reason, achieving the best indicators of GDP growth due to digitalization in Ukraine requires "pulling up" not only digital technologies, but also production technologies and the quality of public institutions to the level of leading countries, as well as consistent solutions to the related problems, primarily in the scientific, technological and institutional spheres.

In the conclusion, the *results* of the study are summed up and the most important of them are highlighted to be used in further researches, as well as in practical activities of state authorities and management, enterprises and organizations in the process of forming and implementing economic policy aimed at further developing and increasing the effectiveness of digitalization processes in emergent economies.

* * *

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1

DIGITALIZATION OF AN ECONOMY AND DEVELOPMENT OF ICT



1.1. DIGITALIZATION AND MODERN ICT. PROPERTIES OF THE ICT SECTOR, ITS STRUCTURE AND INFRASTRUCTURE

The digitalization of the economy associated with the introduction of modern ICT in various spheres of economic relations is one of the dominant trends in the current economic development. This can be confirmed by the rate of accumulation of digital information. Back in 2000, digital storage methods were inferior to analog ones. The turning point arose in 2002, and already in 2007, digital information accounted for more than 95% of the total information volume (Hilbert, Lopez, 2011). Now the volume of digital information in the world is growing exponentially (Reinsel, Gantz, Rydning, 2020). As a result, the global economy is becoming more and more digitalized. ICT takes place at the heart of such revolutionary transformations, opening a new digital era in the development of mankind.

The term "ICT" is relatively new; therefore, such expressions as computer technology, information technology, information communications, etc. are often used synonymously or as those that describe implicitly related concepts. It is not clear from analysis of them what exactly the structure of these concepts constitutes. Such ambiguity in terminology complicates the perception of new technologies not only by end users, but also by the management of enterprises and organizations aimed at introducing the achievements of Industry 4.0, as well as by public authorities. This, in turn, may adversely affect investments, development and implementation of state programs aimed at putting the country's economy on the rails of the new technological order. Therefore, a detailed disclosure of the essence of these concepts, their interrelation and interdependence, as well as the conditions under which the development of new technologies as the main element ensuring the development of digital economy takes place, is relevant.

The Cambridge Dictionary defines ICT as "...the use of computers and other electronic equipment to store and send information"¹ and the Collins English Dictionary as "...activities and studies involving computers and other electronic technology"². These definitions are based on an approach that can be called instrumental: ICT refers exclusively to the use of computer engineering and other electronic equipment for storage and transmission of information or other types of activities. Herein, technological and software components are not mentioned, which reduces the scope of such definitions.

There is another opinion that ICT includes the totality of all technologies used for functioning telecommunications, television and radio broadcasting, "smart" systems for control of buildings and facilities, systems for audio-visual processing and transmission of signals, as well as ones based on the use of electronic networks for control and monitoring³ (Tongia, Subrahmanian, Arunachalam, 2005). This definition, with an emphasis on processes, is supported by experts from the UNESCO Institute for Information Technologies in Education (UNESCO IITE) (Dendev, 2013) and some other scientists (Kaino, 2008).

In many definitions of ICT, in addition to the totality of technologies used for telecommunications, tele and radio broadcasting, electronic devices (mobile phones, pads, computers, etc.) or their components (microcircuits) are included. That is, there is a mixture of ideas about technologies and devices for receiving/transmitting, forming and processing (at least partially) information.

The term ICT is frequently used as a synonym for informational technology (IT). In particular, J. Murray noted that at the very beginning of ICT development that was reasonable⁴. In his opinion, the notion of ICT is much wider than IT due to the inclusion in the former of unified communications (UC) and a number of other technologies and technical means. The author believes that today ICT is integration of telecommunications, computers, intermediate software and data systems that maintain, store and transmit UC links between systems. That is, ICT includes not only technologies for collecting, processing and transmitting data, but also the standards of these technologies, computer equipment and technical means for transmitting, storing and processing data.

Specialists of the Institute for Information Society Development (Moscow) consider ICT and IT as synonyms. They define ICT as a set of methods, production proc-

¹ Cambridge Dictionary (2019). *ICT*. Retrieved 24 September 2019, from <https://dictionary.cambridge.org/dictionary/english/ict>

² Collins Dictionary (2019). *ICT*. Retrieved 24 September 2019, from <https://www.collinsdictionary.com/dictionary/english/ict>

³ Techopedia (2019). *Definition — What is Information and Communications Technology (ICT)?* Retrieved 24 September 2019, from <https://www.techopedia.com/definition/24152/information-and-communications-technology-ict>

⁴ Murray J. (2011). *Cloud network architecture and ICT*. *TechTarget*. Retrieved 24 September 2019, from <http://itknowledgeexchange.techtarget.com/modern-network-architecture/cloud-network-architecture-and-ict/>

esses, software, hardware and linguistic tools integrated for the purpose of collecting, processing, storing, disseminating and using information in the interests of its users (Khokhlov, 2009, p. 61). Thus, in their definition all work on the development of methods and means of operating with information (in fact, certain types of economic activities) is included, which distinguishes this interpretation of the term ICT from those given above.

In Ukraine the term ICT does not have a unified definition either. There are two main documents that determine the trends of state policy concerning the use of information technology and communications facilities: the Law of Ukraine "On the basic principles of the development of an information-oriented society in Ukraine for 2007-2015"⁵ and the Order of the Cabinet of Ministers of Ukraine "On approval of Strategy for the development of information society in Ukraine"⁶. In either of these documents, the term ICT is used, but without its definition. Moreover, in the former, the ICT and information-analytical systems are presented as two different, unrelated to each other objects. In addition, in the Concept for the Development of Digital Economy and Society of Ukraine for 2018-2020⁷ the term ICT is used in line with the term "digital technology".

According to N. Fominykh (Fominykh, 2010, pp. 14-28), in Ukraine two terms coexist: "information technology" and "information and communication technology". The former is understood as a set of methods and technical means for collecting, organizing, storing, processing, transmitting and presenting information which expand the knowledge of people and develop their capabilities to manage technical and social processes (that is, an "instrumental approach" is used, and non-instrumental methods of working on information are also mentioned). Herein ICT is understood as a set of various technological tools and resources (which include computers, internet, radio and tele transmission facilities and devices and telephone communications) used to provide communication processes as well as to create, disseminate, store and manage information. That is, in fact, when defining IT and especially ICT, an emphasis is put on instrumental methods of working on information, that is, on technical devices and means involved in work on information.

To define the concept ICT more precisely with taking into account the realities in which it is used, it is advisable to carry out its structural and etymological analysis. So, technology is "a set of production methods and processes in

⁵ The Verkhovna Rada Of Ukraine (2007). On the basic principles of Information Society Development in Ukraine for 2007-2015: law of Ukraine No. 537-V of 09.01.2007. *Vidomosti Verkhovnoyi Rady Ukrainy*, No. 12. Art. 102.

⁶ Cabinet of Ministers of Ukraine (2013). On approval of the Strategy for the development of the information society in Ukraine: order of the Cabinet of Ministers of Ukraine dated 15.05.2013 No. 386-r. *Ofitsiynyi visnyk Ukrainy*, No. 44, p. 79.

⁷ Cabinet of Ministers of Ukraine (2018). On approval of the concept of development of the digital economy and society of Ukraine for 2018-2020 and approval of the action plan for its implementation: resolution of the Cabinet of Ministers of Ukraine No. 67-R dated 17.01.2018. *Ofitsiynyi visnyk Ukrainy*, No. 16, p. 70.

a certain branch of production, as well as a scientific description of production methods"(Ozhegov, Shvedova, 2001, p. 797) and information is "statements about the world around and the events taking place in it perceived by a person or a special device, as well as messages about the state of something" (Ozhegov, Shvedova, 2001, p. 250); communication is "a way of relations, a connection line", as well as "message, intercourse"(Ozhegov, Shvedova, 2001, p. 287).

Since in today's world information is not only the most important production resource, but also a commodity, the definition of ICT should mean not a separate field, but the whole complex of fields existing in the country, the entire economy of the country and (taking into account globalization) the world economy. Thus, based on the definition of individual ICT components, the term ICT should be interpreted as *a set of methods and processes for the production of information, its storage, processing, transmission and perception by a person or special devices, as well as a scientific description of such methods and processes.*

In this definition, in contrast to those considered above, there is no emphasis on specific means, technologies and processes for collecting information, how and where it is transmitted. Its main components are the production of information, its further promotion to the consumer and his response to it. Such an element as scientific description of information is also highlighted here. It is often ignored, despite the fact that the development of standards and protocols for production and transmission of information, their unification on a global scale can be considered to be a vivid example of scientific approach to the production and transmission of information, which is usually accompanied by formalized description of them.

The proposed definition does not include an instrumental component, which is present, for example, in the work (Kaino, 2008; Fominykh, 2010), but it implies that the engineering tools with which the production, storage, processing and transmission of information are realized exist and are available. This is aimed at preventing changes in this definition, that is, at saving its relevance under the development of technologies that entail significant changes in the related equipment.

Based on the above definition, the Internet as a system of storage and data transmission networks built on the basis of protocols (rules) should be considered as an element of ICT rather than its synonym. As for IoT and IIoT, they are varieties of ICT, with the help of which not only information can be created, but also (indirectly) objects of the material world. The statement that IoT and IIoT are varieties of ICT is also supported by the American Council for an Energy-Efficient Economy (ACEEE).

The current ICT has specific properties (concept 4-C): computing (data processing), communications, content and capacity (accessibility for economic agents and their ability to use ICT (Tongia, Subrahmanian, Arunachalam, 2005, p. 19).

The first two properties are clear intuitively: ICT should provide high rate of computational processes and clear data transmission. The other two ones are not so simple.

As known, in the beginning, ICT was developed predominantly in the United States and spread to the most developed countries of the world, in which English was considered the main means of international communications. Therefore, the content

of information resources as well as accompanying and technological documents were presented in English. As a result, in 2003 about 80% websites presented their content in English only (Suoronta, 2004, p. 317). Those who did not know this language and did not have access to computers with Internet were cut off the new opportunities and advantages offered by ICT.

In connection with the global spread of ICT, it turned out that not in all countries of the world knowledge of English is at a high enough level for significant part of their population to use ICT expertly. Moreover, in many developing countries the problem of illiteracy remains urgent (the percentage of people who cannot read and write is high and varies significantly across countries). For such countries, there is an acute task of filling ICT with content in national languages, creating multimedia applications (videos, graphics, their combinations) that do not require the user to be able to read and high literacy (conventional and computer-related) of the population. In addition, the filling of ICT with content in national languages allows taking into account the country's national and cultural features.

The last properties of ICT, content and capacity, which are often ignored by researchers, are associated with the need to create conditions under which ICT technical means will become more widespread, as well as to improve the computer literacy of the population.

According to the experts of the Asian Development Bank (Asian Development Bank, 2010, p. 1), ICT will be more widely used by the population (both for personal and industrial purposes) if several conditions are met:

- Cultivating an environment in which electronic devices, communication facilities and ICT are economically and legally accessible.
- Developing educational programs and resources aimed at improving the general computer literacy of the population and its professional skills in terms of using and creating ICT.
- Filling ICT with content in national languages.

ICT cannot exist on its own as a kind of virtual reality. It is located on tangible media and uses physical devices and technical facilities in order to produce, store, process, transmit information and provide an opportunity for its adequate perception. Therefore, in a number of international organizations such as the UN (Dendev, 2013), OECD (Mickoleit, 2010), Global e-Sustainability Initiative (Accenture Strategy, 2015), in addition to the concept "ICT", uses such terms as "ICT sector", "ICT industry", and "ICT infrastructure" as well.

Back in 1998, the countries-members of the Organization of Economic Cooperation and Development (OECD) agreed that the ICT sector is a combination of economic activities aimed at producing and providing services for processing, transmission and display of information in the electronic form (OECD, 2002, p. 81). An industrial enterprise is considered to be part of the ICT sector (that is, part of the ICT industry) if its products i) are aimed at performing the function of information processing, transmission and display; ii) use electronic processing to detect, measure and/or record physical phenomena or control physical processes. An enterprise in

the service sector is part of the ICT sector if its products are designed to provide the ability to process and transmit information using electronic means.

At the same time, the ICT industry included enterprises of the following types of economic activities (TEA) presented in ISIC Revision 3 (United Nations, 1991): 3000 – Office, accounting and computing machinery; 3130 – Insulated wire and cable; 3210 – Electronic valves and tubes and other electronic components; 3220 – Television and radio transmitters and apparatus for line telephony and line telegraphy; 3230 – Television and radio receivers, sound or video recording or reproducing apparatus and associated goods; 3312 – Instruments and appliances for measuring, checking, testing, navigating and other purposes, except industrial process equipment; 3313 – Industrial process equipment.

An enterprise in the service sector was referred to ICT if it was engaged in such TEAs as services: 5150 – Wholesaling of machinery, equipment and supplies (if possible, only the wholesaling of ICT goods should be included); 7123 – Renting of office machinery and equipment (including computers); 6420 – Telecommunications; 72 – Computer and related activities (OECD, 2002, p. 81).

In connection with the release of the new classification ISIC Revision 4 (United Nations, 2008), the following types of activities began to be attributed to the ICT sector: 26 – Computer, electronic and optical products ("ICT manufacturing" in the legend); 582 – Software publishing; 61 – Telecommunications; and 62-63 – IT and other information services (OECD, 2017, p. 117).

Summarizing the researches of OECD, Accenture Strategy and Global e-Sustainability Initiative (Accenture Strategy, 2015; Mickoleit, 2010), we can conclude that the ICT sector consists of two interconnected elements: ICT services and ICT industry. In the former, new technologies are developed and implemented that provide services for reception, storage and transmission of information etc., and in the latter, a material-technical base for such technologies is created (Fig. 1.1).

Thus, ICT covers both products of the ICT services sector and technologies that are implemented on the basis of ICT industry products. Taking into account the proposed definition, the given characteristics of the ICT sector structure and interpretation of cyber-physical systems as their new generation with integrated computational and physical properties (Baheti, Gill, 2011), one can assert that cyber-physical systems (IoT, IIoT) are part of the ICT sector and are based on ICT and ICT industry products with minimal human involvement in their functioning (Wolf, 2009). That is, they are the result of the entire ICT sector activities.

The progress and spread of ICT are primarily determined by the development of the ICT infrastructure, the definitions of which in the scientific literature vary significantly as well.

The ICT infrastructure is sometimes understood as a communication system (a system of cables, towers for signal transmission etc.), power system and transport, as well as computer equipment and peripheral devices such as printers etc. In the study (Tongia, Subrahmanian, Arunachalam, 2005, p. 22) ICT infrastructure is defined indirectly as a system of communication and organization of access to ICT. The

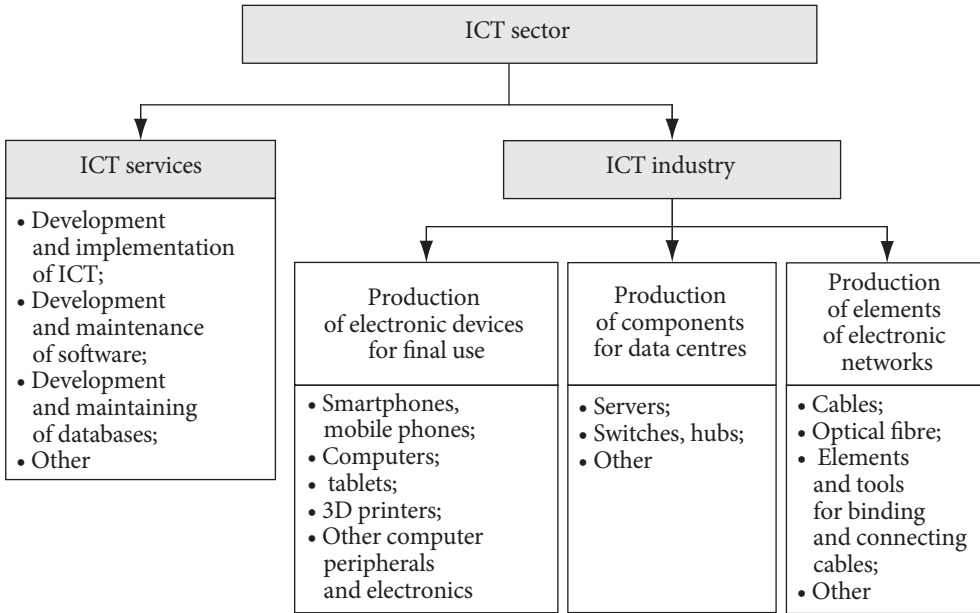


Fig. 1.1. Structure of the ICT sector and its filling with elements
 Source: (Accenture Strategy, 2015; Mickoleit, 2010).

Glossary for the Information Society defines the ICT infrastructure as a set of computer engineering, telecommunication equipment, data transmission channels and information systems, means of communication and managing information flows, as well as organizational structures, legal and regulatory mechanisms that ensure their effective functioning (Khokhlov, 2009, p. 61).

If we proceed from the above definition of ICT and the fact that infrastructure consists of branches of economy, scientific and technical knowledge and social life which directly provide production processes and conditions for the life of society (Ozhegov, Shvedova, 2001, p. 250), then the most correct of the above is the definition of ICT infrastructure proposed in the Glossary for the Information Society (Khokhlov, 2009, p. 61). It is only advisable to supplement it with such an element as a system of training and retraining of personnel in the field of ICT and computer literacy of population.

This is important for the reason that the lack of experts capable of working with ICT and developing products for the ICT sector, as well as systems for their professional training puts a country in the position of a permanent buyer (or a recipient) of foreign ICT and equipment. Obviously, this is associated with significant economic costs, risks of losing part of national sovereignty (since a recipient country becomes dependent on foreign partners) and loss of competitiveness of the domestic industry. And, conversely, a widespread use of modern products of the domestic ICT sector adapted to specific economic conditions and specific markets can significantly reduce

production costs and save resources. In addition, since ICT can act as a commodity, the shortage of specialists capable of innovations in this area limits the possibilities of creating value and getting revenues.

Taking the above into account, the following definition of the term ICT is proposed: *ICT infrastructure is a set of computer engineering, telecommunication equipment, channels for transmission of data and information systems, means of switching and controlling information flows, organizational structures, legal and regulatory mechanisms that ensure their effective functioning, as well as systems providing computer literacy of the population and professional training and retraining of specialists in the ICT sector.*

According to this definition, ICT industry products used in information communications are part of the ICT infrastructure.

1.2. INSTITUTIONAL AND ECONOMIC ASPECTS OF ICT

National and supranational legal norms and specialized organizations in the field of ICT are a necessary part of the ICT infrastructure since they set rules for the behaviour of economic agents related to the production and consumption of ICT, contribute to the solution of controversial issues, determine policy directions (encouragement or discouragement) for the development of the ICT sector which define the possibilities of access to modern digital technology.

Their influence is especially strong in developing countries. For example, in India, back in 2002, the cost of a bit of broadband Internet in the state of Bangalore (which is considered to be the Indian analogue of Silicon Valley) for end users was 300 times higher than in Japan (Tongia, Subrahmanian, Arunachalam, 2005, p. 23). Such a high price was due to the significant license fees imposed on the suppliers, import duty on ICT equipment, legal restrictions concerning ICT services, which are stricter in developing countries than in developed ones. For comparison: in 2002 in developed countries 96% of the operators performing wireless data transmission were exempted from paying a license fee whereas in developing countries only about 40% (Tongia, Subrahmanian, Arunachalam, 2005, p. 37). Moreover, India planned to raise license fees for Internet service providers from 6% of the adjusted gross income (charged in 2007) to 8%⁸. Although the situation in the world has changed significantly since then, and now India, along with many other developing countries and emerging economies (including Belarus, Kazakhstan, Russia, Ukraine) is among the countries with the lowest payment for internet in the world⁹. This better matches the

⁸ Aulakh, G. (2014). *Trai suggests 8% of yearly revenue as license fee for Internet providers; may push up rates. The Economic Times*. Retrieved 24 September 2019, from <https://economictimes.indiatimes.com/industry/telecom/trai-suggests-8-of-yearly-revenue-as-license-fee-for-internet-providers-may-push-up-rates/articleshow/34486749.cms>

⁹ NUMBEO (2020). *Price Rankings by Country of Internet (60 Mbps or More, Unlimited Data, Cable/ADSL). Utilities (Monthly)*. Retrieved 17 November 2020, from https://www.numbeo.com/cost-of-living/country_price_rankings?itemId=33

real buying power of the population in these countries and helps alleviate problems of the global digital inequality.

The development of the ICT sector and provision of the availability of new digital technologies are hampered by problems caused by unfavourable features of development of individual countries, especially developing ones.

Poverty of population and periodic interruptions in power systems or the absence of power supply to small-populated localities do not contribute to the spread of ICT. This is especially urgent for countries with low per capita incomes: power lines may not be connected to remote settlements, and technologies for producing electricity from unconventional sources of energy (for example, solar energy, wind energy) are usually associated with too high costs.

The problems of uninterrupted supply of electricity are still relevant even for such rapidly developing economies as India and China. In these countries, energy problems are caused, among other things, by a huge number of energy consumers (population and enterprises) and the volume of consumption. Governments are solving problems of the energy sectors by increasing investments in renewal of power systems, reducing energy losses in existing networks and their modernization, developing and implementing devices and technologies for saving energy (primarily ICT). These activities in India and China are implemented within the framework of special government programs and plans developed for a long term¹⁰ (Buckley, Nicholas, Brown, 2018; OECD, 2015, pp. 95-96).

As for the relationship between ICT and the general level of development of countries, it is obvious that, other things being equal, it is easier for wealthier countries to develop new methods of production, storage, processing and transmission of information. For example, at the beginning of 1997 the number of internet users in the world was about 60 million people, while in 2002 it was about 580 million. However, the number of internet users markedly differed by region: about 200 million of them lived in the USA and Canada, 185 million in Europe, 170 million in East Asia and the Pacific, 33 million in Latin America, about 6 million in Africa (half of whom lived in South Africa), and in Western Asia up to 5 million (Suoronta, 2004, p. 318). As known, in the four last regions there are predominantly countries with low or lower middle incomes per capita. Currently, due to the acceleration of global digitalization processes and reduction in the cost of digital technologies, the total number of internet users in the world has already exceeded 4.5 billion people, herein the largest number of them live in the largest countries of the world, namely China, India, and the USA¹¹. The number of internet users in Russia is growing at an outstripping pace: in 2002 the audience of the Russian internet segment was 10% of the population and by the end of 2019 it was already 79%. Today Russia is

¹⁰ Chittilapally J. (2017). *Energy in India. The time has come to alter the energy balance, but at what cost. Lifegate*. Retrieved 24 September 2019, from <https://www.lifegate.com/people/lifestyle/energy-in-india-facts-and-figures>

¹¹ Internet World Stats (2020). *Internet Top 20 Countries — Internet Users 2020*. Retrieved 17 November 2020, from <https://www.internetworldstats.com/top20.htm>

one of the world leaders in tokenized secured transactions and the largest market of digital wallets in Europe (BCG, 2019).

In analysing the dependence of the ICT spread on the level of development of country's economy, it should be noted that estimates of the ICT dissemination across the planet and the ICT sector volume are still problematic. Firstly, this is due to the problems of acquiring adequate information: some of the enterprises with activities that do not belong to the ICT sector often develop and release ICT as a "byproduct" or a product for use inside the enterprise. Such enterprises are not included in the ICT sector statistics. Secondly, as noted earlier, the idea of what TEAs are included in the ICT sector is still undergoing changes, and in this respect, there have not yet been standardization and unification over the world countries. Thirdly, while ICT infrastructure and computer literacy (as one of the essential conditions for ICT dissemination) are at least partially measured, there have not yet been reliable estimates of content in the world. Therefore, the current estimates of ICT and the ICT sector should not be considered absolutely reliable.

Table 1.1 shows 10 leading economies in the production of value added in the field of ICT services and the population incomes according to the World Bank (WB) classification.

As seen from the above data, the leaders in this area are, first of all, the most developed countries of the world that control software, giving the opportunity to release hardware to the world regions with low production costs. Nevertheless, many of them are also in the top ten countries in the world regarding the production of

Table 1.1. Countries leading in production of value added in the field of ICT services, 2015

Position	Country	Production of value added, US \$ billions	Share in GDP of country, %	Population income by WB classification
1	USA	1106	6.2	High
2	EU-28	697	4.3	"
3	China	284	2.6	Upper middle
4	Japan	223	5.4	High
5	India	92	4.5	Lower middle
6	Canada	65	4.2	High
7	Brazil	54	3.0	Upper middle
8	Republic of Korea	48	3.5	High
9	Australia	32	2.4	"
10	Indonesia	30	3.5	Lower middle

Source: The World Bank (2018). World Bank Country and Lending Groups. Retrieved 25 November 2018, from <https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups>; UNCTAD 2017, p. 23.

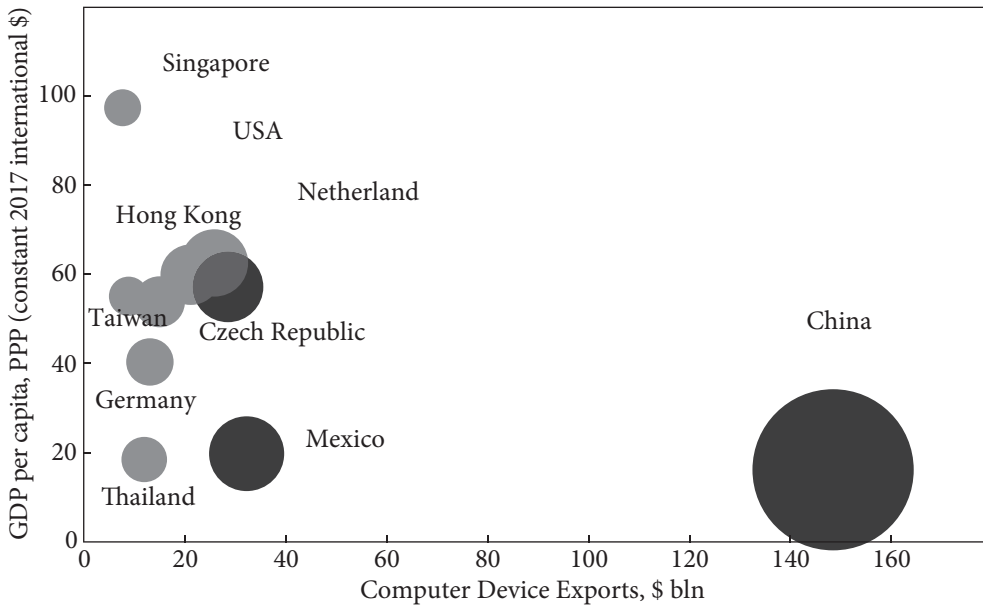


Fig. 1.2. Computer device exports by country, % of the total export volume, 2019

Source: Workman D. (2020) Computer Device Exports by Country, World's Top Exports. Retrieved 24 September 2020, from <http://www.worldstopexports.com/computer-device-exports-country/>; The World Bank (2020). World Development Indicators. Retrieved 24 September 2020, from <http://data-bank.worldbank.org/data/reports.aspx?source=world-development-indicators#>

computers, electronic and optical products (UNCTAD 2017, p. 23) as well as such an important indicator as the exports of computing devices (Fig. 1.2).

As follows from the data presented, the leading countries in the ICT production are among the economies with developed industry. These are traditional world industrial leaders with high per capita incomes, namely the USA and the EU, as well as those countries that have managed to raise domestic production by adapting and localizing foreign technologies. China, which does not refer to countries with high incomes (its per capita income does not exceed \$ 12.5 thousand), is far ahead of the other countries in terms of both ICT production and exports of computing devices. Nowadays the main competition in the world is going on between China and the United States for one of the key technologies in the field of digitalization, the fifth generation of mobile communications (5G). The same two countries are world leaders in terms of R&D funding.

To assess the degree of readiness of the population to benefit from the development of ICT in the world, one can use the network readiness index (NRI), which ranks 134 economies based on their efficiency using 60 variables that characterize the spread of digital technologies in the today's networked world. Table 1.2 shows the leading countries regarding this index in line with some of the leading countries

1. Digitalization of an economy and development of ICT

Table 1.2. Rating by the network readiness index and the level of population income in countries of the world, 2020 (selectively)

Position	Country	NRI	Population income by WB classification
1	Sweden	82.75	High
2	Denmark	82.19	"
3	Singapore	81.39	"
4	Netherlands	81.37	"
5	Switzerland	80.41	"
6	Finland	80.16	"
7	Norway	79.39	"
8	United States	78.91	"
9	Germany	77.48	"
10	United Kingdom	76.27	"
...			
33	Poland	61.80	"
34	Malaysia	61.43	Upper middle
...			
40	China	58.44	" "
...			
48	Russian Federation	54.23	" "
...			
56	Kazakhstan	51.38	" "
...			
59	Brazil	50.58	" "
...			
63	Mexico	49.67	" "
64	Ukraine	49.43	Lower middle
65	Belarus	49.16	Upper middle
...			
73	Indonesia	46.71	" "
...			
88	India	41.57	Lower middle
...			
138	Congo, Dem. Rep.	16.60	Low
139	Chad	14.80	"

Source: Portulans Institute (2020). Network Readiness Index 2020. Available at: <https://networkreadinessindex.org/> (Accessed: 19 November 2020); The World Bank (2020). World Development Indicators. Retrieved 24 September 2020, from <http://databank.worldbank.org/data/reports.aspx?source=world-development-indicators#>

in the provision of ICT services and production of ICT products, Ukraine and some countries bordering on Ukraine, as well as countries with minimum NRI.

The table demonstrates that 10 top positions in terms of NRI are occupied by countries with high per capita incomes, while countries with lower middle or low incomes close the rating.

Ukraine, where the population has lower middle incomes, is not included in the circle of world leaders concerning the provision of ICT services (Table 1.1) and the production of ICT products (Table 1.2), but in terms of NRI it takes position before Belarus, Indonesia and India but after China and Russia.

Overall, the above data support the claim that today many ICTs are inaccessible for countries with lower middle and low income coupled with high levels of illiteracy.

Therefore, no matter how perfect and advanced ICT, electronics, and other ICT sector products are, in case of poverty of the overwhelming part of the country's population or low level of economic development, it is just impossible to use the ICT potential in full. That is, such a property of modern ICT as capacity turns out to be unrealized in practice.

As follows, we can conclude that ICT and the ICT sector themselves are not promises to country's successful development. To achieve a higher income level in the national economy, it is necessary not only to develop ICT and digital economy, but also to simultaneously increase investments in modern production technologies inside or near the country (Vyshnevskiy, 2019, p. 606), to develop the national science and smart industry, which is a driver of innovations and a condition for increasing national competitiveness in the today's world (European Commission 2018). ICT is a tool for more accurate diagnostics of state problems, assistance in developing new ways to solve them when the necessary conditions for their use are created.

As for Ukraine, which has a relatively decent NRI along with lower middle incomes of population, despite the difficult economic situation, there are and continue to operate enterprises that belong to the ICT sector. So, according to the Ukrainian Industry Classification System, they are enterprises of at least 5 types of economic activities (TEA): "Production of computers, electronic, optical products" (section C.26), "Production of wires, cables and electrical devices" (section C.27.3), "Telecommunications" (section J.61), "Computer programming, consulting and related activities" (section J.62), and "Provision of other information services"(section J.63).

Table 1.3 shows data on the volumes of sold industrial products (goods, services) for some of the aforementioned TEAs in 2010-2018. The data on TEA "Production of wires, cables and electrical installation devices" (section C.27.3) is not separately highlighted, since there is available only information for the entire type of economic activity "Production of electrical equipment" (section C.27).

As shown in Table. 1.3, in Ukraine the total volume of products sold through the TEA "Production of computers, electronic and optical products" and "Production of electrical equipment" in the period from 2010 to 2016 decreased (in comparable prices). In 2017-2018, there observed a slight increase in the volume of production through the TEA "Production of electrical equipment". The value of this indicator for the TEA

1. Digitalization of an economy and development of ICT

Table 1.3. Volume of sold industrial products (goods, services) for some types of economic activities of the ICT sector in Ukraine (in comparative prices, 2010 — base year)

Year	Unit of measurement	Type of economic activity		
		Production of computers, electronic and optical products (C.26)	Production of electrical equipment (C.27)	Information and telecommunications (J.61 + J.62 + J.63)
2010	Million UAH	6691.4	1575.52	73015
	% of the precedent year	100	100	100
2011	Million UAH	10095.4	14637.1	72362.4
	% of the precedent year	150.9	92.9	99.1
2012	Million UAH	6398.3	17985.3	73167.2
	% of the precedent year	63.4	122.9	101.1
2013	Million UAH	5847.8	17003.3	73424.7
	% of the precedent year	91.4	94.5	100.3
2014	Million UAH	5465.4	14115.1	71019.8
	% of the precedent year	93.5	83.0	96.7
2015	Million UAH	4244.1	11629.3	72314.8
	% of the precedent year	77.7	82.4	101.8
2016	Million UAH	5108.8	10987.1	71896.5
	% of the precedent year	120.4	94.5	99.4
2017	Million UAH	4663.6	11161.3	64191.3
	% of the precedent year	91.3	101.6	89.3
2018	Million UAH	4908.3	12478.3	No data
	% of the precedent year	105.2	111.8	" "
2019	Million UAH	3492.01	3439.76	" "
	% of the precedent year	71.2	27.6	" "

Source: State Statistics Service of Ukraine. Statistics information. Retrieved 24 September 2020, from <http://ukrstat.gov.ua>

"Production of computers, electronic and optical products" did not have a stable character: from 2014, it either increased or decreased and in 2019 a significant drop in the volume of sold products occurred, while the TEA "Production of computers, electronic and optical products" was maximal for the entire period under consideration.

In a relative presentation, the volume of products sold through the TEAs "Production of computers, electronic and optical products" and "Production of electrical equipment" in total did not exceed 2.2% of Ukraine's GDP in 2011, and in 2019 amounted to merely 0.64% of GDP.

Also, from the data of Table 1.3 we can draw a conclusion about an uneven development of the TEAs "Production of computers, electronic and optical products"

and "Production of electrical equipment". After 2013, the sales indices for them have been decreasing and so far are still significantly lower than those in 2010. This suggests that the ICT industry in Ukraine is currently going through hard times.

A different picture emerges when analysing the performance indicators of the TEA "Telecommunications" (section J.61), "Computer programming, consulting and related activities" (section J.62), "Provision of other information services" (section J.63). From Table 1.3, it can be concluded that, in comparable prices, the volume of sales of goods and services through these TEAs within 2010-2016 remained practically unchanged, and in 2017 there was a rather significant (compared to the changes within 2010-2017) decrease in this indicator, namely by 7.7 UAH billion.

In relative terms, the share of service sales by these TEAs in 2010 amounted to 6.7% of GDP, but in 2011 it decreased down to 6.4%. Over 2011-2015 there was an increase in this indicator (up to 7.55%). In the following two years, the trend changed to the opposite: in 2016 this indicator was 7.3% GDP and in 2017 only 6.36%.

If we compare these data with Table 1.1, we will note that the data on the value added (unlike the volumes of sold products) in the leading countries concerning provision of ICT services are close to those observed many years ago.

In general, the above information contradicts the widespread in Ukraine idea about a rapid development of the ICT sector (TEA "Production of computers, electronic and optical products", "Production of electrical equipment", "Telecommunications", "Computer programming, consulting and related activity" and "Provision of other information services"). Taking into account the fact that the products of the last three of the listed TEAs are focused primarily on foreign rather than domestic markets¹², such dynamics of the ICT services seems unfavourable for Ukraine in comparison with other emerging economies (for example, China and India), not to mention the developed countries.

Under such conditions, Ukrainian enterprises may not receive modern digital solutions and products for production purposes, which will negatively affect their competitiveness and the socio-economic development of the country as a whole.

1.3. PREREQUISITES FOR SUCCESSFUL DEVELOPMENT OF ICT

Summarizing the study of the features of development of ICT and the ICT sector, as well as the general prerequisites for innovation in the context of Industry 4.0 (Holiuchenko, 2017; Vyshnevskiy, Kniazev, 2018; Pidorycheva, 2020), we can conclude that this sector can successfully develop under a number of preconditions.

A stable economy with stable economic institutions, the development of which is sustainable and predictable. It is important for a country to achieve sustainable economic growth that forms positive expectations for the future; herein legislation, in-

¹² B2B-Ray (2017). *People are the narrowest place in Industry 4.0*. Retrieved 24 September 2019, from: https://www.b2b-ray.com/publication/ludi__uzkoie_gorlyshko_v_industry_40/

cluding that in the ICT field, should be transparent and understandable, with rare changes in it, about which economic agents should be notified in advance so that they could have time for preparation for them. In general, the state should create such economic and institutional conditions that increase the effective demand of the population and enterprises for the ICT sector products. It is important for people in countries with lower middle or low incomes, as well as for the poorest people in rich countries, to ensure easy access to ICT. This can be facilitated by the assistance of national and international non-profit organizations and government agencies that create public internet access points. As an example, we can point to India, where a special Universal Service Obligation Fund was created under the auspices of the country's government and the Ministry of Communications. Its task is to provide reliable and high-quality communication and access to ICT for the population living in rural and remote areas. To perform this, the fund finances repair and development of power grids in these areas and build elements of ICT infrastructure¹³.

The Government of India is aware of the importance of development and dissemination of ICT in the country and finds opportunities to allocate funds from the budget for programs on digitalization of society. For those countries where there are no such opportunities, donor technical and technological assistance from more economically developed countries may be a way out. However, this option is only possible if the following condition is met.

High level of education of country's population, including computer literacy. To achieve this, it is necessary to develop the education system, in particular higher education related to the development of ICT and ICT products. The high level of computer literacy of the population makes it possible to effectively use the current ICT, and the system of professional training and retraining of personnel creates potential opportunities for innovations in the ICT sector, which contributes to an increase in the competitiveness of the country's products in international markets and to a decrease in the degree of its dependence on the imports of high-tech products. It is also important to provide conditions under which the gained knowledge will be transformed into research and development work (R&D). For example, Ukraine occupies a fairly high position in world rankings by the quality of education and the level of education of the population, which, however, does not transform into high achievements in the field of R&D (Vyshnevskiy, Kniازهv, 2018). To overcome this shortcoming, the education system should be built in close connection with science and production using the forms of public-private partnership that have proven their effectiveness in different countries of the world (Meissner, 2019).

For the poorest countries, an option to mitigate this problem is to acquire information and services through mobile communications. In particular, many African countries are among the poorest in the world, but even in them, the illiterate population actively uses mobile services, thanks to which this market segment is rapidly develop-

¹³ USOF (2019). *About Universal Service Obligation Fund*. Retrieved 24 September 2019, from <http://www.usof.gov.in/usof-cms/home.jsp>

ing on the continent. Moreover, mobile communications are used not only for communication, but also for financial activities. For example, in Kenya the operator Safaricom provided mobile banking services to 7 million users. Similar examples of using mobile communications exist in South Africa and the Philippines (Spence, Smith, 2010). That is, even if a significant part of the country's population is poor and illiterate, there are types of ICT that can be successfully used, including by education.

Reliable institution for the protection of intellectual property rights. ICT is often an object of unwanted technological spillovers, that is, piracy. On the one hand, because of this, ICT developers lose part of their potential income and the opportunity to make further investments in R&D and create new ICT types. On the other hand, since ICT allows one to acquire new knowledge or act as knowledge itself, useful information is disseminated among a larger number of users than in case of the absence of piracy. No doubt, misappropriation of the results of someone else's labour is a crime. As for ICT, it is necessary to combat such crimes by developing an institution of intellectual property rights. In addition, it should be kept in mind that strict protection of rights to intellectual property objects stimulates their further development and the emergence of new ICTs, since it gives developers an opportunity to get money and re-invest it in production. In addition, it contributes to the formation of an overall favourable environment for innovation and stimulates high-tech products trade between countries (Chen, 2017). At the same time, less strict protection of intellectual property rights contributes to widespread dissemination of ICT and new knowledge in society and hinders rent-aimed behaviour in this area. Therefore, when developing state policy in the field of protecting intellectual property, it is necessary to find a balance between these two extremes, the parameters of which depend on the level of economic development and economy's institutional features.

Hence, for highly developed economies (the USA, the EU core countries, the Republic of Korea, Japan, etc.) with developed innovative ecosystems, the main task is to create fundamentally new products and processes, which requires significant funds, especially at the first stages of the technology lifetime. Therefore, in such economies, priority is given to a strict protection of intellectual property rights. For developing countries and those wishing to bring their economies to a higher level, at least in the beginning it is important to ensure as wide as possible dissemination of new knowledge and skills. They therefore usually practice a less rigid approach to the protection of intellectual property rights. In particular, such an approach is adhered to India and China (Holichenko, 2017), which, due to this, have managed to achieve significant progress in ICT. Perhaps, it will be suitable for Ukraine and other emerging economies, provided the ICT sector in them is supported by the state and develop at an accelerated pace.

Developed ICT market. The larger and more diversified the market for ICT services and goods, the easier it is for economic agents to operate in it and the lower the transaction costs. The development of the ICT market can be facilitated by special legislative and educational initiatives of the authorities. An example of this kind is the actions of the government of Belarus. At the end of 2017 the decree "On the Development of Di-

igital Economy" was signed in the country, which served as a "green light" for development of advanced digital technologies, in particular blockchain technologies. Elements of British law were introduced and the activities of residents of the previously created High-Tech Park were expanded, which began to vary from the creation of self-driving cars to the support for education by IT companies¹⁴.

The government can stimulate the development of the ICT market through government orders and procurement, giving preference to the most advanced ICT products created by national manufacturers, or to goods made using modern digital technologies. Moreover, ICT can be used to optimize the public procurement process itself. For example, in the EU, within the framework of electronic government (e-government), the electronic system of public procurement (e-procurement) is widespread in using electronic communications and processing transactions by government agencies and other public sector organizations when purchasing goods and services or holding tenders for public works¹⁵. The e-procurement system uses electronic communication, special software for conducting online auctions, as well as ICT to carry out a number of stages of the procurement process (searching for necessary goods, services and their sellers, negotiations, ordering, receiving and inspecting after the purchase).

It is believed that the e-procurement system reduces the time and money required to organize this process, allows one to choose the cheapest option out of all possible and promotes greater transparency and competition between sellers of goods (services). For example, the e-procurement system in Slovakia in 2012 made it possible to save from 9% (in the energy sector) to 21% (legal and consulting services) of the cost of goods and services in comparison with the previous (without using the e-procurement system) government procurement (Svidronova, Mikus, 2015).

Furthermore, the state can tighten standards for ICT products, forcing manufacturers to improve them. However, in the case of an underdeveloped national ICT sector, such measures may lead to ousting from the market of domestic ICT products by imported counterparts. Therefore, in such conditions, the following activities may be more appropriate, which are carried out within the framework of a special state policy for the ICT sector development and support.

State financial support for enterprises in the ICT sector, which can be manifested both in direct financing of specific R&D activities carried out by enterprises or their associations with the ICT sector and in provision of targeted grants and/or tax relief concerning the income tax for enterprises in the ICT sector, etc.

An example of such support is the governments of the Republic of Korea and Japan, which finance ICT initiatives (development of ICT infrastructure, creation of an environment conducive to the development and use of ICT, educational programs

¹⁴ Konovalova E., Gutor A. (2018). Why Belarus is becoming a global centre for the development of AI. Retrieved 20 November 2020, from <https://www.forbes.ru/tehnologii/368797-pochemu-belorussiya-stanovitsya-mirovym-centrom-razrabotok-ii>

¹⁵ European Commission (2012). *Frequently Asked Questions: A Strategy for e-Procurement*. Press Release Database. Retrieved 24 September 2019, from http://europa.eu/rapid/press-release_MEMO-12-265_en.htm?locale=en

in the field of ICT development and increasing computer literacy of the population in general, creation of new ICT and information resources in national languages) not only within these countries, but also throughout the Asian region and even in the Middle East and Georgia. Herein the South Korea's government directly contributes to the special ICT Trust Fund and the Knowledge Partnership Fund, and the Japan's government, which makes the largest financial contributions, first allocates funds to the Japan ICT Fund, which transfers funds for specific ICT programs to the ICT Trust Fund and the Knowledge Partnership Fund¹⁶.

Another recent example is a package of measures to support companies in the IT industry in Russia signed in July 2020 including time-unlimited reduction in the income tax rate for IT companies from 20 to 3% and a significant reduction in the burden on the payroll fund by decreasing the insurance premium rate from 14 to 7.6%. As a result, the number of companies wishing to obtain state accreditation as an IT organization, as well as the number of applications for inclusion of them in the register of Russian software immediately grew sharply¹⁷.

ICT can be aimed at improving the well-being of the whole society (for example, programs for analysing the state of the natural environment, meteorological conditions, warning systems for floods or earthquakes, free educational platforms aimed at covering wide segments of the population). In these cases, ICT is, at least partly, a kind of common good, proper provision of which requires governmental regulation.

At the same time, it is important to take into account the fact that with the allocation of direct state funding or grants, unfair preferences may arise, including those associated with illegal methods for obtaining state aid from the leadership of individual enterprises. Therefore, the development of the most transparent conditions for obtaining such financing and accounting is becoming an especially urgent task, which can be facilitated by development of e-procurement systems in the country. In turn, the provision of tax exemptions to enterprises in the ICT sector, at least for a limited time, allows such firms to offset their R&D costs, and, in combination with strict protection of intellectual property rights, to generate profits that can be directed to the creation of new ICT services and products.

In addition, it is important to keep in mind that a large-scale allocation of tax incentives to national ICT enterprises in line with operating restrictions on foreign companies or enterprises with foreign investment can be perceived as a national policy of protectionism, with all the ensuing consequences, or lead to an outflow of foreign investments from the country. This must be taken into account when developing a balanced state policy in the development of the ICT sector.

Antitrust regulation and maintaining a competitive environment for ICT enterprises. Since one of the tasks of the ICT sector development is dissemination of knowledge, ex-

¹⁶ Asian Development Bank (2019). *ICT: Funding and Partnerships*. Retrieved 24 September 2019, from <https://www.adb.org/sectors/ict/funding-and-partnerships>

¹⁷ Balashova A., Skobelev V., Skrynnikova A., Dzyadko T. (2020). *In Russia, the number of IT companies wishing to get on the "state account" has sharply increased*. Retrieved 20 November 2020, from https://www.rbc.ru/technology_and_media/29/10/2020/5f9974a89a7947df0c62d656

cessive protection of intellectual property rights for a long time in case of a small number of competing enterprises can lead to market monopolization, overpriced ICT (licenses for the right to use). It was such a behaviour that the US Department of Justice suspected of such giants in the IT sphere as Google, Facebook, Amazon and Apple: in July 2019, an antitrust investigation was launched against them, which was supposed to determine whether they inflated prices for their products, did not satisfy consumer rights and undermined the foundations of competition by their activities¹⁸. During the hearing, a statement was made that the companies abused their control over current technologies to expand their power¹⁹. In October 2020, following the investigation, democrats in the US Congress declared Google a monopolist which used anti-competitive methods to dominate in the search and advertising market. The lawsuit can take years and trigger a cascade of other antitrust lawsuits from state attorney-generals. Obviously, the government victory can significantly change the entire internet economy²⁰.

In this regard, it is appropriate to recall that in the early 2000s the US Department of Justice took antitrust measures against Microsoft, a large manufacturer of ICT and ICT equipment at that time, which led to the division of the company into two parts and imposition of strict restrictions on it (Economides, 2001).

Antitrust regulation in ICT application is compounded by the problem of big data, which can create barriers to entry the market and affect it, especially when companies have unique datasets that cannot be replicated by competitors. Everything is not simple here, since many modern enterprises that develop and test high-tech products (jet engines, turbines, cars, etc.) collect a huge amount of data on their products, which, for obvious reasons, are not available to competitors. And this does not cause concern for the antitrust authorities. However, when access to significant amount or variety of data is important to competitiveness in the market (which is an issue of specific market), big data can create barriers to the market entry because new entrants cannot collect data or acquire access to data of the same volume or variety as the existing companies can (Modrall, 2017). Herein questions arise about ensuring the legality of processing personal data, protecting the rights of citizens in the digital environment, etc. Nowadays there are several different approaches to regulating data in the world, which can be conditionally subdivided into European (more stringent in terms of protecting the rights of citizens), American (market-oriented) and Chinese (nation-oriented) ones²¹.

¹⁸ Pietsch, B. (2019). Explainer: *What Google, Facebook could face in U.S. antitrust probe*. Reuters. Retrieved 24 September 2019, from <https://www.reuters.com/article/us-tech-antitrust-explainer/explainer-what-google-facebook-could-face-in-u-s-antitrust-probe-idUSKCN1UJ2Z3>

¹⁹ Robertson A. (2020). *Everything you need to know from the tech antitrust hearing*. Retrieved 20 November 2020, from <https://www.theverge.com/2020/7/29/21335706/antitrust-hearing-highlights-facebook-google-amazon-apple-congress-testimony>

²⁰ Kang C., McCabe D., Wakabayashi D. (2020). *U.S. Accuses Google of Illegally Protecting Monopoly*. Retrieved 20 November 2020, from <https://www.nytimes.com/2020/10/20/technology/google-antitrust.html>

²¹ Serebryanikova A. (2020). *Big data management*. Retrieved 20 November 2020, from <https://digital.ac.gov.ru/opinions/4284/>

All these processes of development of legislation and regulatory practices are going on and are far from complete.

Taking into account the above, it is especially important to improve antitrust legislation in a balanced manner and simultaneously with the development of an institute of intellectual property law, creating proper conditions for entry and exit from the market for new enterprises of the ICT sector. Strict protection of intellectual property rights in combination with financial incentives during the first years of ICT creation, followed by complete or partial cancellation of preferences for enterprises-developers and weakening the regime for protection of intellectual property rights, can contribute to successful spread of new knowledge and further development of the sector. At the same time, during the action of these measures, enterprises-developers should be able to compensate their expenses while their customers — to strengthen their competitive positions in the market through using new digital technologies.

To briefly sum up, we should note that it is important to create the above-mentioned prerequisites for a successful development of ICT as a complex, since they mutually complement and reinforce each other. In this sense, it is reasonable to talk about the need to take not just individual measures, but rather to create integral digital ecosystems. And like ecosystems in biology (biogeocenoses) ensure their survival and resistance to external impacts due to diversity of organisms interacting with each other and with the abiotic environment, digital ecosystems, consisting of communities of interconnected ICTs of various organizations and people, should correspond properly to the historical, socio-cultural, institutional, technical-technological and economic particularities of individual countries and regions.



2

TECHNOLOGIES OF DIGITALIZATION OF AN ECONOMY



2.1. TRANSFER FROM TRADITIONAL TO DIGITAL BUSINESS

Digitalization of the economy is a technical, technological and socio-economic phenomenon, which is new in the historical dimension and changes the reality around us. Computers and a variety of digital devices stimulate a human brain functions on the path to better understanding and the formation of improved living environment. Expansion of Internet access allows to do this in a faster and better manner. All these changes affect people all over the world, both at home and at work. In the economic sphere, the latest developments make it possible to create new and customize well-known products, enter new markets, automate complex business tasks and design new business models, reduce production costs and develop new skills and abilities. The World Economic Forum report "Deep Shift. Technology Tipping Points and Societal Impact" (World Economic Forum, 2015, p. 4) noted that the world is experiencing an exponential rate of changes due to the development of software and the growth of digital services. Therefore, it is relevant to identify modern trends in the digital sphere, to establish its place in the traditional classification of types of economic activity and the factors of its influence on the economy.

Currently, the new paradigm of the digital economy continues to develop and transform, including under the influence of the global pandemic, which has already created a new economic reality. For many, it does not look very optimistic as "the 90% economy" (The Economist, 2020). At the same time, there is ample evidence that digitalization can help solve many of the problems that have arisen, and investment in the digital infrastructure and digital economy can provide better fiscal multiples and long-term return on investment (Huawie, Arthur D. Little, 2020).

However, before starting a substantive analysis of the factors of digitalization impact on the economy, it is advisable to define the meaning of terms "digitalization", "digital economy", "digital sector of the economy", etc. This, in particular, is necessary in order to avoid misunderstandings, associated with different interpretations of new concepts.

The current transition from traditional to digital business is often described in terms of "digitization", "digitalization", "digi-

tal transformation", etc. It is important to distinguish these concepts in order to better understand the essence and importance of digital transformations, which radically change not only the economy, but also the individual life of every person.

"Digitization" was the first term that started a person's acquaintance with digit in the context of ICTs. In a broad sense, it is the process of transition from analog to digital form of signals, that is, the transformation of handwritten and typewritten texts and other information (audio, video) into digital format, that is, a digital image of an object or a digital form of a signal in the form of binary numbers (binary code or other system of numbers). Digitization is used to process, store and transmit any information.

Examples are scanning of analog photographs, audio (for example, vinyl records) and video recordings (films, videotapes) for recording on electronic media, 3D scanning or modelling, creating electronic geographic maps by scanning traditional paper ones and satellite images, creating e-books, documents and other text and graphic materials through the processing of paper media.

Digitization of a person (personality) can be called the digital profile of a user in the network, from personal characteristics, preferences and needs in social networks to financial condition, transactions on users' profile pages in Internet pages of banks and physical health on users' profile pages in Internet pages of diagnostic centres, private clinics or fitness applications. It also includes digital imitation of a person using artificial intelligence (as an example, bots, avatars, etc.) and digital systems of social control of people (such as "Social Credit System", "Social Monitoring", etc.).

Digitalization is closely related to digitization, however, in contrast to it, it includes the digitization of not only information, but also economic relations and processes through digital technologies that provide new opportunities for creating value and generating income¹. This can include, for example, the automation of manufacturing, training and retraining of personnel to work in new conditions, the use of online platforms, etc. The value of digitalization for enterprises lies in increasing labour productivity and reducing production and sales costs. Most often, this definition is used to characterize business processes, but in reality, digitalization also changes the relationship between individuals, individuals and legal entities, transforms the format and means of labour. Thus, a new "world of labour" is being created (Muro, Liu, Whiton, Kulkarni, 2017), in which digital skills and digital devices are part of human culture.

An example of digitalization of manufacturing is the employment of sensors, actuators and other digital devices to connect equipment and mechanisms to the industrial Internet of Things in order to collect information, process and transmit data for decision-making, as well as to remote control of various tasks and functions. According to BusinessInsider's forecast, in 2027 the number of devices connected to the industrial Internet of Things will be over 41 billion².

¹ Gartner (2021). Definition of Digitalization — Gartner Information Technology Glossary. Retrieved 15 January 2021, from <https://www.gartner.com/en/information-technology/glossary/digitalization>

² Newman, P. (2020). *The internet of things 2020: Here's what over 400 IoT decision-makers say about the future of enterprise connectivity and how IoT companies can use it to grow revenue*. Retrieved 15 January 2021, from <https://www.businessinsider.com/internet-of-things-report>

Furthermore, digitalization has made it possible to launch creation of autonomous cars and mechanisms, primarily vehicles, which, according to KPMG research, can prevent up to 90-95% of road traffic accidents caused by human error and save up to 1 million lives per year³.

In modern cars, devices are installed that transmit information to the manufacturer about the car functioning, its use and mechanical condition. Access to a customer's data allows companies to improve and expand their service capabilities, use an individual approach, customize products and expand sales markets (Leonard, Mindell, Stayton, 2020).

A deeper digital conversion of business is digital transformation of business processes, competencies, business models in order to fully use the possibilities of digital technologies and their impact on the activities of enterprises, customers and the state of markets (Box 2.1).

Box 2.1. Examples of businesses' digital transformation in Ukraine

One of the examples of successful digital transformation is the experience of reforms of the international mining and metallurgical group of companies "Metinvest". It created a corporate system of unified communications, automated the process of managing employees' offers at 14 enterprises, introduced an electronic procurement platform, based on SAP Ariba solutions at 8 enterprises and transferred IT infrastructure to the Microsoft Azure cloud platform. These solutions helped to reduce costs for the group and optimize its budget. "Metinvest" plans to introduce the goal setting and performance management system SAP SuccessFactors and digital transformation of the sale function to the Swiss trading company MISA on the basis of SAP Sales Cloud and SAP CPQ solutions.*

*At the pipe-and-wheel holding "Interpipe", the basis of digital transformation processes was the implementation of a unified information system IT-Enterprise. It was created to combine the information flows of individual enterprises of the group and improve the efficiency of business process management (a system for tracking the movement of materials in production, automation of pipes' marking and branding, automation of inventory, online service of pipe products' verification and automation of fixed assets management). The result of the system application was a rise in the efficiency of production personnel by 45%, an increase in the speed of document turnover, a reduction in the time of equipment downtime and coordination of orders, decrease in the risk of making errors when entering data into the system and fining for complaints**.*

* Metinvest Digital (2020). Serhii Detyuk: Metinvest Digital manages a portfolio of 100 digital transformation projects. Retrieved 15 January 2021, from <https://metinvest.digital/page/489>

** IT Enterprise (2020). Projects for digital transformation of "Interpipe" holding. Retrieved 15 January 2021, from <https://www.it.ua/ru/cases/article/interpipes-digital-transformation-of-manufacturing>

³ Threlfall, R. (2018). *Autonomous Vehicles Readiness Index*. KPMG International. Retrieved 15 January 2021, from <https://assets.kpmg/content/dam/kpmg/tw/pdf/2018/03/KPMG-Autonomous-Vehicle-Readiness-Index.pdf>

On the one hand, introduction of a holistic system of digital technologies leads to fundamental changes in the organization of a business functioning and its strategy. On the other hand, these technologies change the way we do business (flexibility and focus on a customer become its main requirements), thus producing a cultural shift in the enterprises and organizations' functioning.

An example of such a digital transformation is the use of Big Data to form a new business models, based on huge amounts of information (including unstructured ones), which can significantly improve competencies and performance results. Big Data analytics helps companies to make optimal decisions on development strategies, production, goods and services, employees, etc.

A well-known digital transformation is the change in the business model of retailers, who have started using websites and mobile apps for online sales, reaching more customers through various communication channels. Additionally, in order to improve service and increase sales, information about consumers (for example, via social networks) and the purchase history is collected and analysed.

Digital transformation in marketing makes it possible to reduce costs, move from conventional mailing of advertising to organizing advertising processes using the capabilities of email and other messenger apps. At the same time, it has become possible to automate marketing, work with large amount of data, analyse customers' behaviour and conduct dialogues with them, optimize the offer of goods and services through personalized targeting.

Thus, with the appearance of digital technologies, it became possible to cover a wider range of economic, social, cultural and other aspects of life.

The fourth version of the International Standard Industrial Classification of All Economic Activities (ISIC), which serves as a model for the development of national classifiers of types of economic activities and is used to collect, systematize, analyse and store data for economic analysis, gives a definition of the ICT sector as a component of the information (digital) economy. This sector includes the production of goods and services in the relevant industry, primarily aimed at processing and diffusion of information through electronic (digital) means (Table 2.1).

The activities of this sector can be grouped according to the branches, involved in ICT manufacturing, ICT trade, and ICT service industries. By ISIC, the ICT industries also include the sector of content and media.

However, these changes do not take into account the rapid development of digital activity, functioning of digital platforms, Big Data analysis, augmented reality, etc. Therefore, the digital economy is often defined rather narrowly, including only sectors that are directly related to information and telecommunications.

According to the experts from the Asian Development Bank Institute (Juswanto, Simms, 2017, p. 2), the digital economy combines e-commerce, app stores, online advertising, online payment services, cloud computing technologies, as well as information and other platforms. That is, such a description of the digital economy is focused on more specific types of activities that have been developed in line with the spread of the Internet and increase in the data transfer speed.

The above facts indicate significant transformations taking place in society in general and in the economy in particular and entailing the expansion of activities, associated with the further development of the digital economy. Thus, the description of the digital economy, proposed by the experts of the Asian Development Bank Institute, does not take into account all these potential opportunities and therefore requires clarification.

Obviously, all types of economic activity that use digital technologies, infrastructure and digitized data may be considered as components of the digital economy. *That is, the digital economy is an economic activity, based on digital ICTs and a wide network of connections, created with these technologies between individuals and legal entities, material and virtual objects, production and non-production processes, etc.*

Table 2.1. ICT Sector in the International Standard Industrial Classification of All Economic Activities (ISIC Rev. 4) (United Nation, 2008, p. 278)

Divisions, Groups, Classes	ICT manufacturing industries
26	Manufacture of computer, electronic and optical products
2610	Manufacture of electronic components and boards
2620	Manufacture of computers and peripheral equipment
2630	Manufacture of communication equipment
2640	Manufacture of consumer electronics
2680	Manufacture of magnetic and optical media
	<i>ICT trade industries</i>
4651	Wholesale of computers, computer peripheral equipment and software
4652	Wholesale of electronic and telecommunications equipment and parts
	<i>ICT services industries</i>
5820	Software publishing
61	Telecommunications
6110	Wired telecommunications activities
6120	Wireless telecommunications activities
6130	Satellite telecommunications activities
6190	Other telecommunications activities
62	Computer programming, consultancy and related activities
6201	Computer programming activities
6202	Computer consultancy and computer facilities management activities
6209	Other information technology and computer service activities
631	Data processing, hosting and related activities; web portals
6311	Data processing, hosting and related activities
6312	Web portals
951	Repair of computers and communication equipment
9511	Repair of computers and peripheral equipment
9512	Repair of communication equipment

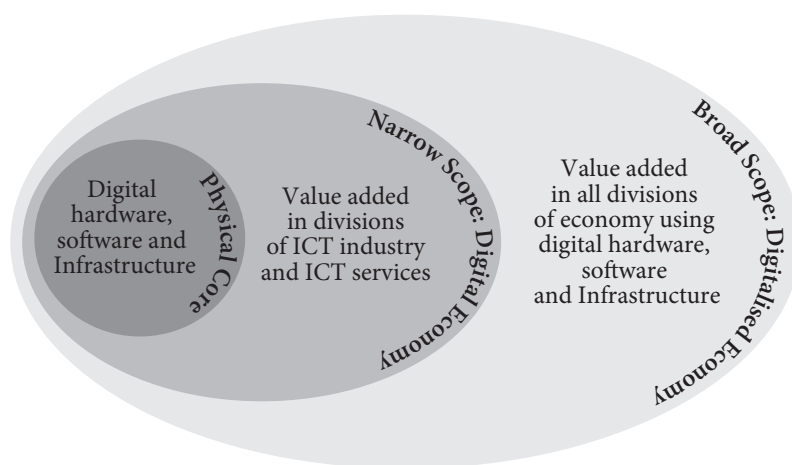


Fig. 2.1. Graphic illustration of digital economy concept

In terms of the scope of economic activities, the digital economy in the narrow sense is the value added, created in divisions of ICT industry and ICT services (this is a more specific and operational definition), and the digital economy in a broad sense, or, in other words, the digitalized economy (Huawie, Arthur D. Little, 2020, p. 12) is the value added, created in all divisions of the economy with ICT technologies and ICT infrastructure (Fig. 2.1).

Of course, the above definitions are not final and complete, since, as noted earlier, a large-scale digital transformation of economic life is just unfolding, and scientific concepts are reflection of the results of previous development, circumstances of place and time, which rapidly change. Appendix 2.1 contains a number of other definitions of the "digital economy", formulated in studies of foreign and Ukrainian researchers.

The digital economy has changed the priorities, directions and dynamics of development in many areas of business. For example, it contributed to the intensification of using the Internet and accelerating activities, related to increasing the data transmission speed. With the emergence of the digital economy began a massive increase in the quantity and quality of digital technologies along with investments in all areas, related to software, digital services, communications, etc. The Internet has become not only one of the types of communication and information resources, but also a web-business with high profitability indicators.

Entrepreneurs and trade enterprises have adapted their activities to modern digital conditions by starting online businesses. According to Statista, in 2019 retail e-commerce sales in the world amounted to \$ 3.53 trillion, and in 2022 may reach \$ 6.54 trillion⁴.

Due to the spread of digitization of photo, music and video, the market of CD and DVD disks as physic storages of information has almost disappeared; fewer

⁴ Statista (2020) *Global retail e-commerce market size 2014-2023* | Statista. Retrieved 15 January 2021, from <https://www.statista.com/statistics/379046/worldwide-retail-e-commerce-sales/>

newspapers and magazines are bought. The same is applied to the service sector: more and more bank customers use mobile apps, carrying out transactions online, ordering food or medicine, booking rooms in hotels or tickets for airplanes, trains, buses, etc. That is, some material goods have disappeared, and instead digital goods and services have appeared.

Along with the positive shifts that the digital economy brings, its negative consequences, in addition to environmental risks (see Chapter 3), include the risks of reducing employment in types of activity that are most susceptible to digitalization, decrease in demand for low- and medium-skilled workers, further growth of inequality in income. The leading international organizations such as the UN, the International Labour Organization, the International Monetary Fund, the World Bank, expressed their concern about changes in the labour market in numerous studies (Chang, Huynh, 2016; Partington, 2019; Bandholz, 2016).

Indeed, in the process of adapting to new changes in the digital economy, many professions and specialties are radically transformed or may disappear altogether. The new technologies are prompting governments to reform education systems, to reveal and focus on the comparative advantages and new skills of the population. Life-long learning in conditions of digital economy is no longer an entertainment, but a necessity that allows a person to feel more comfortable in the continuous flow of new knowledge and technological changes.

At the same time, with the advent of digital tools, new jobs appear related to the advance, implementation and maintenance of digital technological solutions, which means new requirements for potential employees. Also, the digital economy requires a developed infrastructure, a well-functioning Internet, mobile networks and telecommunications. All this needs large investments, which in many countries, especially those with lower-middle incomes, are problematic to raise.

Digital technologies, such as the Internet, Internet of Things, Big Data analytics, wireless networks, mobile devices and social networks, are changing the activities of people and enterprises, as well as traditional ways of doing business. Not long ago, the attributes of an enterprise were tangible and intangible assets and labour, located on the same territory. Today in the digital economy conditions, despite the possible absence of some of these components, an enterprise can successfully function, making a profit (for example, Airbnb is an online marketplace for searching and short-term rentals of private housing around the world).

Digital technologies' employment transforms business models: new products and services constantly appear, the content of labour and the format of work (outsourcing, online platforms, advanced automation and robotization) change, data digitization and real-time work are fundamentally changing ways of management, manufacturing and sales.

Thus, the digital economy already covers a significant and growing part of traditional industries and creates new types of economic activity, which together throw down new challenges and open up new prospects for economic development and the formation of a new "smart" society or Society 5.0 (Government of Japan, 2015).

2.2. FACTORS OF DIGITALIZATION IMPACT ON RESULTS OF ECONOMIC ACTIVITY

As noted, due to the lack of a unified approach to measuring the contribution of the digital economy to the global one, data on its size and influence are very different. For example, according to the Grand View Research, Inc., in 2019 the digital transformation market was estimated at \$ 284 billion, with an average annual growth rate of 22.5% from 2020 to 2027, which is facilitated by the growing use of mobile devices and apps, implementation and integration of digital technology products and analytics in business operations (Grand View Research, Inc., 2020).

Somewhat different figures are presented in the study by MarketsandMarkets Research Private Ltd., which estimates this market at \$ 470 billion in 2020 and \$1,010 billion in 2025 with an average annual growth rate of 16.5%⁵. But according to the forecast by Meticulous Research, in 2025 the digital transformation market will reach \$ 3.29 trillion with an average annual growth rate of 22.7% (from 2019 to 2025)⁶. All this indicates that the understanding of the digital economy and the initial data on the digital transformation market in the above studies differ significantly.

The report of the World Economic Forum and the consulting company Accenture predicts that by 2025 digital technologies will have been able to drive the global economy up to \$100 trillion (World Economic Forum, 2016). Although the digital economy is only at the initial stage of evolution, the results of its development are significant, and now it is advisable to have tools and methods for assessment of the size of the digital transformation market and the impact of "digit" on economic indicators of business activity. After all, measurement systems shape our beliefs and conclusions: "What we measure affects what we do; and if our measurements are flawed, decisions may be distorted" (Stiglitz, Sen, Fitoussi, 2009, p. 7).

Over recent years, lots of studies have appeared on defining factors, affecting the final results of economic activity in the digitalization conditions.

For example, in the report "Digital disruption: Development unleashed. Multiply innovation, collaboration and impact through digital in international development"⁷ of the consulting company Accenture, the following five new digital technologies that can transform global economic development are identified:

⁵ MarketsandMarkets Research Private Ltd. (2020). *Digital Transformation Market*. Retrieved 15 January 2021, from <https://www.marketsandmarkets.com/Market-Reports/digital-transformation-market-43010479.html>

⁶ Meticulous Market Research Pvt. Ltd. (2020). *Digital Transformation Market Worth \$3,294 Billion by 2025, Growing at a CAGR of 22.7% from 2019*. Retrieved 15 January 2021, from <https://www.globenewswire.com/news-release/2020/06/10/2046146/0/en/Digital-Transformation-Market-Worth-3-294-Billion-by-2025-Growing-at-a-CAGR-of-22-7-from-2019-Global-Market-Opportunity-Analysis-and-Industry-Forecasts-by-Meticulous-Research.html>

⁷ Ford F.R., Lobo I. (2018). *Digital disruption: Development unleashed. Multiply innovation, collaboration and impact through digital in international development*. Retrieved 15 January 2021, from https://www.accenture.com/t20170601T083538Z__w_/us-en/_acnmedia/PDF-40/Accenture-Digital-Disruption-Development-Unleashed.pdf

- Internet of Things as a network of physical objects, systems, platforms and programs containing built-in sensors, which record and exchange information in real time.
- Artificial intelligence as information systems and programs that can feel, understand and act; intelligent machines, which perform important data processing operations faster and more accurately than people.
- Blockchain as a data transfer technology, which creates decentralized general registers for safe movement of assets, currency and information on completed contracts.
- Big Data as an aggregation of data sources in one system for cost-efficient collection, analysis and exchange of information.
- Automation of robotic processes as application of digital technology to automate execution of repetitive tasks.

The study notes that digital technologies have great potential to deliver high-quality and sustainable results to developing countries and help to bridge the technological divide and barriers to sustainable economic growth.

The experts of Boston Consulting Group (Gerbert, Lorenz, Rübmann, Waldner, Justus, Engel, Harnisch, 2015) identify nine basic technologies, on which digital transformation is based: (1) Autonomous Robots; (2) Industrial Internet of Things (IIoT); (3) Horizontal and Vertical System Integration; (4) Additive Manufacturing; (5) Augmented Reality; (6) Simulation; (7) Big Data and Analytics; (8) Cloud Computing; (9) Cybersecurity.

The results of the survey of business managers showed that 46.6% of the respondents believe that the threat of "disruption" of their firms, which may occur in the upcoming decades due to the aggravation of competition, can be averted by introduction of new technologies, including artificial intelligence and machine learning (88.5%), digital technologies (75.4%), cloud computing (65.6%), blockchain technology (62.3%) and fin-tech solutions (57.4%).

Analyst for Forbes G. Press based on the report "Top Technologies for Digital Predators, 2017", identified five factors that can be considered as a driving force for rapid business growth in the digital economy ⁸:

- Intelligent Agents, that is, artificial intelligence products that can interact with users, study their behaviour and understand their needs, as well as make decisions on their behalf, increasing productivity, customer loyalty and reducing costs.
- Augmented and virtual realities, which create a new interactive digital environment that radically changes the quality of customer service and equipment.
- Internet of Things as a way of doing business that provides companies with constant information about the current state of their equipment, products, operations and customers.
- Cognitive technologies for development of artificial intelligence, which, by imitating natural human cognitive functions, create unique differentiated customer value and significantly improve internal production processes.

⁸ Press G. (2018). *5 Top Technologies for Digital Disruption*. Retrieved 15 January 2021, from <https://www.forbes.com/sites/gilpress/2017/04/27/5-top-technologies-for-digital-disruption/?sh=23a5cd0c4898>

2. Technologies of digitalization of an economy

- Hybrid wireless technologies, such as interfaces and software, which allow devices to simultaneously use and broadcast information among two or more different wireless providers, protocols and frequency bands.

Deloitte specialists conduct annual researches to reveal digital technologies that form the basis for business transformations. In one of the latest analyses, they highlighted implementation of digital technologies, Big Data and analytics, cloud services, digital reality technologies, cognitive technologies (machine learning, neural networks, automation, artificial intelligence, etc.), blockchain technology (Bechtel, Briggs, Buchholz, 2020).

Digital transformation requires different approaches from the business administration, a kind of "digital roadmap" from creating a continuous process of digital improvements to innovative management and the formation of an innovative culture. All this, in turn, changes the mentality, strategic vision and forms new rules for business relationship. In order to take in full advantages of digital technologies, companies must integrate them into their daily processes.

MIT Sloan Management Review and Deloitte's experts surveyed 4,800 managers and analysts across 27 branches of industry from 129 countries on the role of strategizing in the companies' digital development (Kane, Palmer, Phillips, Kiron, Buckley, 2019). Only 15% of the respondents from companies, which just started their busi-

Table 2.2. Some aspects of digital transformation strategy

Task	Result
What is a digital transformation strategy?	Efficient management of changes. Action plan on repositioning business in digital economy, ensuring construction of new (digital) business models, using new technologies
What is necessary?	Technologies as tools used to create a transformed business. Simple digitizing of existing products and services is not enough for this
Result	Increased business efficiency and agility
Main tasks:	
diagnostic process	Identification of current problems, the solution of which will lead to the desired result
development of strategy directions	General approach to the solution of problems, revealed during the diagnosis (information management, customer focus, creation of new digital ecosystems, introduction of new technologies, etc.)
action plan	Successive plan of concerted actions to implement the governing policy. It consists of steps that are coordinated with each other to work together to implement the strategy
Strategy support	Vision Hierarchy of goals Strategy implementation and introduction Assessment of changes and adjustment

nesses' digitalization, confirmed that their enterprises had a digital transformation strategy. At the same time, 81% of the digital transformation leaders are companies that have improved and expanded their businesses by introducing digital technologies via combining a clear and consistent digital strategy with a digital culture and knowledge management system. These companies use digital technologies to achieve strategic goals, drive solutions and accelerate innovations. Some aspects of the digital transformation strategy are presented in Table 2.2.

In the study "Mastering the duality of digital: How companies withstand disruption", McKinsey & Company experts state that gradual changes in traditional business models are not enough for progress of companies, but one of the decisions that can positively affect the development of enterprises in the digital economy era is the introduction of digital innovations with the simultaneous digitization of major assets⁹. According to them, a number of companies could digitalize their business by 20%, open a new digital business and receive a revenue growth of 25% or more.

The list of digital technologies that have or will have a significant impact on the economic performance of enterprises may be continued. New studies on the influence of digital technologies on modern economic processes appear every year; experts in this area identify "breakthrough" factors that will exert the greatest impacts in the near future.

For example, there are techniques, by which one can define the efficiency of a digital marketing campaign and calculate the efficiency and profitability of digital marketing¹⁰. Some methods allow calculating the investment attractiveness of Big Data (Mello, Leite, Martins, 2014), or testing digital skills (in particular, Van Deursen, Helsper, Eynon, 2014). The sources of information for such calculations, as a rule, are indicators of work with Big Data (e.g., Google Analytics, AdWords, Adobe Analytics, Webtrends, content and video marketing tools, etc.), expert opinions and survey results. Such assessments are non-systematic and carried out for individual companies and do not give a complete picture of development of digital technologies and their impact on business performance.

Thus, it can be stated that at present there are not many studies, where a reliable assessment of the digitalization impact on the economic activity results has been made and the initial data and calculations, reflecting the degree of introduction of the "digit" to the economy have been presented. Therefore, researches in this direc-

⁹ McKinsey (2019). *Mastering the duality of digital: How companies withstand disruption*. Retrieved 24 September 2019, from <https://www.mckinsey.com/bussines-functions/mckinsey-digital/our-insights/mastering-the-duality-of-digital-how-companies-withstand-disruption>

¹⁰ Takiguchi K. (2018). *3 Ways to Accurately Measure Digital Marketing ROI*. Startups.com. Retrieved 15 January 2021, from <https://www.startups.com/library/expert-advice/accurately-measure-digital-marketing-roi/>; Tyagi R. (2017a). *Latest Digital Marketing Trends and Statistics*. Retrieved 15 January 2021, from <https://www.techmagnate.com/blog/digital-marketing-trends-and-statistics/>; Tyagi R. (2017b). *How to Measure Digital Marketing Campaign*. Retrieved 15 January 2021, from <https://www.techmagnate.com/blog/how-measure-digital-marketing-campaign/>

tion needs to go on, in particular — on the basis of improving statistical reports and building quantitative dependences of development indicators on digital spending in the national and international contexts.

2.3. DEVELOPMENT OF TECHNOLOGIES FOR AN ECONOMY'S DIGITAL TRANSFORMATION (ON EXAMPLE OF 5G, BIG DATA AND BLOCKCHAIN)

2.3.1. 5G of mobile communications

The history of the mobile communications' development (1G-5G) demonstrates that each of its new generation was ahead of the previous one, mainly in terms of its physical characteristics. This opened up new possibilities to use such technology for:

1G (1980's) — voice transmission over analog (cellular) networks; maximum Internet access speed is 2.4 Kb/s.

2G (~1990) — voice transmission over digital networks of 1G: Code Division Multiple Access (CDMA), Global System for Mobile Communications (GSM), Time Division Multiple Access (TDMA) and Short Message Service (SMS); maximum Internet access speed 64 Kb/s.

3G (~2000) — high-speed data transmission (HSPA) with the ability to transmit voice on IP networks, MBB (Mobile Broadband) Internet access; maximum Internet access speed 2 Mb/s.

4G (~2010) — MBB access based on LTE (Long-Term Evolution), LTE-A (Long-Term Evolution Advanced), WiMAX (Worldwide Interoperability for Microwave Access) and voice transmission (VoLTE); maximum Internet access speed 100 Mb/s.

5G (2020's) — a new generation of mobile communications, operating on millimetre waves, well known to specialists (these waves have been used in the defence sphere for several decades); the maximum Internet access speed over 1 Gb/s.

5G technology has several fundamental advantages over 4G. First of all, they are: much higher data transfer rate (over 10 Gb/s at the peak); lower response time (millisecond or less) and higher density of devices served (up to a million per square kilometre) (Fig. 2.2).

All this is not just another incremental improvement, but a real breakthrough, a revolution in the technologies of mobile communication networks, which can become a driver for the development of not only radio electronics (Mekhanik, 2020), but also the global industry as a whole. As a consequence of the abovementioned advantages, 5G networks can serve millions of simultaneously connected devices (which was previously unrealistic). Without this feature one cannot create truly smart things, transport, factories, houses, cities, as this is just impossible. 5G is a key technology to advance Industry 4.0, which will define the competitiveness of national economies and their position in the global division of labour in the upcoming decades.

The fifth generation of mobile communication (in short 5G) has already become the basic technology for development of digital infrastructure and the subsequent promotion of such breakthrough technologies of the digital economy as the transfer

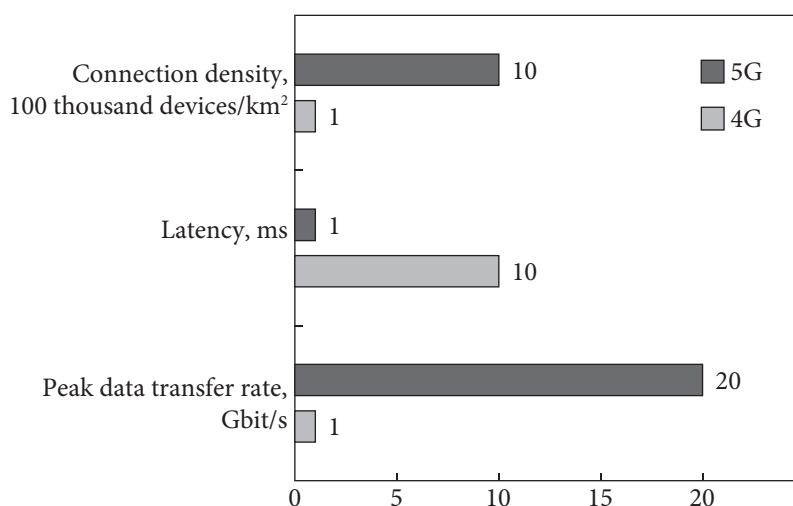


Fig. 2.2. Comparison of key characteristics of mobile communication technologies 4G and 5G (1 ms — for Ultra Low Latency Reliable Communication)

Source: Mekhanik, 2020; Hordovskiy D. (2019). 5G: how the technology works and for what it is. Retrieved 4 January 2021, from <https://rb.ru/longread/what-is-5G>

of large volume of data, Internet of Things (including industrial), production robotization, artificial intelligence, etc.

Among the problematic issues of 5G, it should be noted that the best signal transmission occurs between devices that are in the line of sight at a distance of up to 250 m, otherwise the signal quality drops sharply (since millimetre waves, used for 5G, have less penetrating power and quickly fade away (Khutoretskyi, 2019)). Although this problem can be solved by developing appropriate infrastructure (significant increase in the number of various transmitters), the issues of security, preservation and confidentiality of information transfer remain open. In addition, other challenges appear: several times higher energy consumption; increase in consumption of raw materials and formation of electronic wastes, which increases an anthropogenic burden on the environment; negative impact on local ecosystems, etc.

Today, it is planned to use 5G in different radio frequency spectrums. In addition to the 3.4-3.8 GHz band, which has become the most popular in the world (this is the lowest of the free bands, where wide spectrums can be distinguished), 700 MHz frequencies are used (for the operation of unmanned vehicles, robots and automated equipment in industry) and frequencies from 24 GHz (Shafi et al., 2017). The main reason for the transition to new bands is the lack of frequencies in the segment below 6 GHz. In order to provide operators with new frequencies and, at the same time, with wider bands to transfer large amounts of data, two ranges are allocated for mobile communications: FR1 (Frequency Range 1) and FR2 (Frequency Range 2). The former includes traditional frequencies below 6 GHz, the

latter — fundamentally new millimetre-wave frequencies, from 24 to 100 GHz, depending on the operator's country.

Another important peculiarity of 5G is large-scale virtualization, that is, the use of a technology that is beyond purely hardware solutions (Abdelwahab, Hamdaoui, Guizani, Znati, 2016). Most of its functions are implemented in software, that is, not at the level of physical infrastructure and hardware solutions (through hardware improvements). Therefore, 5G is often referred to as "system" or "platform", rather than "a network". The 5G platform is built on the basis of software solutions, in particular — software-defined network (SDN) and network function virtualization (NFV).

5G functions are realized in software virtual network functions (VNF), operating in the NFV infrastructure. The difference between the two concepts is that VNF is a function, while NFV is a technology, implemented in the physical data centre (DC) infrastructure on the basis of the commercial COTS (Commercial Off the Shelf) equipment, which includes three types of standard devices, namely — servers (computing devices), switches (network devices) and data storage systems. Thus, the equipment of traditional mobile networks is replaced by software systems, operating in data centres on standard servers and virtual machines (Virtual machines, VM) ¹¹.

As noted, 5G significantly expands the limited functional of previous generations of mobile networks. Its main features are as follows ¹²:

- Enhanced mobile broadband eMBB (enhanced MBB).
- Reliable communications with low latency ULLRC.
- Massive of machine type communications Massive IoT/IIoT, mMTC.
- Low data transfer latency between unmanned vehicles and cloud data centres for remote control and maintenance V2X (Vehicle-to-Everything).
- Satellite access.

Unlike the networks of previous generations, the service range of which was not large, the 5G platform services are scalable and not limited to the original functional. In fact, 5G acts as a platform for development of new services and DevOps apps, where new functions are created by developers in close coordination with the teams of people, responsible for their implementation. A key aspect of the technology, in addition to the increased parameters of network power, is the approach to the formation of a customized product. Frequency bands, design features of transmission means, and software components are adapted to consumers of different categories, from ordinary users of gadgets to industrial enterprises and urban infrastructure. Also, due to 5G networks, it will be possible to improve the quality of existing services, which involve large volumes of traffic.

Standardization of technologies and solutions for 5G is to be completed in 2021. Therefore, the term 5G so far denotes only fragmentary solutions, which in the future will be a part of the full-scale solution ITM-2020. Such technologies are being

¹¹ TAdviser (2019). *5G — The fifth generation of mobile communication*. Retrieved 3 January 2021, from <http://www.tadviser.ru/a/270048>

¹² Scott Fulton III (2020). *What is 5G? The business guide to next-generation wireless technology*. Retrieved 15 January 2021, from <https://www.zdnet.com/article/what-is-5g-the-business-guide-to-next-generation-wireless-technology/>

deployed in different countries, but so far, they are mainly of a local test nature and do not provide all the planned functional of ITM-2020 networks.

The development of this standard was first declared in 2015 by the ITU agency¹³. In addition to that, a number of other international organizations are also involved in standardization issues in the 5G field, such as the 3rd Generation Partnership Project (3GPP), European Telecommunication Standard Institute (ETSI), Internet Engineering Task Force (IETF), etc. In this regard, it is important to note that the mentioned standard is much more significant than just another standard for mobile communications. Its use for ultrafast low-latency data transfer with high bandwidth capability will drive an accelerated development of IoT and everything that goes with that. Therefore, the country (or group of countries) that will be the first to overcome technological and organizational barriers and widely deploy 5G networks can receive important strategic technical and economic advantages. That is why the race for leadership in 5G between the United States and China has become so acute and partly turned into a struggle between civilizations: "At the heart of this is a dilemma, which the West has not faced before: how to cope with a technology superpower, whose values are fundamentally opposed to our own"¹⁴. The winner will be able to apply their successful experience to roll out the new generation networks in other countries, which opens up opportunities for increasing technological and economic impact on them. Thus, 5G for the United States and China is also a new potential tool for expanding their spheres of influence¹⁵.

In the EU, the issue is not so critical, and the Europeans are striving to maintain their technological autonomy in relation to both the United States and China¹⁶. Russia adheres to a position, similar to that of the EU. The Government of the Russian Federation sets the task of creating its own telecommunications industry, operating mainly on Russian-made equipment. According to local experts, the country has the opportunity to build its technological loop of 5G-telecommunication equipment with the participation of third parties on the principles of open standards (Mechanic,

¹³ ITU (International Telecommunication Union) UN agency (Geneva) is an international organization that distributes the global radio spectrum and satellite orbits and develops technical standards that ensure a smooth interaction of networks and technologies. The agency is the organizer of the World Radiocommunication Conference (WRC), at which key issues on the development of this field of activity are discussed every few years. See: ITU (2020). *About International Telecommunication Union*. Retrieved 3 January 2021, from <https://www.itu.int/en/about/Pages/default.aspx>.

¹⁴ The Economist (2020). *The geopolitics of 5G. America's war on Huawei nears its endgame*. Retrieved 5 January 2021, from <https://www.economist.com/briefing/2020/07/16/americas-war-on-huawnears-its-endgame>

¹⁵ Trepalina Yu. (2018). *Is Huawei a Hostage in 5G Leadership Fight between US and China?* Nag.ru. Retrieved 5 January 2021, from <https://nag.ru/articles/artic-le/102937/huawei-zalojnitsa-borbyi-ssha-i-kitaya-za-liderstvo-v-5g-.html>

¹⁶ The Economist (2020). *The geopolitics of 5G. America's war on Huawei nears its endgame*. Retrieved 5 January 2021, from <https://www.economist.com/briefing/2020/07/16/americas-war-on-huawnears-its-endgame>

2020, p. 57), although at the end of 2020 Russia was clearly lagging behind in promoting 5G technology¹⁷.

Thus, the current struggle between the United States and China for leadership in the field of high digital technologies divides the world into two big camps. Representatives of the former claim that the equipment of Chinese manufacturers threatens the national security of countries, since it can be used by Chinese authorities for espionage and cyber-attacks. The latter, despite Washington's accusations, continues to cooperate with Chinese firms Huawei and ZTE, which have been able to achieve the greatest progress in the development of new digital technologies¹⁸.

After the US Congress issued in 2012 a report, identifying Huawei and ZTE as a threat to national security, the country's government took a series of measures to block Chinese manufacturers from entering the US market. In 2018, the budget law banned the Pentagon and other government agencies, as well as government contracting firms, against using Huawei and ZTE equipment and services. In addition, the Federal Communications Commission of the United States introduced rules, by which mobile operators cannot use government subsidies to purchase equipment and services from companies that pose a threat to US national security¹⁹.

Following the United States, such countries as Australia, New Zealand, Japan and some EU member states did not allow Huawei and ZTE to participate in projects for the 5G networks construction on their territories. The UK, based on the findings of its intelligence agencies about the risks of using Huawei equipment for the national telecommunications network, excluded the Chinese manufacturer from the list of bidders for the supply of equipment for 5G networks, and also began withdrawing Huawei equipment from its 3G and 4G networks²⁰.

One of the reasons for the EU countries' distrust of the Huawei concern is the law on intelligence services and law enforcement agencies of the PRC, according to which government authorities can enforce the obligation of Chinese enterprises of all forms of ownership to collect information about their customers and hand it over to the government²¹. However, Huawei denies the existence of such instructions from the Chinese government and the technical capabilities to spy with its equipment. The corporation declares that it adheres to national data protection regulations and laws in all countries, where its equipment is used.

¹⁷ Ookla (2020). *Ookla 5G Map*. Retrieved 5 January 2021, from <https://www.speed-test.net/ookla-5g-map>

¹⁸ Huawei, which has been working in the development and deployment of 5G networks for a long time, is one of the three world leaders in this field (together with Ericsson and Nokia).

¹⁹ Trepalina Yu. (2018). *Is Huawei a Hostage in 5G Leadership Fight between US and China?* Nag.ru. Retrieved 5 January 2021, from <https://nag.ru/articles/article/102937/huawei-zalojnitsa-borbyi-ssha-i-kitaya-za-liderstvo-v-5g-.html>

²⁰ FT (2020). *UK draws up 3-year plan to remove Huawei from 5G networks*. Retrieved 6 January 2021, from <https://www.ft.com/content/1c226144-a3a9-4533-ab14-88d65142ba05>

²¹ Becker A. (2019). *Huawei and 5G – it's a minefield*. Retrieved 6 January 2021, from <https://www.dw.com/en/huawei-and-5g-its-a-minefield/a-51300798>

With this in mind, Spain has already engaged Huawei to build a 5G network, and Germany stands out for applying exclusively technical security criteria to telecommunication equipment suppliers to deploy 5G communications, without considering the political course of the country that produce equipment²². A number of operators in Canada, India, France, Italy, Portugal, Poland, Ireland and other countries have already announced the purchase of Huawei equipment for deploying 5G networks.

Although today the United States are able to slow down the rate of economic growth of China by various methods (including through sanctions). However, it is unlikely that they will be able to undermine Chinese scientific and technological development, and, apparently, sooner or later the moment will come, when they will have to negotiate²³. There is a reason to believe that after the "hot" phase of the trade, investment and technological conflict, a new (predominantly bipolar) structure of the world will form, and both of these economies will move to a certain form of complementarity. This will be facilitated by the fact that within both countries there are powerful groups of influence that seek to normalize the situation, since China is one of the main sources of income for American companies, and vice versa (Danilin, 2018).

In September 2020, 113 operators in 52 markets provided 5G communication services in the world²⁴.

The fifth generation of mobile communications, as a new technology, is at the bottom of the S-shaped technology curve (Foster, 1986), that is, at the stage, when significant financial resources are invested in the technology, both from the governments of the leading states and the corporate sector, on the basis of the potential growth of productivity and income from its use in the future. The projected amounts of future revenues from the 5G implementation are based mainly on expert estimates and, accordingly, vary significantly. Perhaps the only indicator for today that can demonstrate a real financial return from the development of 5G technologies is revenue from the sales of frequencies for 5G to mobile operators in different countries of the world (Fig. 2.3).

Such sales are governed by national laws and are not subject to a single algorithm. Some states make direct contracts with mobile operators for the acquisition of frequencies, but in most cases, sales are carried out at auctions through tender procedures.

A unique example is Japan, which in 2019 distributed 5G frequencies free of charge to mobile operators, under their commitments to invest in the development of 5G networks in the amount of \$ US 14.4 billion until 2024.

As for Ukraine, the country is currently among the outsiders in the implementation of 5G due to a number of reasons, starting with technical (lack of significant national developments in the 5G field) and institutional (Ukrainian regulatory base

²² Shpross H., Grunkel E. (2019). *The head of Huawei on 5G network in Europe, US sanctions and accusations of espionage*. Retrieved 5 January 2021, from <https://www.dw.com/>

²³ GT (2020). *Will Biden reset China-US ties?* 27 Nov. Retrieved 5 January 2021, from <https://www.globaltimes.cn/content/1208199.shtml>

²⁴ Osio J., Keith E. (2020). *52 markets worldwide have commercial 5G services*. S&P Global. Retrieved 5 January 2021, from <https://www.spglobal.com/marketintelligence/en/news-insights/research/52-markets-worldwide-have-commercial-5g-services>

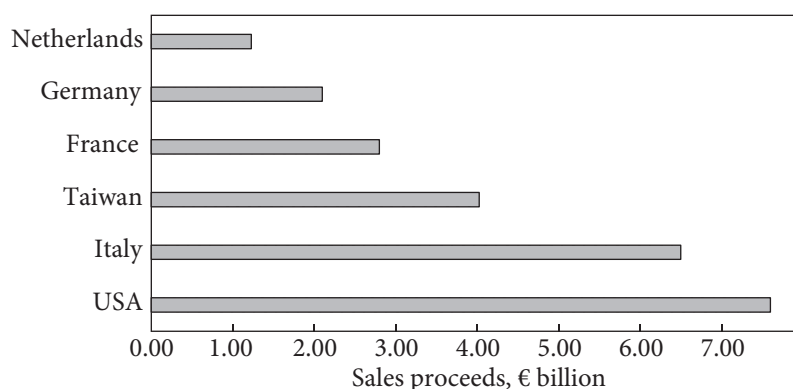


Fig. 2.3. Revenues from sales of frequencies for 5G by countries of the world
Source: Tadviser (2020). Retrieved 27 November 2020, from <https://www.tadviser.ru/index.php/>

in the field of telecommunications and frequencies' use is one of the least developed in Europe) and ending with economic ones (in Ukraine, the level of Internet costs per person per month is low, and the main consumers of 5G services — national business production systems — have not yet formed the demands for these services).

The most probable result for Ukraine concerning 5G development is the entry into the orbit of one of the leaders (or a group of leaders) of this process. This is confirmed by the fact that the Ministry of Digital Transformation of Ukraine and Ericsson Company signed a memorandum on advisory support in the field of fixed and mobile communication systems of new generation 4G (LTE-Advanced) and 5G²⁵, which provides for the formation of a joint working group to work on technical expertise in the field of development of mobile and fixed Internet, as well as providing advisory and information support to the Ministry of Digitalization of Ukraine.

At the same time, in order to avoid the mediocre role of a raw-material appendage of more developed countries, Ukraine should focus on the formation of a national digital ecosystem, ensuring the development of new communication technologies, which, in turn, will define the performance and efficiency of cyber-physical production systems.

The action plan for the introduction of 5G system in Ukraine²⁶ is directed towards the implementation of these tasks and comprises researches in order to define the cost of the radio frequency resource in the 700 MHz and 3.4-3.8 GHz bands for the 5G im-

²⁵ Ukrinform (2020). Launch of 5G in Ukraine: The Ministry of Finance and Ericsson signed a memorandum. Retrieved 5 January 2021, from <https://www.ukrinform.ua/rubric-technology/2884008-zapusk-5g-v-ukraini-mincifri-ta-ericsson-pidpisali-memorandum.html>

²⁶ Cabinet of Ministers of Ukraine (2020). Order of 11.11.2020 №1409-p "On approval of the action plan for the introduction of the fifth-generation mobile communication system in Ukraine". Retrieved 5 January 2021, from <https://zakon.rada.gov.ua/laws/show/1409-2020-p#Text>

plementation, as well as the regulatory framework improvement in the field of licensing the use of the radio frequency resource of Ukraine, holding tenders and issuing licenses for using the radio frequency resource of Ukraine for the 5G system.

To implement 5G technology, the Cabinet of Ministers of Ukraine approved the plan for using the radio frequency resource of Ukraine until 2025, and also supplemented it with new basic standards LTE / LAA, eLTE-U and PMP.

At the same time, certain questions arise about the tasks to be solved by the actions of the authorities within the framework of this plan. In particular, the Ministry of Digital Transformation of Ukraine sets one of the main tasks to provide 95% of the Ukrainians with access to high-speed mobile Internet within 3 years. The changes should allow users to get more stable and higher speed, when watching videos and listening to music. The rollout of the 5G network is expected to begin in 2022 in the largest settlements. In remote rural areas and along highways, 4G will be used. At the same time, the issues of automation of industrial technological processes through capabilities of the new generation of communication are considered as secondary.

As noted above, this position does not take into account the fact that the main consumers of 5G services are business-production systems, which in Ukraine have not yet generated demands for these services, including due to systemic problems in the development of the Ukrainian industry. The lack of such demands after the deployment of 5G networks can lead to a significant increase in the cost of communication services for people and a decrease in the income of mobile operators. Also, the government plans do not contain any mention of studies and assessments of possible negative impacts of the 5G infrastructure development on human health and surrounding natural ecosystems, while in many large EU cities, local authorities and territorial communities block the development of 5G networks just on these grounds.

2.3.2. Big Data and analytics

One of the basic technologies, on which the digital transformation of the economy is based, is Big Data and Analytics (Gerbert, Lorenz, Rießmann, Waldner, Justus, Engel, Harnisch, 2015).

Big Data have become a familiar element of the new reality, since modern digital technologies have provided opportunities to accumulate, process and store huge amounts of structured and unstructured information. In the beginning, in the economy such information was used mainly for marketing, crediting and logistics. But now, data on manufacturing processes' improvements can be isolated from information flows and used.

For example, a McKinsey's research informs that application of Big Data analysis can improve the efficiency of a wind farm by adjusting the turbines properly, which can produce 10% more energy with the same amount of wind²⁷. The BCG report describes

²⁷ McKinsey (2016). How companies are using big data and analytics. Retrieved 24 September 2019, from <https://www.mckinsey.com/business-functions/mckinsey-analytics/our-insights/how-companies-are-using-big-data-and-analytics>

the experience of using Big Data by the semiconductor manufacturer Infineon Technologies: by comparing the data of the chips with the technological data, collected during the production process, the enterprise was able to build models that help to identify damaged chips at the beginning of the production process and improve the quality of products (Gerbert, Lorenz, Rüßmann, Waldner, Justus, Engel, Harnisch, 2015). In Ukraine, the energy company DTEK has succeeded in using Big Data by launching the MODUS digital transformation program, which has helped to improve the safety and optimization of the resource extraction cycle at the Yuvileina mine²⁸.

According to the NewVantage Partners survey, 92% of the surveyed enterprises are increasing their investment rates in Big Data, but only 31% have succeeded in managing data as a business asset and 28% — in creating a data-driven culture²⁹. According to Dresner Advisory Services' "Big Data Analytics Market Study", in 2017 53% of companies used such data in their activities that is, 36% more than in 2015³⁰. Most actively Big Data technology is used in such industries as technology (14%), healthcare, financial services (12), telecommunication (7), education, consulting services (5), energetics, industry and business services (3%).

Enterprises receive the greatest return from Big Data analysis by reducing costs and creating new opportunities for innovation: 49.2% of enterprises noted that they were able to reduce the volume of operating costs through investments in Big Data, 44.3% found new opportunities for innovation, 27.9% of enterprises managed to create and establish an effective system for their use (Data-Driven Culture)³¹.

McKinsey Analytics' global survey "Analytics comes of age" defined the business areas, where Big Data has the greatest impact³². The information was collected through an online survey of 530 companies' senior executives from different regions and industries.

Thus, by their estimates, the analysis of Big Data significantly changed the practice of sales and the field of marketing and markedly affected the R&D field. Also, this digital technology is used in supply chains, personnel management, production and other areas of enterprise activity.

According to the survey, a growing proportion of companies use Big Data to generate revenue. Monetization takes place by creating higher company value for its

²⁸ New time (2020). Leap of civilization: how digital technologies are changing the energy industry in Ukraine. Retrieved 3 January 2021, from <https://nv.ua/project/programma-modus-vnedrenie-innovaciy-i-cifrovyyh-sistem-vo-vse-sistemy-energeticheskogo-biznesa-50131588.html>

²⁹ NewVantage Partners, LLC (2019). *Data and Innovation How Big Data and AI are Accelerating Business Transformation*. Big Data and AI Executive Survey 2019. Executive Summary of Findings. Retrieved 24 September 2019, from <https://newvantage.com/wp-content/uploads/2018/12/Big-Data-Executive-Survey-2019-Findings-Updated-010219-1.pdf>

³⁰ Dresner Advisory Services, LLC (2017). *Big Data Analytics Market Study. Wisdom of Crowds Series*. MicroStrategy. Retrieved 24 September 2019, from https://www.microstrategy.com/get-media/cd052225-be60-49fd-ab1c-4984ebc3cde9/Dresner-Report-Big_Data_Analytic_Market_Study-WisdomofCrowdsSeries-2017

³¹ Ibid.

³² McKinsey (2018). *Analytics comes of age*. Retrieved 24 September 2019, from <https://www.mckinsey.com/business-functions/mckinsey-analytics/our-insights/analytics-comes-of-age>

customers and business via developing new business models, creating pools from companies of related industries using Big Data, providing new services, using new directions and types of product sales, increasing the level of product quality, etc. It was found that the share of monetized Big Data in the total income of companies, which use their analysis to generate income, can be over 20%³³.

Every year, a new direction of Big Data application, namely — the use of predictive models (Big Data analytics), develops more rapidly in the public sector of the economy. Government agencies throughout the world appreciated the importance of handling large amount of information long ago. Now it is possible to manage Big Data, therefore government bodies have received a tool for the efficient use of Big Data in order to build a safer society, improve administrative functions, forecast and reduce government spending.

Big Data analytics makes it possible to predict a person's behaviour in society, his reaction to force majeure, provides law enforcement and emergency management bodies with new opportunities to develop predictive policy and adjust their plans and objectives, from raids on gambling halls up to forecasting possible places of ignition of objects. Big Data can also be useful in government's responding to rapidly changing events that are transforming public attitudes, showing the society discontent or need for help. Big Data also opens up new opportunities for reducing the time and public funds in the field of taxation, since the personal data of taxpayers, collected by the state tax authorities, are often duplicated several times and stored in several places at the same time, so taxpayers have to fill out new forms with information that government bodies already possess. Now that can be avoided, since the Big Data analytics toolkit allows one to systematize, update and efficiently use the accumulated amount of information for the purposes of tax administration without additional spending money and time.

A number of countries around the world (Singapore, Norway, Kenya, Australia, Finland, Spain, Russia) have made significant progress in digital tax administration via using Big Data, making the administration smoother and less problematic (OECD, 2020).

The Big Data toolkit helps minimize fraud in tax and social security fields by identifying patterns of suspicious transactions in real time from receiving financial government assistance to providing benefits in case of receiving large income from different sources.

In the sphere of medical services, Big Data is used to predict health care needs based on data on accidents, diseases, population preferences for prevention and treatment of them, as well as on the state of the environment, social status of people, etc.

Separately, it should be noted, that savings in public funds can also take place in the field of control over the work of government officials, their expenses, business trips, etc. For example, the world-famous Chinese Social Credit System pro-

³³ McKinsey (2018). *Analytics comes of age*. Retrieved 24 September 2019, from <https://www.mckinsey.com/business-functions/mckinsey-analytics/our-insights/analytics-comes-of-age>

vides for the use of incentive mechanisms and punishment not only in the social and commercial activities, but also in government and judicial affairs (Liang, Das, Kostyuk, Hussain, 2018).

However, along with the successful experience of Big Data employment at enterprises and organizations, the experts also point to the existing barriers to their implementation, such as insufficiently prepared organizational structure (42.6%), lack of understanding at the middle management level (41.0), resistance or misunderstanding of staff (41.0), lack of a coherent strategy (29.5), lack of a common vision (26.2), lack of policy and practice for managing Big Data (21.3%)³⁴. Therefore, many enterprises seek help from specialized companies that provide technical support and other services, related to the use of Big Data. Currently, a new business line, based on Big Data management and analytics, is one of the most dynamic and rapidly growing segments of the ICT sector. The clients of specializing in Big Data companies are both large corporations and small businesses. According to the forecasts of the statistical portal Statista (Statista, 2018)³⁵, the market of Big Data (sales of commercial technologies, equipment, software and services, related to the receipt, processing and further use of Big Data) in 2027 may amount to more than \$ 100 billion.

To assess the development of the Big Data market according to the CRN journal, which annually publishes the "Big Data 100" list, the following list of 5 top companies in this field of activity was compiled (Table 2.3).

The first five are companies, specializing in business analysis and software development for business analysis, analytics and visualization.

The second five are companies, developing technologies for Big Data management and integration. The software, offered by these enterprises, is used for multidimensional analysis, business intelligence and data management.

The third five are companies that offer enterprises equipment (hardware servers) and software (software platforms, electronic apps, cloud services, etc.), as well as infrastructure technologies for Big Data processing.

As presented in Table 2.3, the Big Data market is very dynamic: every year there occurs a change in the leaders, which increase their capital and have high financial indicators. For example, the revenues of Alteryx, the leader in the field of business intelligence, in 2017 amounted to \$ 132 million, 2018 — \$ 254 million, 2019 — \$ 418 million, for 3 quarters of 2020 — \$ 335 million³⁶. The leading company in the field of cloud technologies and platforms — Amazon Web Services — has been holding its

³⁴ NewVantage Partners, LLC (2017). Big Data Business Impact: Achieving Business Results through Innovation and Disruption. Big Data Executive Survey 2017. Executive Summary of Findings. (2017). New Vantage. Retrieved 24 September 2019, from <http://newvantage.com/wpcontent/uploads/2017/01/Big-Data-Executive-Survey-2017-Executive-Summary.pdf>

³⁵ Statista (2018). Big data market size revenue forecast worldwide from 2011 to 2027 (in billion U.S. dollars). Retrieved 24 September 2019, from <https://www.statista.com/statistics/254266/global-big-data-market-forecast/>

³⁶ Alteryx, Inc. (2020). *Financials – Quarterly Earnings*. Retrieved 30 November 2020, from <https://investor.alteryx.com/financials/quarterly-earnings/default.aspx>

Table 2.3. Top-5 companies by specific areas of Big Data use (2016-2020)

Rating	2016	2017	2018	2019	2020
<i>Business Analytics</i>					
1	Algorithmia	Alpine Data Labs	Alteryx	Alteryx	Alteryx
2	Alpine Data Labs	Alteryx	Anodot	Anodot	Anodot
3	Alteryx	Anodot	Arcadia Data	Arcadia Data	AtScale
4	Arcadia Data	Arcadia Data	Attivio	Attivio	Databricks
5	Attivio	Attivio	Birst	Datameer	Datameer
<i>Management of Data and Integration</i>					
1	Alation	Alation	1010 Data	Action	Action
2	AtScale	AtScale	Action	Actifio	Actifio
3	Attunity	Attunity	Alation	Alation	Alation
4	Bedrock Data	Bedrock Data	AtScale	AtScale	Alluxio
5	Confluent	Confluent	Attunity	Cazena	Cazena
<i>Big Data Platforms</i>					
1	Altiscale	Amazon Web Services	Amazon Web Services	Amazon Web Services	Amazon Web Services
2	Amazon Web Services	BlueData Software	BlueData Software	Cloudera	Cloudera
3	BlueData Software	Cazena	Cazena	Dell EMC	Dell Technologies
4	BlueTalon	Cloudera	Cloudera	Google	Google Cloud
5	Cazena	Dell Technologies	Dell Technologies	Hewlett Packard Enterprise	Hewlett Packard Enterprise

Sources: Computer Reseller News (2016). The Big Data 100 2016, CRN. Retrieved 24 September 2019, from <https://www.crn.com/news/applications-os/300080545/the-2016-big-data-100.htm>; Computer Reseller News (2017). The Big Data 100 2017, CRN. Retrieved 24 September 2019, from <https://www.crn.com/news/applications-os/300084738/the-2017-big-data-100.htm>; Computer Reseller News (2018). The Big Data 100 2018, CRN. Retrieved 24 September 2019, from <https://www.crn.com/news/applications-os/300102856/the-2018-big-data-100.htm>; Computer Reseller News (2019). The Big Data 100 2019, CRN. Retrieved 30 November 2020, from <https://www.crn.com/news/storage/the-big-data-100-2019>; Computer Reseller News (2020). The Big Data 100 2020, CRN. Retrieved 30 November 2020, from <https://www.crn.com/news/cloud/the-big-data-100-2020>.

positions for four years: its revenues in 2017 were \$ 17.5 billion, in 2018 — \$ 25.7 billion, in 2019 — \$ 35.0 billion, for 3 quarters of 2020 — \$ 32.6 billion and represented a significant portion of Amazon's total revenue³⁷. All this confirms the emergence

³⁷ Amazon.com, Inc. (2020). *Quarterly results*. Retrieved 30 November 2020, from <https://ir.aboutamazon.com/quarterly-results/default.aspx>

of a new economy segment that generates value added and is rapidly expanding. Research and Markets predicts that the size of the global Big Data market will grow from \$ 138.9 billion in 2020 to \$ 229.4 billion in 2025 (MarketsandMarkets, 2020). According to forecasts, made by Allied Market Research in the study "Big Data and Business Analytics Market Statistics", in 2027 the size of the global Big Data and business analytics market is expected to reach \$ 420.98 billion, at an average annual rate growth of 10.9% from 2020 (Borasi, Khan, Kumar, 2020).

Unified parameters for assessing the Big Data market have not yet appeared, but, taking into account experts' estimates that the generated data volume will grow by a geometric progression, further growth in the value of Big Data both for the business environment and the public sector is expected.

It should be noted that when defining the impact of digitalization on the GDP, it is advisable to take into account such an indicator as the income of enterprises, operating in the field of software, equipment and Big Data services. However, as a rule, it is hard to find information on such a request in the state statistical bodies. Herein, commercial statistical platforms, for example Statista³⁸, as well as large analytical companies such as Gartner³⁹, IDC⁴⁰, Forrester Research⁴¹, etc., whose researches are based on data from client bases (i.e., hundreds and thousands of enterprises and organizations), possess and provide such information, but the price in certain cases may be very high. At the same time, companies are emerging as communities of experts, good at consulting and practice, who share open reference materials (in particular, Wikibon)⁴².

Since the monetization of Big Data started not so long ago, and this process is rapidly spreading, it is advisable to develop recognized at the state level methodology for assessing the impact of Big Data on income growth, value added and GDP as a whole. The main indicators for such a methodology can be:

a) To assess Big Data providers — the number of companies, operating in this field (Big Data vendors), income of these companies from the production of software for Big Data and their analysis, as well as the cost of services, related to the collection, storage and analysis of Big Data.

b) To assess Big Data consumers — the number of enterprises and organizations that use Big Data in their activities (size, types of economic activities, regions), costs

³⁸ Statista (2019). *Big Data — Statistics & Facts*. Retrieved 24 September 2019, from <https://www.statista.com/topics/1464/big-data/>

³⁹ Gartner (2018). *100 Data and Analytics Predictions Through 2021*. Retrieved 24 September 2019, from <https://www.gartner.com/doc/3746424?ref=mrktg-srch>

⁴⁰ Independent Directors Council (2018). *Worldwide Big Data and Analytics 2017–2021 Forecast: Market Opportunity by Industry*. Retrieved 24 September 2019, from <https://www.idc.com/getdoc.jsp?containerId=US43104117>

⁴¹ Forrester Research (2018). *Big Data*. Retrieved 24 September 2019, from <https://www.forrester.com/search?tmxtxt=big+data+%&source=typed&dateRange=1&showAtoms=true>

⁴² Kobiellus J. (2018). *Big Data. Wikibon*. Retrieved 24 September 2019, from <https://wikibon.com/ai-democratization-ibm-deep-cognition-cloudera/>

of Big Data for enterprises, the specific income of the company, created through the use of Big Data, etc.

As a result, statistical bodies will gain information at their disposal, which can be used to assess the development of Big Data markets, analyse the activities of enterprises and develop forecasts for the economy development in the context of digitalization. In the case the methodology for assessing Big Data is agreed and unified among countries, experts, national government agencies, international organizations and associations, there can appear the opportunity to compare levels of using Big Data by countries and develop (or improve) new trends for further digitalization of the economy.

To collect the performance indicators of enterprises which are Big Data consumers the State Statistics Committee of Ukraine should develop new statistical forms, and enterprises should define, possibly using appraisal methods, the share of income received because of Big Data.

As for collection of statistical information on new businesses, created in the field of Big Data in Ukraine, the situation here is more complicated, since this type of activity is not yet available in the list of types of economic activity codes of the national classifier. Such activities can be referred to Section J "Information and Telecommunications", Group 62 "Computer Programming, Consulting and Related Activities", Class 62.01 "Computer Programming".

To help national statistical bodies, in 2013 the special team for Europe's Big Data Task Force at the UN Economic Commission developed the Big Data Classification⁴³, which was subsequently supplemented with subcategories, proposed by the IMF (Hammer, Kostroch, Quirós, STA Internal Group, 2017). It can be used as a guide for the development of national statistical standards in the field of digitalization. To collect additional information on the activities of companies that supply Big Data, one can use the experience of the German company "Experton Group", which has developed a methodology for assessing Big Data vendors and applied it to monitor the relevant market.

Due to the growing importance and strong influence that the use of Big Data is gaining, the related aspects of information security and protection cannot be ignored. So, recently a great public response was caused by the issues of legality of processing personal data and observance of the rights of citizens. Therefore, at the state level, various methods of data regulation are practiced on the basis of the degree of development of digitalization and Big Data markets, the accumulated experience of their employment, as well as historical, scientific, technical, cultural and other peculiarities of the social advancement.

In Europe and the USA, data protection legislation appeared almost simultaneously in the 1970s. At the international level, the "OECD Guidelines on the Protec-

⁴³ UNECE (2020). *Classification of Types of Big Data — Classification of Types of Big Data — Statswiki*. High-Level Group for the Modernisation of Official Statistics UNECE. Retrieved 30 November 2020, from <https://statswiki.unece.org/display/bigdata/Classification+of+Types+of+Big+Data>

tion of Privacy and Transborder Flows of Personal Data" were developed in 1980. In 1981, the Convention for the Protection of Individuals with regard to the Automatic Processing of Personal Data was signed (STE No. 108). In 1995, the Directive 95/46/EC of the European Parliament and of the Council of 24 October 1995 on the protection of individuals with regard to the processing of personal data and on the free movement of such data was adopted.

Since these documents prioritize strict regulation of the protection of user data and cover all the main aspects of regulation of privacy issues, they differ from the US legislation in this field. In the United States, the protection of personal information and confidentiality has traditionally been based on the right to free speech and consumer protection rules. It is regulated by several laws with a narrow scope. At the same time, numerous legal acts at the federal and state levels are combined with administrative regulations, as well as industry guidelines for self-regulation (Boyne, 2018). As a result, many countries, including Ukraine, prefer to use the European experience as a model for developing their national laws.

The Chinese approach to data protection, which incorporated many of the EU and US models, is based on the principles of explicit consent of subjects to collect and process data, respect their legitimate interests, prevent and control risks. In June 2017, the PRC Cybersecurity Law came into force, becoming the first national law to protect data privacy. Since then, many additional rules and guidelines have been issued to refine its main provisions (Bigg, Cheung, 2019). As a major Internet power, China has adopted a people-centered approach to cybersecurity, as noted by Chinese experts, and its concept of building a people-centered cyberspace community has already gained some international recognition⁴⁴. Nevertheless, it is obvious that many problems remain and for objective reasons they cannot be solved quickly: modern technologies make it possible to accumulate detailed personal data without informing individuals on that, and these data can be used in politics, technical and other purposes. When aggregating various data, confidentiality of personal information may be violated; information asymmetry is growing, since the opportunities and abilities of government and commercial structures to control the population grow exponentially, while the opportunities and abilities of citizens to hold them accountable (e.g., through counter-observation and control) are clearly lagging behind (Liang, Das, Kostyuk, Hussain, 2018, p. 434).

In Ukraine, a number of normative acts have been developed on the basis of the European approach to data protection, the main of which is the "Law on the Protection of Personal Data". However, it did not stop the leaks of personal data information, which occurs now and then (from directories published on the network with personal information of citizens to the sending of unwanted messages)⁴⁵. This is due both to the peculiarities of national law enforcement practice and to the fact that the

⁴⁴ Peiyong C. (2020). *Building a world of shared cyberspace*. Retrieved 3 January 2021, from <http://www.chinadaily.com.cn/a/202011/25/WS5fbd9389a31024ad0ba96356.html>

⁴⁵ Kulakov V. (2019). *Massive leaks of personal data in Ukraine*. Retrieved 3 January 2021, from https://protocol.ua/ua/massovie_utechki_personalnih_dannih_v_ukarine/

law does not clearly spell out provisions on the permissible fields of personal data usage, on the obligatory informing of the regulator by the owners and managers of personal data on the facts of their leakage, as well as on control and amenability for such violations. Therefore, in this area, there is still a lot of work to be done to form an integral set of rules for the protection of personal data, based on the implementation of the standards and rules used for this purpose in the European Union.

2.3.3. Blockchain

The development of the modern smart industry (Industry 4.0) is based on new digital technologies, one of the main among which is blockchain. Expert opinions on the technology's future are ambiguous: from enthusiastic to rather highly reserved. For example, General Manager of Google E. Schmidt recognizes prospects of blockchain and bitcoin as brilliant: "Bitcoin is a remarkable achievement in the field of cryptography, and its ability to create something that cannot be duplicated (counterfeited) in the digital world is of great importance... lots of people will build a business on its basis"⁴⁶. At the same time, P. Krugman, a Nobel Prize winner in economics, expresses certain doubt and calls himself a crypto sceptic. He explains his criticism of bitcoin by the peculiarities and limitations of the blockchain technology, which is its foundation: "...cryptocurrency enthusiasts are effectively celebrating the use of cutting-edge technology to set the monetary system back 300 years." Instead of lowering transaction costs, Bitcoin requires a continuous increase in costs to maintain the blockchain system in an adequate state: "...the high costs — making it expensive to create a new Bitcoin or transfer an existing one — are essential to the project of creating confidence in a decentralized system"⁴⁷.

Interest in blockchain has long depended on the success of the cryptocurrencies it generated. On 17 December 2017, the price of bitcoin reached a record level at that time over \$ 19.7 thousand. Before then, there had been about 11 million open bitcoin wallets, interest in the blockchain was high. But at the beginning of 2018, there was a tremendous drop in the rate of almost all cryptocurrencies (in March 2019, the bitcoin rate was \$ 4.2 thousand). After this speculative bubble burst, the number of blockchain opponents has risen. Some experts doubt the prospects of its existence and development. Many strongly condemned it. For example, the founder of True Link Financial K. Stinchcombe argued that the blockchain has not realized itself over the past decade anywhere, except for the "sandbox" of enthusiasts and controversial digital currencies, so one should not expect significant achievements from it in the future⁴⁸.

⁴⁶ Rosulek M. (2017). *14 Bitcoin quotes by famous people*. Medium. Retrieved 22 October 2020, from: <https://medium.com/@MartinRosulek/14-bitcoin-quotes-by-famous-people-6e7a1a009281>

⁴⁷ Krugman P. *Transaction Costs and Tethers: Why I'm a Crypto Skeptic*. The New York Times. 2018. 21 July. Retrieved 22 October 2020, from <https://www.nytimes.com/2018/07/31/opinion/transaction-costs-and-tethers-why-im-a-crypto-skeptic.html>

⁴⁸ Stinchcombe K. (2017). *Ten years in, nobody has come up with a use for blockchain*. Retrieved 22 October 2020, from <https://medium.com/@kaistinchcombe/ten-years-in-nobody-has-come-up-with-a-use-case-for-blockchain-ee98c180100>

In early 2020, the situation in the cryptocurrency markets was worsened by the coronavirus pandemic. In particular, in February–March the bitcoin rate decreased from \$ 10.5 thousand to \$ 3.8 thousand. However, due to the slowdown in business activity in different sectors of the world economy, decline in demand for oil products and raw materials, adoption of large-scale stimulating measures by the world's central banks, some cryptocurrencies (Bitcoin, Ethereum), despite their status as risky assets, began to act as insurance against the continuing devaluation of the main world currencies. As a result of all these events, by February 2021 the cost of bitcoin increased to \$ 35.5 thousand, and Ethereum — to \$ 1.4 thousand (in March 2020, it was \$ 90)⁴⁹.

Against the background of such ups and downs, the news about the achievements of blockchain technology in other fields, where a bright future was predicted as well, looks much more modest in reforming government bodies, countering tax evasion, streamlining business operations, etc. For example, the government of Georgia in 2018 announced the beginning of transfer of the land registry to blockchain, despite the fact that only about 25% of all land in Georgia was registered in digital form⁵⁰. The creation of own cryptocurrency El Petro, announced at the same time by Venezuela, seems to have turned into a gamble⁵¹. The use of blockchain in some countries for voting, in particular in Switzerland, is at the testing stage⁵². There are many pilot projects in the field of medical services (Israel), electricity metering (Chile), and the provision of public services (USA, Delaware)⁵³. However, it is too early to talk about the successful and large-scale implementation of blockchain in trade, production and in the field of public services.

It is obvious that the ambitious project of transition from a cryptocurrency to a generalized blockchain system faced a number of difficulties. Now blockchain is represented by three generations that exist simultaneously, but do not fully satisfy the needs of the real sector of the economy. The industrial versions of the blockchain are developing extremely slow, and the attention of investors and developers, as before, is attracted by the cryptocurrency: according to the portal aggregator CoinGecko, the total capitalization of the cryptocurrency market at the beginning of 2021 exceeded \$ 1 trillion⁵⁴.

⁴⁹ Bitfinex. (2021). Retrieved 2 February 2021, from <https://trading.bitfinex.com/t/BTC:USD?demo=true>

⁵⁰ Bacchi U. (2020). *Tension heats up between church and villagers amid Georgia land ownership debate*. Retrieved 22 October 2020, from <https://www.reuters.com/article/us-georgia-land-rights-religion-feature-t/tension-heats-up-between-church-and-villagers-amid-land-ownership-debate-idUSKBN1ZR03O>

⁵¹ Sharma R. *Why Venezuela's cryptocurrency, Petro, is a failure*. (2018). Retrieved 22 October 2020, from <https://www.investopedia.com/news/why-venezuelas-cryptocurrency-petro-failure/>

⁵² Meyer D. (2018). *Blockchain Voting Notches Another Success-This Time in Switzerland*. Retrieved 22 October 2020, from <http://fortune.com/2018/07/03/blockchain-voting-trial-zug/>

⁵³ Howells-Barby M. (2019). *The Ultimate List of Blockchain Statistics for 2019*. The Coin Offering. Retrieved 24 September 2019, from <https://thecoinoffering.com/learn/blockchain-statistics/>

⁵⁴ CoinGecko (2021). *Cryptocurrency Global Charts*. Retrieved 22 January 2021, from https://www.coingecko.com/en/global_charts

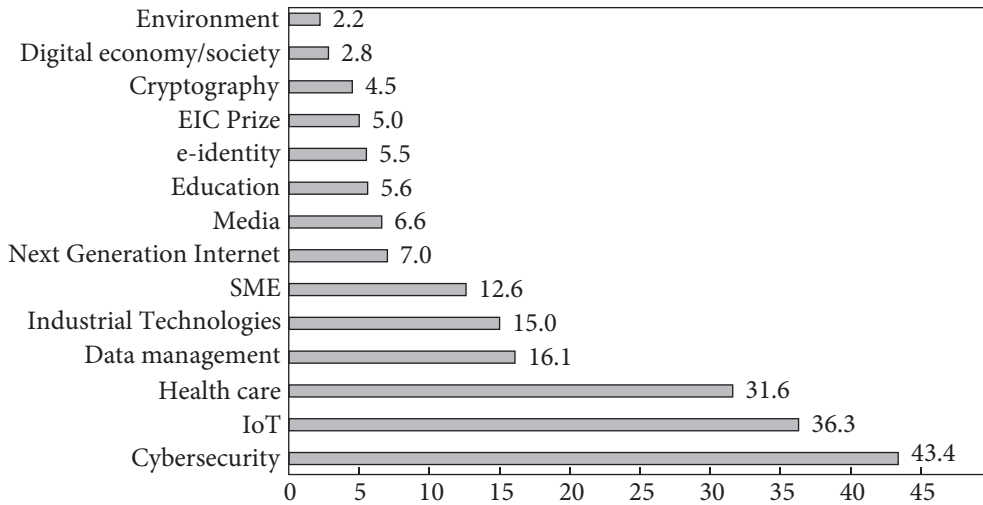


Fig. 2.4. Blockchain projects funded by the EU (project amount \geq € 100,000)

Source: European Commission. (2019). EU-Funded Projects in Blockchain Technology — Shaping Europe's digital future. Retrieved 22 January 2021, from <https://ec.europa.eu/digital-single-market/en/news/eu-funded-projects-blockchain-technology>

The turn towards financing other sectors of the economy such as banking, security, education, industry, cloud storage, media, etc. proceeds gradually, and the investments are still insignificant. For example, in recent years about € 190 million has been allocated for such projects in the EU (Fig. 2.4).

Blockchain problems are largely related to the investment trap. It is unprofitable for exchanges and manufacturers of mining equipment, who were drivers of the first generations of this technology, to invest in the industrial blockchain, where the payback rates are significantly lower than those for the cryptocurrency. The "beehive" of small investors (mainly from China and the USA), mobilized through Initial Coin Offering (ICO), that is, the use of blockchain to attract investments, is also absorbed by cryptocurrencies more than by universal technologies. Long-term investments in R&D can only be afforded by large players in the software market, together with global financial and trading corporations. A typical example is the R3 consortium (discussed below).

Because of the enthusiasm of some investors and developers (including open software), a fairly large ecosystem of three generations has developed.

The first generation of blockchain is actually bitcoins and similar cryptocurrencies. The blockchain architectures serving them are capable of performing only the simplest transactions, and their performance is rapidly degrading.

The second generation appeared while creating a blockchain system for the Ethereum cryptocurrency and provided participants with the opportunity not only to transfer tokens to each other, but also to make full-fledged smart contracts among themselves. Self-executing contracts, but with a limited functional, were possible in bitcoin as well, but practically were not used. Smart contracts are algorithms, written in

special languages (such as Solidity for Ether) to automate the execution of user transactions, stored in the blockchain and executed in a virtual machine environment.

It can be said that the second generation "opened the doors" for large-scale digitalization of the real economy, because on the basis of smart contracts it is theoretically possible to digitize not only simple transactions, but also technological processes, supply logistic chains, legal structures and norms. The leading players in the world industry, trade and finance have recently been actively involved in the development of new generations of blockchain. Forbes has published a list of Top-50 blockchain researchers, which includes Toyota, Samsung, Oracle, IBM, Apple, Bank of China, Bank of America, IMG, Alibaba⁵⁵.

However, now it looks like "the mountain gave birth to a mouse." The potential of the second generation was clearly insufficient for a real breakthrough, so the penetration of blockchain into a real sector of the economy remains insignificant. This is confirmed by the results of a survey of IT-managers. Among them only 14% showed that they take blockchain into account in their plans for the future⁵⁶. Most of the respondents, interviewed by Deloitte, testify to being tired of this boring technology, because after a loud debut, its "maturation" has been delayed⁵⁷.

The excessive popularity of blockchain has been formed due to numerous "naive" investors. Experts are unanimous in the opinion that for such investors, blockchain is an attractive idea, rather than a specific embodiment of it. Therefore, most often they invested only in the very idea of "blockchainization" (57%), rather than in the product demanded by the market. Only 7% of projects funded in Q4 2018 were client oriented. The majority (59%) of projects that raised venture funding in 2018 did not produce a product at all⁵⁸. This explains the reasons for the bankruptcy of almost 85% of projects, which raised funds through ICO.

In addition to the investment trap, there is also a technological one. After the initial surge of optimism, it became clear that the transition from the cryptocurrency purpose of blockchain technology to the universal one requires a deeper than expected transformation of the technological core, which is harder and longer than the transformation between the first and second generations.

Not all blockchain bottlenecks were eliminated in the second generation. The projects that are currently forming the third-generation ecosystem are primarily aimed at overcoming a deep contradiction, the "birth trauma" of the technology, which the creator of Ethereum V. Buterin called the "trilemma of blockchain technol-

⁵⁵ Castillo M. (2018). *Big Blockchain: The 50 Largest Public Companies Exploring Blockchain*. Forbes Staff. Retrieved 22 October 2020, from <https://www.forbes.com/sites/michaeldelcastillo/2018/07/03/big-blockchain-the-50-largest-public-companies-exploring-blockchain>

⁵⁶ DGT Network (2019). *BGX Blockchain Market Report*. Retrieved 22 October 2020, from <https://medium.com/@bgxglobal/bgx-blockchain-market-report-2019-7e9a0b3ed8c>

⁵⁷ Arnold A. (2018). *The 6 Major Blockchain Trends For 2018 Outlined by Deloitte*. Forbes. Retrieved 24 September 2019, from <https://www.forbes.com/sites/andrewarnold/2018/07/27/the-6-major-blockchain-trends-for-2018-outlined-by-deloitte>

⁵⁸ DGT Network (2019). *BGX Blockchain Market Report*. Retrieved 22 October 2020, from <https://medium.com/@bgxglobal/bgx-blockchain-market-report-2019-7e9a0b3ed8c>

ogy"⁵⁹. This trilemma characterizes the internal limitation of the blockchain, which makes it impossible to simultaneously achieve high-quality performance, decentralization and security, since the implementation of any two goals contradicts the third.

The efforts of researchers and developers are focused on finding compromise solutions to the trilemma: for example, to increase the technology performance without significant loss in decentralization and security. Specific tasks facing the third generation are the growth of the technology's versatility for its application in various industries, simplification of the interaction of various blockchain systems by introducing intersystem smart contracts, as well as the full integration of the blockchain with the external physical world (e.g., creating triggers for linking the execution of smart contracts with events outside)⁶⁰.

Outlines of the third generation blockchain are just acquiring a shape, so alternative solutions are to go through natural selection. One of the promising candidates in the new generation is "sharding", used to create a distributed system. In contrast to the currently used storage of a full copy of the database on each node, sharding suggests storing only a fragment of it in separate nodes. Then the complete base will be formed like a mosaic from separately preserved fragments. Sharding significantly increases the performance of the system⁶¹, which is especially important for the use of technology in the financial and real sectors of the economy.

In 2015, Lightning Network and similar approaches were developed, called two-layer protocols⁶². Unlike sharding, they solve the problem of poor blockchain performance by reducing the security requirements for private transactions. So, numerous transactions, individually not critical, small, with acceptable risk (in practice they make up majority), are performed outside the blockchain system (off-chain), that is, without consensus. And only when a group of small tasks is completed, they are merged into one mega-transaction, which is checked and carried out classically, that is, they are placed on the blockchain according to general rules through consensus. The load on the system decreases and the performance increases. According to the law of large numbers, it is expected that the cost of risk for many small off-chain transactions will not exceed the gain from increasing blockchain speed by hundreds and thousands of times.

An interesting example of breaking the trilemma deadlock is the Exonum project by Bitfury Company — one of the leaders in the hardware manufacturing for blockchain and mining. This project is a decentralized system with a limited number of

⁵⁹ Ometoruwa T. (2019). *Solving the Blockchain Trilemma: Decentralization, Security & Scalability*. Coinbureau. Retrieved 22 October 2020, from <https://www.coinbureau.com/analysis/solving-blockchain-trilemma>

⁶⁰ Provable (2019). The Provable™ blockchain oracle for modern DApps. How it works. Retrieved 22 October 2020, from <https://provable.xyz/>

⁶¹ Jordan R. (2018). How to Scale Ethereum: Sharding Explained. Medium. Retrieved 22 October 2020, from <https://medium.com/prysmatic-labs/how-to-scale-ethereum-sharding-explained-ba2e283b7fce>

⁶² Lightning Network (2018). *Scalable, Instant Bitcoin/Blockchain Transactions*. Retrieved 22 October 2020, from <https://lightning.network>

active nodes. Due to limited scaling and the use of original consensus algorithms, high performance was achieved (up to 15 thousand operations per second). Realizing that cryptographic strength in such a system may be at risk, the Exonum creators decided to take care of strengthening security in their own way: now and then the system creates synchronization points, storing checksums of the blockchain state in the distributed blockchain bitcoin (the most secure for today). This procedure was called "anchoring". The authors of the project believe that, although data fabrication in their system is potentially possible, it will definitely be noticed, and the truth can be easily restored. The Exonum's advantages allowed it to take part in the project of transition to the blockchain of the Georgian land registry.

Besides the existing internal contradictions of the technology, its implementation is also hampered by the traditional rejection of innovations. Reengineering of a business, aimed at moving to blockchain, is a rather risky and expensive undertaking for a well-oiled company. Therefore, the introduction of a blockchain, according to Deloitte, is more interesting for a business created "from a blank sheet"⁶³.

However, there are already solution designs that make it easy to implement blockchain in operating companies. One of the leaders in B2B sphere is Hyperledger Fabric, founded in 2015 by Linux Foundation with contributions from IBM and donated to the free software community. The project corresponds to the second generation of blockchain and is constantly developing, expanding the scope of industrial applications. Hyperledger Fabric is an implementation of a cryptographically secured decentralized ledger of transactions with a limited number of nodes. There are a number of similar limitedly scalable permissioned "quasi-blockchain" projects, named so to distinguish them from open and distributed "true" blockchain systems.

The developers offer these projects for financial calculations, credit provisions, customs procedures, medicine, taxation, etc. The most famous example is Corda, created by the R3 consortium (includes 200 companies, among which the giants Barclays, Credit Suisse, Goldman Sachs, JP Morgan). Corda was implemented by Cargill to control the movement of goods and settlement accounts with partners, providing the multinational company with the opportunity to increase the transparency and security of international trade and financial transactions, as well as to accelerate the receipt of circular notes⁶⁴.

Such systems do not absolutely correspond to the original philosophy of the blockchain (security of information storage with high scalability and openness of systems), but nevertheless they can be more easily implemented. These projects are difficult to consider as a revolution or a catalyst for rapid development of economic institutions; rather, they are more complex tools (protocols) for storing and exchanging informa-

⁶³ Arnold A. (2018). The 6 Major Blockchain Trends for 2018 Outlined by Deloitte. Forbes. Retrieved 24 September 2019, from <https://www.forbes.com/sites/andrewarnold/2018/07/27/the-6-major-blockchain-trends-for-2018-outlined-by-deloitte>

⁶⁴ Noble L. (2018). Cargill blockchain shipping transaction cuts exchange time to 24 hours. *The Global Treasurer*. Retrieved 22 October 2020, from <https://www.theglobaltreasurer.com/2018/05/14/cargill-blockchain-shipping-transaction-cuts-exchange-time-to-24-hours>

tion. Sometimes they are viewed by practitioners as an excessive and ineffective add-on to traditional databases, which often leads to abandonment of implementation.

However, there is a common feature of quasi-products (unallocated and closed) and classical blockchain technology, which provides the former with such advantages that allow standing on the same step with the latter. This is tokenization, that is, the creation of a unique, cryptographically protected digital representation of an asset in the registry. Tokenization as part of the general trend towards the digitalization of the economy can be used not only for payments, but also for goods, services, rights, personalities, etc. It greatly facilitates identification in the digital space and excludes multiple use of the same object as security for payment or collateral. Moreover, this is relevant not only for tangible assets. In particular, tokenization of service facilities, service hours, rental area, etc., will significantly increase investors' confidence, facilitate pre-sales and financing of developers and manufacturers. What is now characterized as a boom of the initial coin offering (ICO) for IT and web projects, may become a common practice of investing in tangible assets over time.

Because of these capabilities, the blockchain creates an environment for attracting investments and optimizing capital. The most famous example is the acceleration of crediting to manufacturing and trade operations through supply chain finance. The use of blockchain as an information platform for the formation of tax and accounting documents, the so-called e-Invoicing, helps to minimize the risks of the parties by improving the quality of information (e.g., openness and mutual audit), that is, to reduce the cost of raising loans in factoring schemes. A number of publications have considered examples of how companies of the IBM scale, such as Maersk, Dianrong, implement international blockchain-based supply chain financing systems (see, for example, Hofmann, Strewe, Bosia, 2018).

One of the most promising innovations in the field of blockchain can be considered its symbiosis with e-Invoicing, that is, procedure for issuing and transferring invoices, commodity and tax invoices by trading partners to each other, as well as to fiscal authorities in the digital form, as opposed to paper or even scanned "paperless" documents⁶⁵.

The E-Invoicing and blockchain technologies evolved independently, but as they reached maturity, they became complementary. The digitization of invoices and their introduction in the blockchain in connection with smart contracts reduce transaction costs, related to compliance with contractual and legislative norms by the parties of trade agreements. More examples of successful e-Invoicing on the third generation blockchain platform are expected to emerge in the upcoming years. In the field of public finance, this way of using blockchain creates the preconditions for a further transition to digital taxation of value added (VATCoin) (Ainsworth, Alwohaibi, 2017; Kimani, Adams, Attah-Boakye, Ullah, Frecknall-Hughes, Kim, 2020).

Another promising trend of blockchain application to industry is its symbiosis with Internet of Things (IoT) technologies (Groopman, Owyang, 2018). The produc-

⁶⁵ European Commission (2020). *E-Invoicing — Internal Market, Industry, Entrepreneurship and SMEs*. Retrieved 22 October 2020, from https://ec.europa.eu/growth/single-market/public-procurement/digital/einvoicing_en

tion and improvement of smart goods take place in almost all industries. They are: the industrial Internet of Things (IIoT) in enterprise resource planning systems, self-diagnosed and maintained equipment, networks of miniature devices that form a "web" of senses for powerful artificial intelligence and much more. In the conditions of low confidence in IoT devices, blockchain can be a solution to security problems that require high performance and scalability at the same time (in the context of the blockchain "trilemma"). If in the third-generation reasonable compromises are proposed for this puzzle, combination of IoT and artificial intelligence with the blockchain will be able to trigger a new stream of industrial innovations.

APPENDIX 2.1

Some definitions of "digital economy" by foreign and Ukrainian researchers

Definition	Source
The recent and still largely unrealized transformation of all sectors of the economy by the computer-enabled digitization of information	Understanding the Digital Economy: Data, Tools, and Research/ Ed. by E. Brynjolfsson and B. Kahin. The MIT Press, 2002, p. 2
The digital economy is comprised of markets based on digital technologies that facilitate the trade of goods and services through e-commerce. The digital economy is a vital sector, driving very substantial growth. Furthermore, the impact of the digital economy extends beyond information goods and services to other areas of the economy as well as lifestyles more generally	DAF/COMP (2012)22: The Digital Economy. Organization for Economic Cooperation and Development, 2012, p. 5
The digital (electronic) economy is an economy, a characteristic feature of which is the maximum satisfaction of the needs of all its participants through the use of information, including personal information. This is possible due to the development of information, communication and financial technologies, as well as the availability of infrastructure, which together provide the possibility of full-fledged interaction in the hybrid world of all participants in economic activity: subjects and objects of processes of creation, distribution, exchange and consumption of goods and services	Introduction in "digital" economy / Keshelava A.V., Budanov V.G., Rumiantssev V.Yu. et al. Editor A.V. Keshelava; Cons. I.A. Zimnenko. VNIIG, 2012, p. 12
A specific form of economic manifestation of production and service flows, dominated by digital technologies, where associated information flows are functionally dependent on ICTs	Encyclopedia of Information Science and Technology / M. Khosrow-Pour editor (Information Resources Management Association, USA), Third Edition, 2014, p. 21
The economic activity that results from billions of everyday online connections among people, businesses, devices, data, and processes. The backbone of the digital economy is hyperconnectivity which means growing interconnectedness of people, organizations, and machines that results from the Internet, mobile technology and the internet of things (IoT)	Cassar C., Heath D., Micallef L. What is Digital Economy? Unicorns, transformation and the internet of things. Deloitte, 2015

Continuation of the Appendix 2.1

Definition	Source
<p>A broad range of economic activities that include using digitized information and knowledge as the key factor of production, modern information networks as an important activity space, and the effective use of information and communication technology (ICT) as an important driver of productivity growth and economic structural optimization</p>	<p>G20 DETF 2016: G20 Digital Economy Development and Cooperation Initiative. Hangzhou Summit, 2016, p. 1</p>
<p>The digital economy is the share of total economic output derived from a number of broad "digital" inputs. These digital inputs include digital skills, digital equipment (hardware, software and communications equipment) and the intermediate digital goods and services used in production. Such broad measures reflect the foundations of the digital economy</p>	<p>Knickrehm M., Berthon B., Daugherty P. Digital disruption: The growth multiplier Optimizing digital investments to realize higher productivity and growth. Accenture, 2016, p. 2</p>
<p>The digital economy is amalgamation of several general-purpose technologies (GPTs) and the range of economic and social activities carried out by people over the Internet and related technologies. It encompasses the physical infrastructure that digital technologies are based on (broadband lines, routers), the devices that are used for access (computers, smartphones), the applications they power (Google, Salesforce) and the functionality they provide (IoT, data analytics, cloud computing)</p>	<p>DEV/DOC/WKP(2016)6: Dahlgren C., Mealy S., Wermelinger-M. Harnessing the Digital Economy for Developing Countries, Organisation for Economic Cooperation and Development, 2016, p. 11</p>
<p>An economy which functions primarily by means of digital technology, especially electronic transactions made via using the Internet</p>	<p>Wong J. Digital Economy and Inclusive Trade. Government policy imperatives for the SDGs. United Nations ESCAP, 2017, p. 2</p>
<p>Change in the technological base of the economy, allowing automation of routine operations</p>	<p>Ivanov V.V., Malinetskiy H.H. Digital economy: myths, reality, prospects. Russian Academy of Sciences, 2017, p. 6</p>
<p>Innovative dynamic economy, based on the active introduction of innovation-information and communication technologies in all types of economic activities and spheres of society, which makes it possible to increase the efficiency and competitiveness of individual companies, the economy and living standards</p>	<p>Karcheva H.T., Ohorodnia D.V., Openko V.A. Digital economy and its effect on development of national and international economy, Finansovyi prostir, 2017, No 3, p. 14</p>
<p>A hyperconnected economy, characterized by a growing interconnected people, organization and machines through the web and by the means of digital technology, which include: advanced manufacturing, robotics and factory automation, new sources of data from mobile and ubiquitous Internet connectivity, cloud computing, big data analytics, and artificial intelligence</p>	<p>Mundula L., Auci S. Institutional Entrepreneurship, Trust, and Regulatory Capture in the Digital Economy. Handbook of Research on Entrepreneurship and Marketing for Global Reach in the Digital Economy, 2018, p. 78</p>

2. Technologies of digitalization of an economy

The end of Appendix 2.1

Definition	Source
<p>Type of economy, characterized by active introduction and use of digital technologies for storage, processing and transmission of information to all spheres of human activity.</p>	<p>Kraus N.M., Holoborodko O.P. Digital economy: trends and prospects of vanguard development, <i>Efektivna ekonomika</i>, 2018, No. 1</p>
<p>The segment of activity, where materialization of value added in the production of goods and services is carried out using digital technologies, especially for industries that are Internet-dependent. Herein it makes sense and value if digital technologies and infrastructure facilitate cooperation in all spheres of the economy and levels of management.</p>	<p>Panshin B. Digital economy: concepts and directions of development. <i>Science and innovation</i>. 2019, No. 193, p. 48-55</p>
<p>Digital economy is activities for the creation, distribution and use of digital technologies and related products and services</p>	<p>What is the digital economy? Trends, competencies, measurements: Report at Internat. conf. on problems of economic and social development, Moscow, 9-12 April 2019 / G.I. Abdrakhmanova, K.O. Vishnevsky, L.M. Gokhberg et al./ Ed.L.M. Gokhberg. Nat. University "Higher School of Economics". Moscow: House of the Higher School of Economics, 2019, 82 p.</p>



3

ENVIRONMENTAL ASPECTS OF DIGITALIZATION OF THE ECONOMY



3.1. GLOBAL TRENDS IN THE ECOLOGICAL AND DIGITAL TRANSFORMATION OF THE ECONOMY

In the long-term strategies of innovation-oriented industrial countries of the world (the USA, the European Union, Scandinavian countries, Japan, South Korea, China, etc.), directions of an economy's digitalizing and greening are considered to be a priority and mutually complementary, contributing to the inclusive, socially responsible and sustainable development.

The threat of a global environmental crisis¹, associated with irreversible climate changes, depletion of fossil resources, loss of biodiversity by ecosystems, etc., has led to consolidation of efforts to prevent all that at the international level. The UNEP Global Green New Deal initiatives (UNEP, 2011, p. 2), as well as the Green Growth Economic Policy, officially adopted by the Organization for Economic Co-operation and Development (OECD) as a dominant strategy until 2030 (OECD, 2011), contributed to popularizing the green economy as a promising field of R&D, carrying out political and market reforms that stimulate the transition to environmentally neutral and/or environmental friendly technologies, introducing mandatory environmental standardization of a product life cycle, through changing priorities of investment in R&D and others (Barbier, 2010).

The re-prioritization of economic development in the context of the paradigm of smart growth (European Commission, 2010), the digital revolution and the rapid spread of modern smart industry, also known as Industry 4.0 (Schwab, 2017), have formed a new model of industrial development based on digitalization, robotization and customization of manufacturing. Cyber-physical transformation of business processes and the fusion of material industrial platforms with virtual reality can provide, in combination, a drastic increase in the labour productivity and the efficiency of national and global economies.

¹ TOM Agency (2020). *Ecological wealth of nations. Global Footprint Network*. Retrieved 21 November 2020, from: http://www.footprintnetwork.org/ecological_footprint_nations/

The commonality of the development driver, that is, physical innovations aimed at smart change in the dominant technological order, defines the congruence of greening and digitalization strategies. The modern practice of environmental standardization of a product life cycle and the obligatory environmental review of new projects imply, on the one hand, that the digitized industry being formed should, by default, comply with the green requirements. On the other hand, as a result of the technological order shift, all existing green industries should become digitalized and acquire the properties of smart ones. It is, however, evident that meeting these challenges will not be easy and will require deliberate efforts at the national and international levels.

Back at the beginning of the XXI century 22 OECD member countries developed a package of state programs and business initiatives related to solving environmental problems in the manufacturing and use of ICTs in order to increase the efficiency of energy consumption, prevent global climate changes, utilize toxic pollutants, prevent depletion of non-energy resources² (Reimsbach-Kounatze, 2009). Research of the Global Enabling Sustainability Initiative (GESI)³ also defines the ICT industry as a key driver for creation of a highly intelligent and low-carbon society. In the message of the EU Commission (European Commission, 2020) to the European Parliament, the creation of digital green industrial ecosystems and, accordingly, the achievement of climate-neutral digital leadership of the industry are identified as priority tasks for the next decades and the key to maintaining competitive advantages and geopolitical influence of the European Union.

However, besides wide range of opportunities, an economy's digitalization, like any new and understudied phenomenon, creates challenges, including environmental ones, and significantly affects the structure of the ecological footprint. So, on the one hand, according to European experts and provided the current trends remain, by 2040 the share of the digital sector in the global CO₂ emissions may increase from the current 2% up to 14%⁴. But, on the other hand, the targeted use of green digital technologies in order to decarbonize the world economy can reduce greenhouse gas emissions by 15%, that is, reduce the anthropogenic burden on the global ecosystem and achieve carbon neutrality of the digital industry.

Experts' assessments show that the digital-based smart industry has a high potential to reduce costs and increase labour productivity (McKinsey & Company, Inc., 2016, p. 7). At the same time, as noted in Huawei's report⁵, the constantly growing "digital

² Reimsbach-Kounatze C. (2009). *Towards Green ICT Strategies: Assessing Policies and Programmes on ICT and the Environment*. OECD Digital Economy Papers. № 155. Retrieved 10 August 2020, from: <http://doi.org/10.1787/222431651031>

³ GeSI (2020). *Global Enabling Sustainability Initiative*. Retrieved 21 November 2020, from: <https://gesi.org>

⁴ European Commission. (2020). *Supporting the green transition: shaping Europe's digital future*. Retrieved 10 October 2020, from: https://ec.europa.eu/info/strategy/priorities-2019-2024/europe-fit-digital-age/shaping-europe-digital-future_en

⁵ Huawei Technologies Co., Ltd. (2018). *Results of research of GCI 2018*. Retrieved 10 October 2020, from: <https://www.huawei.com/minisite/russia/gci2018rus/>

divides"⁶ between innovative leaders and less technologically advanced economies contribute to the conservation of outdated environmentally dirty and resource-intensive technological modes, which fixes the latter's role as raw-material appendages and final places of hazardous wastes allocation. A clear indication of this "institutional ecological trap" is the map of electronic wastes' (e-wastes') emigration (Fig. 3.1).

As follows from the analysis of logistic flows of e-wastes, there is a certain pattern in the geopolitical distribution of links in global value-added chains. Environmentally clean and economically prosperous countries with strict environmental legislation and high costs of legal utilization of e-wastes prefer to import it into less developed regions with a relatively loyal attitude towards environmentally "dirty" types of economic activity and with cheap physical labour. The exception is China, which is both the largest producer of digital products and a place of e-wastes' accumulation.

The dialectical connection between ecology and "digit" is also manifested in the fact that high green requirements, primarily in developed countries, create obstacles for widespread diffusion of digital technologies. Thus, the environmental standardization of a product life cycle increases transaction costs on the quality control, manufacturing and operation conditions, post-sale environment friendly utilization of electronic products and the related infrastructure. The inability (technical and/or financial) to meet the established quality standards is one of the most common market barriers in the international and national markets. A strong environmental lobby in the government, as well as protest movements of nature conservation organizations, forms a negative image of new digital technologies' developers, hindering economic development, scientific and technological progress by increasing investment risks and tax burden for entrepreneurs.

At the same time, it is important to realize that the environmental consequences of digital innovations may be truly difficult to predict. For example, an increase in the wave radiation intensity due to the development of digital communications provokes a rise in the number of congenital genetic mutations of living organisms (birds, fish, insects, etc.), changes in their basic behavioural reactions (especially in the case of social species: ants, wasps, bees, termites, bumblebees), in their migration routes and habitats, which disrupts the established food chains in ecosystems and leads to a decrease in biodiversity and, in some cases, to the collapse of ecosystems. For example, the mass extinction of bees leads to a reduction in pollination processes of fruit crops, as well as of some plant species, which can fatally affect the range and quantity of food products (Sivani, Sudarsanam, 2013).

Thus, the creation of new unique digital products and processes does not guarantee an automatic reduction in the level of anthropogenic burden on ecosystems, since this may be accompanied by involvement of new types of natural resources in the technogenic circulation, formation of additional sources of a still unknown

⁶ Huawei identifies 5 key indicators, with which the digital divide between countries is most evident: (1) coverage of users with mobile broadband networks; (2) the number of IT experts; (3) investments into ICTs relative to GDP; (4) the number of downloaded subscriptions; (5) the number of installed bases of the Internet of Things.

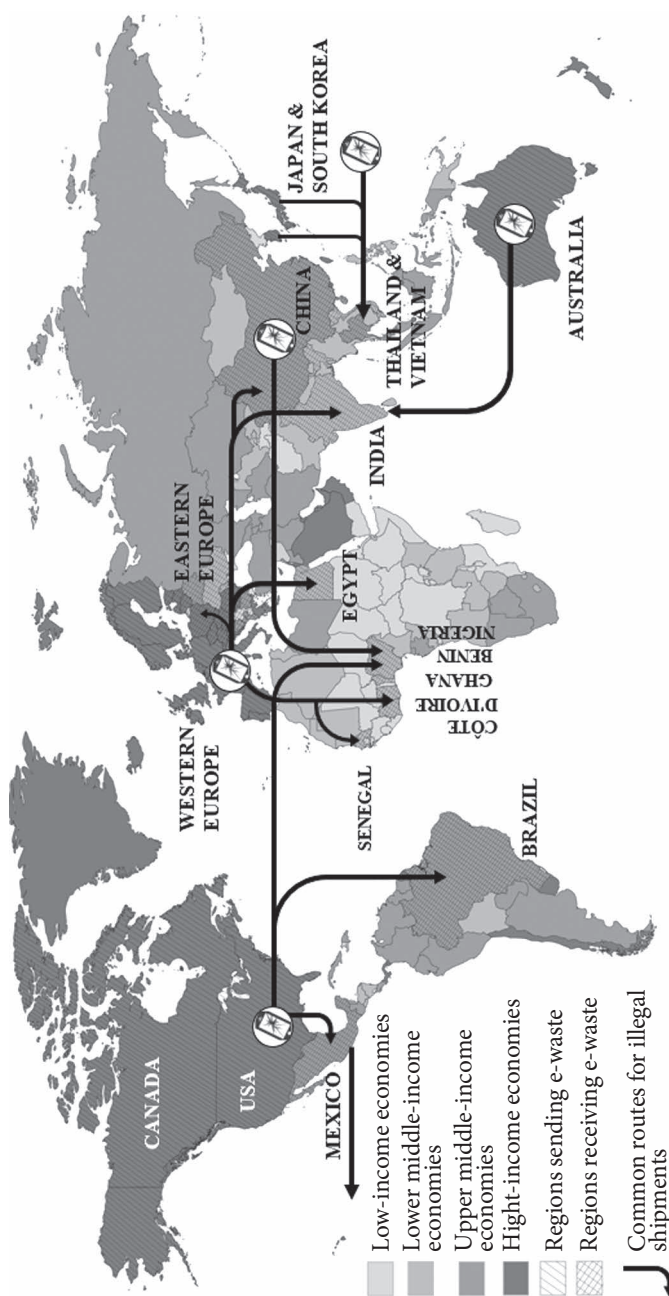


Fig. 3.1. The map of e-waste emigration

Source: The World Bank. (2020) World Bank Country and Lending Groups. Retrieved 10 October 2020, from: <https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups>; World Economic Forum, 2019, p. 14

(potentially dangerous) impact on the quality and viability of ecosystems and by growth of certain types of wastes' (mainly e-wastes) formation and accumulation.

By developing an approach, offered in (Servaes, 2012)⁷, to the typology of ICTs' impacts on the environment, the following impacts of digital technologies on the size and structure of the ecological footprint can be distinguished:

- *Direct positive impact* is a consequence of the so-called "dematerialization", that is, saving of consumption of material resources by enterprises, organizations and end users, and, accordingly, reduction in waste formation due to digitalization of document circulation, information products, business processes, commercial and administrative services.
- *Direct negative impact* as an increase in consumption of energy and other natural resources (including non-renewable ones), waste formation (including e-wastes) and greenhouse gas emissions, caused by the running and deterioration of digital hardware and infrastructure.
- *Potential positive impact* represents a reduction of energy and resources consumption in other (non-digital) industrial sectors due to the use of new opportunities, opened by digital products and technologies.
- *Potential negative impact* appears in stimulating delayed long-term effects that disrupt the natural balance in ecosystems via decreasing their ability to self-restoring and reducing biodiversity; an objective assessment of this type of impact is complicated because of its unpredictability, long duration, large scale and cost of experiments in the real world.
- *Systemic positive behavioural impact*: a digitalization-driven change in the current patterns of behaviour of economic agents (population, governments, enterprises and organizations) to environment friendly ones; this is not only a reduction in resource consumption and waste generation throughout manufacturing processes, but also a rejection from the consumer's attitude towards the natural environment.
- *Systemic negative behavioural impact* consists of provoking psycho-neuro-logical disorders of the population⁸, formation of a distorted consumers' values structure and attitudes in order to get a monopole quasi-rent from an accelerated change in generations of goods through aggressive advertising, deliberate incompatibility of software and hardware, etc.

The above examples show that digital and green economies have obvious contact points, which, on the one hand, can give a new impetus to the sustainable development

⁷ According to (Servaes, 2012), there are three types of such impacts: direct, potential and systemic.

⁸ So-called "computer addiction" or "addiction to gadgets" is accompanied by the development of social anxiety, social maladjustment, decline in business activity and work capacity, causing scattering of attention (World Health Organization. (2020). *ICD-11 — Mortality and Morbidity Statistics*: 6C51 Gaming disorder.icd.who.int. Retrieved 06 November 2020, from: <https://icd.who.int/browse11/lm/en#/http://id.who.int/icd/entity/1448597234>). All this reduces labour productivity and increases the risk of industrial accidents, which, therefore, requires the adoption of additional control measures and sanctions, including those at the legislative level, which diverts resources and increases transaction costs.

3. Environmental aspects of digitalization of the economy

Table 3.1. Environmental advantages of digitalization

Cases of digitalization	Casually related environmental effects		Consequences for ecosystems
Transition to electronic document circulation Expansion of commercial and administrative digital services Diffusion of remote digital communications	Dematerialization of goods and services Reduction in physical logistic flows	Saving renewable and non-renewable natural resources Reduction of pollutants' emissions into the environment Reduction of risks of technogenic disasters	Reduction in technogenic burden
Use of smart automatic systems in industry and households	Flexible response to changes in environmental conditions in real time to ensure the most efficient use of resources and minimize costs Customization of production Improvement of manufacturing monitoring systems, reduction in risks, associated with equipment failures (due to undetected technical malfunctions, human factors, etc.)		

of national economies and, on the other hand, create new problems, associated with difficult-to-predict and diverse for different countries environmental consequences.

The most obvious environmental advantages of digitalization are listed in Table 3.1.

A more targeted environment friendly effect of digitalization is "smartness" of robotized industrial systems, which improves monitoring and control systems in real time, increases the efficiency of business processes and reduces costs. Smart power grids, ventilation and climate control systems in smart buildings, 3D printing, automated product quality control systems, industrial robotics, smart logistics, etc. contribute to customizing production, saving resources, optimizing stocks and timely detecting possible malfunctions, preventing failures and emergencies and, as a result, reducing the technogenic burden on ecosystems.

The environmental disadvantages of digitalization (Table 3.2) are due to the growing demand for smart products and digital services, provoking an increase in energy consumption and greenhouse gas emissions, accumulation of e-wastes, which is aggravated by unfair competition, desire to maximize monopoly quasi-rents from pseudo-innovations, when real R&D is replaced by marketing policy, which stimulates excessive prestigious consumption. In addition, risks for ecosystems increase because of poor knowledge of the impact of digital technologies, including 5G technology, on flora and fauna ⁹.

⁹ Curran C. (2020). *What Will 5G Mean for the Environment?* The Henry M. Jackson School of International Studies, University of Washington. Retrieved 10 October 2020, from: <https://jsis.washington.edu/news/what-will-5g-mean-for-the-environment/>

Table 3.2. Environmental disadvantages of digitalization

Cases of digitalization	Causally related environmental effects	Consequences for ecosystems
<p>Widening of the technical devices differentiation</p> <p>Increase in the number of technical devices due to increased demand</p> <p>Increase in the duration of using technical devices per day</p>	<p>Increase in energy consumption (by industry and households)</p> <p>Increase in greenhouse gas emissions</p> <p>Increase in industrial consumption of rare-earth metals</p> <p>Increase in generation of electronic wastes, including those, containing toxic substances</p> <p>Increase in risk of industrial accidents due to imperfection of digital technologies, accumulation of errors and system failures</p>	<p>Disruption of the circulation of substances in ecosystems</p> <p>Break of food chains and reduction of habitats, decrease in the ecosystems' biodiversity</p> <p>Deformation of a society's values structure</p>
<p>Change/emergence of new technologies for information signal transmission</p> <p>Accelerated change of generations of technical devices (early shutdown) due to the desire of manufacturers to obtain a monopoly quasi-rent</p>	<p>Increase in the intensity of wave radiation per unit of territory</p> <p>Development of poor-studied negative effects on the structure of genomes, reproductive systems' functioning and behavioural reactions of living organisms</p> <p>Growth in consumption of natural resources due to aggressive advertising and unfair competition (deliberate technological incompatibility of software and technological support; industrial espionage, trade wars)</p>	

The current government strategies for the sustainable development and political programs for the development of "green" digital technologies and reduction of man-made impact on the environment are usually focused on the period to 2040-2050. (Ferreboeuf, 2019; European Commission, 2020). A common element in them is the trend towards the use of digital technologies in order to decarbonize and save energy in the industrial sector through the development of "smart power grids", "smart buildings", "smart transport", etc. At the same time, in the absence of a unified methodology for calculations and necessary statistical information for a representative period of time, quantitative estimates of the current and anticipated energy and carbon footprint of the digital sector vary depending on the applied approaches to forecasting, which differ in purposes, levels of complexity and detailing.

In particular, the following assessments have been made:

- Portion of digital technologies in the total global energy consumption may be over 3% (Andrae & Edler, 2015; Ferreboeuf, 2019).
- Carbon footprint of digital industry may be from 1.1 to 1.4 billion tons of CO₂-equivalent (Andrae & Edler, 2015; GeSI, 2015, p. 10; Malmodin, Moberg,

3. Environmental aspects of digitalization of the economy

Lunden, Finnveden, Lövehagen, 2010; Malmodin, Bergmark, Lunden, 2013; Malmodin, Lunden, 2018; Belkhir & Elmeligi, 2018).

- Potentially possible reduction in global greenhouse gas emissions due to "green" digital technologies may be 15-20% of the projected total emissions of all economy sectors (GeSi, 2015, p. 10; European Commission, 2020).

As noted in (Belkhir, Elmeligi, 2018, p. 449), some of the early estimates of global CO₂ emissions and energy consumption (Gartner, 2007; GeSi, 2008) are based on rough, uncertain and outdated data, and are, therefore, not quite transparent and reliable; the others are more substantive (Malmodin, Moberg, Lunden, et al., 2010; Malmodin, Bergmark, Lunden, 2013) since they usually focus on narrower and specific tasks, in particular — on the total energy consumption by ICTs. However, in spite of all discrepancies indicated, the obtained estimates are generally rather close (Table 3.3).

Thus, despite the topicality of research on the possibilities of using green digital technologies and the general influence of an economy's digitalization on a sustainable

Table 3.3. Results of calculations of the digital sector's carbon footprint according to various methods

Scenario	Year of forecast	Volume of emissions (by forecast)		Source
		CO ₂ -equivalent, bln t	% of the global emission	
Basic	2020	1.43	2.7	(GeSI, 2008)
	2020	1.27	1.97	(GeSI, 2012)
	2030	1.25	2.3	(GeSI, 2015)
"Green"	2020	-7.80	—	(GeSI, 2008)
	2020	-9.10	—	(GeSI, 2012)
	2030	-12.08	20	(GeSI, 2015)
Basic *	2007	0.62	—	(Malmodin, Moberg, Lunden, et al., 2010)
	2010	0.72	—	(Malmodin, Bergmark, Lunden, 2013)
	2020	1.1	—	(Malmodin, Lunden, 2018)
	2015 **	0.73	—	(Malmodin, Lunden, 2018)
Basic	2030	3.4	—	(Andraea & Edler, 2015)
Better	2030	1.2	—	
Worst	2030	13.8	—	
<i>Degree of influence</i>				
Min	2020	1.11	—	(Belkhir, Elmeligi, 2018) ***
Max	2020	1.31	—	

* Basic scenario implies remaining current trends. ** The study was not aimed at forecasting until 2020. *** The difference in the estimates of the minimum and maximum impact is due to the duration of equipment use.

Source: Malmodin, Moberg, Lunden, et al., 2010; GeSI, 2015, p. 10; Malmodin, Berg mark, Lunden, 2013; Andraea & Edler, 2015; Belkhir, Elmeligi, 2018; Malmodin, Lunden, 2018.

development, there remains some methodological uncertainty, and discussions continue on assessing the current and predicting future volumes of carbon footprint of the digital sector and the economy as a whole, taking into account the general trend towards its progressive digitalization.

3.2. ANALYSIS OF THE DIGITALIZATION IMPACT ON SUSTAINABLE DEVELOPMENT

To confirm the hypothesis about the existence of a direct relationship between the levels of digitalization and sustainable development (in terms of its environmental component), we assessed the strength of the relationship between the ICT Development Index, which characterizes the achievements of the world countries in this field, Table 3.4) and the Environmental Performance Index (EPI), which reflects the combined result of preserving the quality of the environment and natural resource management, Table 3.5).

For this, different countries of the world were selected, which vary in the level of economic, scientific and technological development, parameters of national production and, accordingly, in the size and structure of anthropogenic burden on ecosystems. In order to increase the analysis results' fairness, the following countries were excluded: (a) with a population of under 1 million inhabitants, (b) which do not submit the necessary statistical information regularly and (c) with atypically high incomes due to appropriation of rent from the sale of minerals (primarily hydrocarbons). As a result, the final sample included 106 world economies ¹⁰.

The distribution of the sample countries by the level of ICT development and environmental efficiency and the type of the resulting dependence are shown in Fig. 3.2.

The determination coefficient ($R^2 = 0.85$) indicates a high strength of the positive linear relationship between the ICT Development Index (x) and the Environmental Performance Index (y) of the countries analysed. The average error of approximation between the calculated and fact indexes of environmental performance is 11%, which indicates that the constructed relationship can be considered satisfactory. The value of Spearman's nonparametric rank correlation coefficient (0.93) also indicates the presence of a statistically significant relationship between the phenomena analysed.

¹⁰ The 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, Honduras, Greece, 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, Cote d'Ivoire, 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 Land, Tanzania, Tunisia, Turkey, Uganda, Hungary, Ukraine, Uruguay, Philippines, Finland, France, Croatia, Czech Republic, Chile, Switzerland, Sweden, Sri Lanka, Jamaica, Japan.

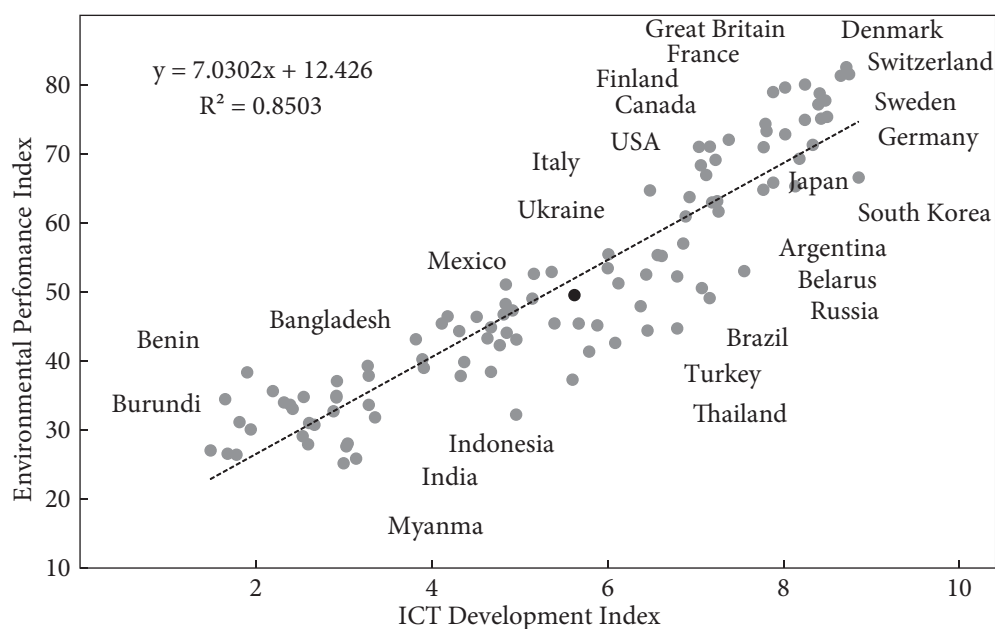


Fig. 3.2. Relationship between the ICT Development Index and the Environmental Performance Index (106 countries, 2017-2020)

Source: International Telecommunication Union. (2020). The ICT Development Index (IDI): conceptual framework and methodology. Retrieved 06 November 2020, from <https://www.itu.int/en/ITU-D/Statistics/Pages/publications/mis2017/methodology.aspx>; Wendling Z.A., Emerson J.W., de Sherbinin A., Esty D.C., et al. (2020). Environmental Performance Index. New Haven, CT: Yale Center for Environmental Law & Policy. 2020. Retrieved 10 October 2020, from <https://epi.yale.edu>

Thus, the most economically developed and innovatively active countries (Germany, Denmark, Finland, France, Switzerland, Japan, etc.) with a high level of digitalization of the economy and, accordingly, a high ICT Development Index are generally characterized by better results in terms of providing environmental efficiency, that is, by a lower anthropogenic burden on ecosystems and a more efficient environmental policy.

However, from the viewpoint of economic and environmental policy, such a worldwide relationship is of a limited value. The point is that economic institutions (formal and informal rules and norms of behaviour) that work well in some countries cannot be automatically transferred to other countries. Likewise, the transition from some dominant production technologies, which define, among other things, the degree of environmental efficiency, to others is not a "smooth" process: it is described by the category "technological gap" between countries (Vyshnevskiy, Harkushenko, Kniazev, 2020). It, therefore, makes sense to divide the specified set of countries into relatively homogeneous clusters (groups), within which there are some general laws of social, economic and digital processes, which environmental processes depend on.

3.2. Analysis of the digitalization impact on sustainable development

Table 3.4. Qualitative structure of the ICT Development Index

ICT sub-index	Indicator	Weight in the index, %	
		Partial	Composition
Access	Fixed telephone lines per 100 inhabitants	20	40
	Mobile cellular telephone subscriptions per 100 inhabitants	20	
	International Internet bandwidth (bit/s) per Internet user	20	
	Portion of households with a personal computer	20	
	Portion of households with Internet access	20	
Use	Portion of households with Internet access at home	33	40
	Fixed telephone broadband subscribers per 100 inhabitants	33	
	Mobile broadband subscribers per 100 inhabitants	33	
Skills	Adult literacy rate	33	20
	Secondary gross enrolment ratio	33	
	Tertiary gross enrolment ratio	33	

Source: International Telecommunication Union. (2017). ICT Development Index 2017. Retrieved 10 October 2020, from <https://www.itu.int/net4/ITU-D/idi/2017/index.html>

Table 3.5. Qualitative structure of the Environmental Performance Index

ICT sub-index	Indicator	Weight in the index, %	
		Partial	Composition
Environmental health	Air quality	20	40
	Sanitation and drinking water	16	
	Heavy metals content	4	
	Waste management		
Ecosystem vitality	Climate change	24	60
	Biodiversity and habitat	15	
	Ecosystem services	12	
	Fisheries		
	Agriculture	9	
	Pollution emissions		
	Water resources		

Source: Wendling Z.A., Emerson J.W., de Sherbinin A., Esty D. C., et al. (2020). Environmental Performance Index. New Haven, CT: Yale Center for Environmental Law & Policy. 2020. Retrieved 10 October 2020, from <https://epi.yale.edu>

3. Environmental aspects of digitalization of the economy

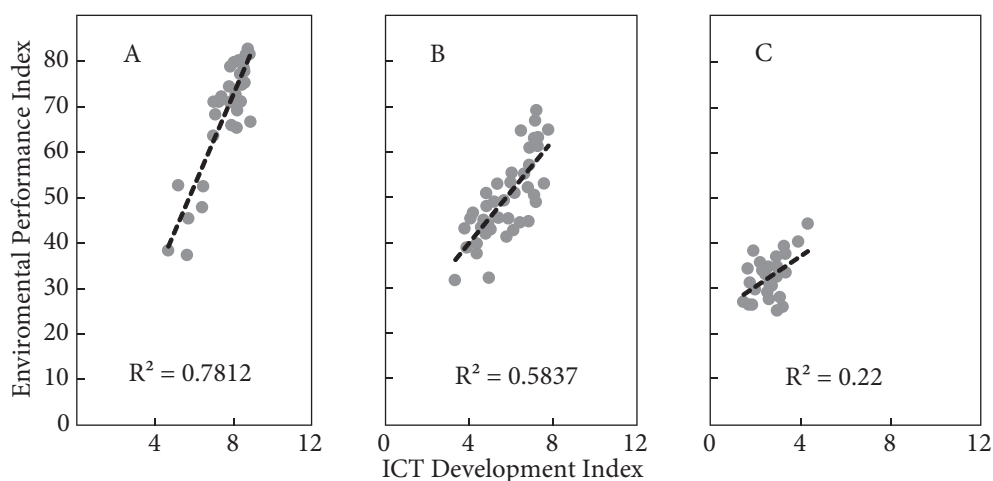


Fig. 3.3. Relationship between the ICT Development Index and the Environmental Performance Index for the clusters of world's countries: A – Clusters of "Leaders" and "Chasers" (with high level of digitalization); B – Cluster of "Catchers" countries (with middle level of digitalization); C – Cluster of "Outsiders" (with low level of digitalization)

Source: International Telecommunication Union. (2020). The ICT Development Index (IDI): conceptual framework and methodology. Retrieved 06 November 2020, from <https://www.itu.int/en/ITU-D/Statistics/Pages/publications/mis2017/methodology.aspx>; Wendling Z.A., Emerson J.W., de Sherbinin A., Esty D.C., et al. (2020). Environmental Performance Index. New Haven, CT: Yale Center for Environmental Law & Policy. 2020. Retrieved 10 October 2020, from <https://epi.yale.edu>; World Bank. (2020). Databank. Worldbank. Retrieved 18 May 2020, from <https://databank.worldbank.org/source/world-development-indicators#>

Clustering was performed using the computer program STATISTICA¹¹. The following variables were used: (1) Income per capita; (2) Manufacturing share in GDP; (3) Human development index (HDI); (4) ICT goods and services export; (5) the number of fixed telephone broadband subscriptions and mobile subscriptions, (6) the number of individuals using Internet. The first three indicators characterize the general level of development of national economies and their industrial sectors, the rest — the level of development and the degree of using ICTs and the Internet. All statistics for the countries of the world concerning digital technologies and digitalization indicators were obtained from the World Bank website¹².

As a result of the cluster analysis (using the k-mean method), four relatively homogeneous groups of countries were identified, which can be conditionally called as: "Leaders" (typical representatives are the Scandinavian countries,

¹¹ StatSoft Russia (2020). *STATISTICA: Data Mining, data analysis, quality control, forecasting, training, consulting*. Retrieved 01 November 2020, from: <http://statsoft.ru/>

¹² World Bank. (2020). *Databank. Worldbank*. Retrieved 18 May 2020, from: <https://databank.worldbank.org/source/world-development-indicators#>

Box 3.1. Brief description of countries' clusters

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

The second cluster, conditionally called "Outsiders", includes countries with diametrically opposite results: their average values of all indicators are the worst among the clusters. As a rule, these countries gained their independence only in the twentieth century, and during the Cold War were considered as a Third World countries.

The third cluster is the largest by the number of countries. It includes economies that are characterized by high and above average income levels but are inferior (by the average values of the studied indicators) to the "Leaders" and "Chasers", overcoming the indicators of the "Outsiders". They are predominantly the former countries of the socialist bloc, as well as countries that belonged to the Third World, but were able to improve their social and economic situation from the time of the Cold War. Some of the countries of this cluster are now members of the EU (Cyprus, Greece and Portugal), however, during the study period (2009-2018), either they could not improve their social and economic situation to the level of the leading countries, or due to the influence of various external and internal factors (in particular, the global financial crisis) have lost their development stability. Conditionally, the countries of the third cluster can be called "Catchers".

The fourth cluster includes countries that by all indicators, except for the indicator "ICT goods exports (% of the total goods exports)", are very close to the leading countries (cluster 1), and by the value of this indicator even exceed their results. This cluster includes countries, that have been actively developing their national industry over at least the latest 30 years (including due to offshoring) and some new EU members that were part of the USSR or the socialist bloc. The countries of this cluster can be conditionally called "Chasers".

Note. The "Leaders" cluster composition: Switzerland, Ireland, Norway, Denmark, Netherlands, Sweden, Japan, Germany, Finland, Austria, USA, Great Britain, Belgium, Israel, France, Canada, Australia, Italy, New Zealand, Slovenia, Spain (21 countries).

The "Chasers" cluster composition: South Korea, Czech Republic, Malaysia, Estonia, Slovak Republic, Hungary, China, Philippines, Costa Rica, Thailand, Mexico (11 countries).

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

The "Outsiders" cluster composition: Namibia, Bolivia, Nicaragua, Honduras, Cambodia, India, Cote d'Ivoire, Laos, Senegal, Lesotho, Gambia, Nepal, Zimbabwe, Bangladesh, Kenya, Nigeria, Zambia, Benin, Cameroon, Pakistan, Uganda, Tanzania, Myanmar, Guinea, Burkina Faso, Madagascar, Mozambique, Ethiopia, Burundi (29 countries).

Western EU countries and the USA), "Chasers" (fast developing Asian countries — China, South Korea, etc.), "Catchers" (countries of Eastern Europe and the former USSR, including Ukraine, etc.) and "Outsiders" (mostly underdeveloped African and Asian countries) (Box 3.1).

Then, for each of the selected clusters, their own relationships were constructed between the ICT Development Index and Environmental Performance Index (Fig. 3.3).

As follows from the results of the calculations presented in the figure, global dependences and trends cannot be directly extrapolated to the national economies that are not referred to the developed ones, since the relationship between the development of ICTs and the environmental performance in the clusters of "Catchers" and "Outsiders" is not strong enough. Moreover, as can be clearly seen from the slope of the trend lines, digitalization of the economy in these clusters has a clearly less positive impact on the environment. At the same time, the elasticity of the EPI relative to the ICT development index in the "Outsider" cluster is about 3 times less than that in the group of "Leaders" and "Chasers", whereas in the "Catchers" cluster it is about 2 times less. In particular, this means that, with the same percentage increase in the ICT development index, the EPI result in Ukraine will be approximately half of that in the developed European countries.

Thus, digitalization by itself, without connection to the general level of development of the economy as a whole and technologies of the real sector in particular, does not provide an environmentally sustainable growth. Therefore, to solve the problem, it is important to take into account the specifics of national R&D as well as its general strategic trend.

3.3. ENVIRONMENTAL AND DIGITAL PROFILE OF UKRAINE

For a general description of the environmental and digital profile of Ukraine, with taking into account the specifics of national R&D, we can use the corresponding indices, calculated by recognised international organizations.

Let us start with the digital part of the profile.

According to the Network Readiness Index, in 2020 Ukraine occupied the 64th position out of 134 possible¹³. At the same time, the direction "Impact of technology on the economy and quality of life" received the lowest rating (49 points, 79th place) and in terms of "Contribution to the achievement of sustainable development goals" Ukraine is assigned to the subcategory that requires critical attention. The low level of this indicator evidences a weak use of ICTs for solving humanitarian problems and achieving the key strategic goals of the UN.

According to the ICT Development Index, Ukraine ranks 79th out of 176 possible places¹⁴. The value of the Ukrainian index is 5.62 points, which is higher than

¹³ Portulans Institute (2020). *Network Readiness Index 2020*. Retrieved 24 September 2019, from: <https://networkreadinessindex.org/>

¹⁴ The rating is based on the results of 2016. The maximum score is 8.98 points (the result of Iceland); the average score for the sample is 5.11 points.

the average for the sample as a whole. In particular, the result of Ukraine exceeds that of China (5.60 points), Iran (5.58), Venezuela (5.17), Mexico (5.16), India (3.03 points) and many other developing countries. That is, judging by the presented indicator values, the ICT sector of Ukraine is promising enough and possesses certain opportunities for further development. However, to obtain a more objective assessment of Ukrainian economy's levels of digitalization and greening, it is important to compare the indicators of its development not with the worldwide or among randomly selected countries' average, but rather with the indicators of those countries that have similar territory, climate and population. Taking into account the current geo-economic priorities, Germany and France (the cluster of "Leaders"), as well as Poland (the cluster of "Catchers") meet these criteria best of all.

As follows from the example, presented in Table 3.6 and Figs 3.4 and 3.5, the greatest lagging behind of Ukraine from these countries is observed in terms of GDP per capita (by almost 15 times). The divide with Poland is somewhat smaller — by 4.7 times. Also (which is important for a correct understanding of the situation), there is a very large gap, especially from the "Leaders" cluster countries, in terms of the portion of ICT exports, which characterizes the national R&D level. At the same time, by the number of mobile subscriptions per 100 inhabitants, Ukraine surpasses Germany and France, which is typical for countries with a low-income level, where the population actively uses mobile communications, applying the technological achievements of more developed economies.

Additionally, the level of digitalization of the industrial sector should be considered, which, on the one hand, is a globally recognized driver of innovations, and, on the other hand, is one of the main polluters of environment.

According to statistics¹⁵, in 2017-2019 the number of Ukrainian enterprises using computers continued to grow. More than 98% of enterprises that took part in the survey had access to the Internet. The average number of employees using computers with Internet access in 2019 was about 30%.

In the context of certain types of economic activity in the field of ICTs' application, enterprises of such TEA as "Manufacturing" and "Wholesale and retail trade, as well as motor vehicles' repair" dominate, accounting for 25% each. Herein, the TEAs, directly related to the sphere of communications, account for 4 to 8% of the sample¹⁶. And enterprises of TEAs "Electricity, gas, steam and conditioned air supply" and "Water supply, sewerage, waste management" occupy only 2 and 3% of the sample, respectively. That is, the "green" orientation of digital technologies in Ukraine is poorly expressed for energy and resource-saving.

As for the use of digital technologies at the enterprise level (Fig. 3.6), the following applications prevail: the use of e-mail (85.4% of the sample), banking (84.3) and other online financial services (35.8), receiving information about goods and services

¹⁵ State Statistics Service of Ukraine (2020). *Application of ICTs by enterprises*. Retrieved 10 September 2020, from: http://ukrstat.gov.ua/operativ/operativ2018/zv/ikt/arh_ikt_u.html

¹⁶ "Transport, storage, postal and courier activities", "Information and telecommunications", as well as "Activities in the field of administrative and auxiliary services."

Table 3.6. Indicators of digitalization and ecological efficiency of Ukraine and reference countries (average values in 2009-2018)

Cluster type	Position in cluster rating by level of digitalization	Country	Indicators							
			GDP per capita in comparative prices, bln US \$ (2010, basic)	Manufacturing share in GDP, %	HDI*, points	Exports of ICT goods and services, % of the total volume of exports	Fixed broadband subscriptions per 100 inhabitants	Mobile subscriptions per 100 inhabitants	Individuals, using the Internet, % of the population	EPI**, points
"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	1.2	0.74	1.0	9.3	130.7	41.6	49.5
			<i>Ukraine, difference in indicators with selected countries</i>							
"Leaders"	8	Germany	-41.4	-7.8	-0.19	-3.7	-26.8	+9.0	-42.5	-257.7
	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 in % of the average indicators			9.0	77.9	83.5	18.3	30.0	109.6	54.1	68.1

* HDI — Human Development Index; ** EPI — Environmental Performance Index.

Source: World Bank. (2020). Databank. Worldbank. Retrieved 18 May 2020, from <https://databank.worldbank.org/source/world-development-indicators#>

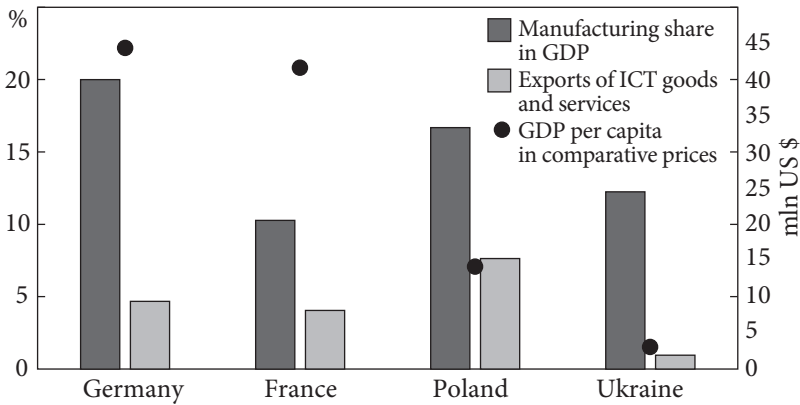


Fig. 3.4. Comparative assessment of economic indicators of development of Ukraine and reference countries

Source: World Bank. (2020). Databank. Worldbank. Retrieved 18 May 2020, from <https://databank.worldbank.org/source/world-development-indicators#>

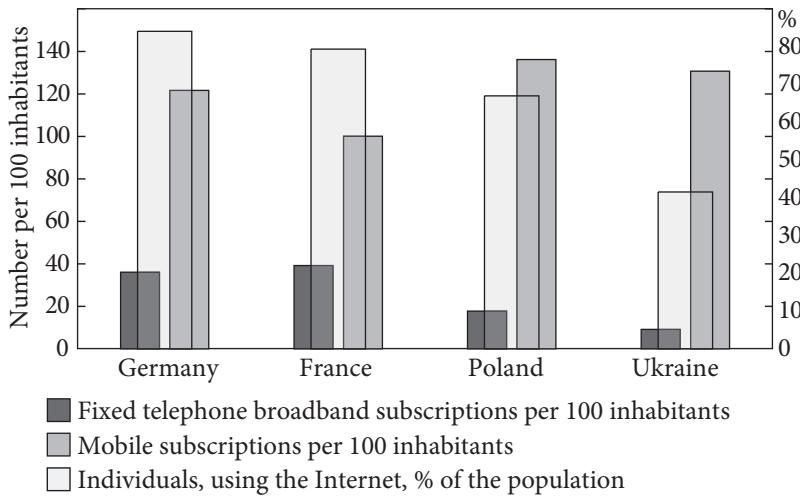


Fig. 3.5. Comparative assessment of digitalization indicators of Ukraine and reference countries

Source: World Bank. (2020). Databank. Worldbank. Retrieved 18 May 2020, from <https://databank.worldbank.org/source/world-development-indicators#>

(77.1), receiving information from public authorities (70.4), performing other transactions with public authorities (46.1%). Such more advanced digital technologies as e-commerce, 3D printing, Big data analysis, etc., which require additional investments and highly qualified personnel, are less common. According to the results of the analysis (Cabinet of Ministries of Ukraine, 2020, pp. 122-124), there is a lack of professional skills of Ukrainian IT specialists in the most promising digital spheres:

sufficient experience and qualification in the field of artificial intelligence (14%), Big Data (4), and Internet of Things (1%). Due to the belated launch of 4G technology, the coverage of high-speed mobile Internet in Ukraine is one of the lowest in the region under consideration, namely — 83% (Cabinet of Ministries of Ukraine, 2020, p. 123), in line with the worst average speed of mobile Internet in Europe (25.5 Mb/s).

There are no available official sources of statistical information on the use of environment-targeted ICTs or "green" digital technologies. In the recently developed by the government Strategy "Vectors of Economic Development 2030" (Cabinet of Ministers of Ukraine, 2020, pp. 301, 304) environmental aspects of digitalization of the Ukrainian economy are also mentioned superficially and in a general context. Nevertheless, some quantitative development indicators¹⁷ are directly related to the areas that are sensitive to the digitalization impacts, in particular — the industrial and energy sectors, transport and infrastructure. Also, such measures as stimulation of resource- and energy-efficient technologies, development of circular economy based on wastes' recycling and reuse, which can be achieved through the employment of "green" digital technologies (smart power grids, smart building, smart logistics) are identified as priorities for industrial development (Cabinet of Ministries of Ukraine, 2020, p. 155).

In general, according to the government's data (Cabinet of Ministries of Ukraine, 2020, p. 120), in 2019 the ICT sector created 4.5% of GDP. It accounts for 3.2% of the employed and 3.8% of the total amount of tax revenues. As for the structure of market, there prevail outsourcing services (about 68%), research and manufacturing according to individual orders for individual customers (17%) and the creation of own digital products (15%).

The potential for further development of the sector by 2030 is estimated by the government very optimistically, namely — at the level of 10% of GDP. In addition to the growth of the domestic market (by 200%), an increase in the exports of IT services is envisaged due to digitalization of the state and corporate sectors and development of IT clusters on the basis of Kyiv, Kharkiv and Lviv. The major barriers to digital development are a low supply of experts, insufficient demand level due to a low level of digitalization, outdated and imperfect regulatory institutions, unsatisfactory development of digital ecosystems, and facilitating implementation of startups.

Then, let us turn to the "green" part of Ukraine's profile.

According to the Environmental Performance Index (EPI), Ukraine occupies the 60th position in the world rating (out of 180 possible places)¹⁸. Its result is 49.5

¹⁷ Within the framework of the "Vectors of Economic Development 2030" (Cabinet of Ministries of Ukraine, 2020, p. 173), it is planned by 2030 to: reduce the carbon footprint of the fuel and energy complex, raise \$ 10 billion investments in renewable energy, bring energy generation from renewable sources up to 25% of the total electricity production. Although these objectives are mentioned outside the context of the digitalization of the economy but reducing the carbon footprint is one of the areas closely related to it.

¹⁸ The rating was compiled at the end of 2019. Maximum score was 82.5 points (Danish result); the average for the sample — 50.66 points.

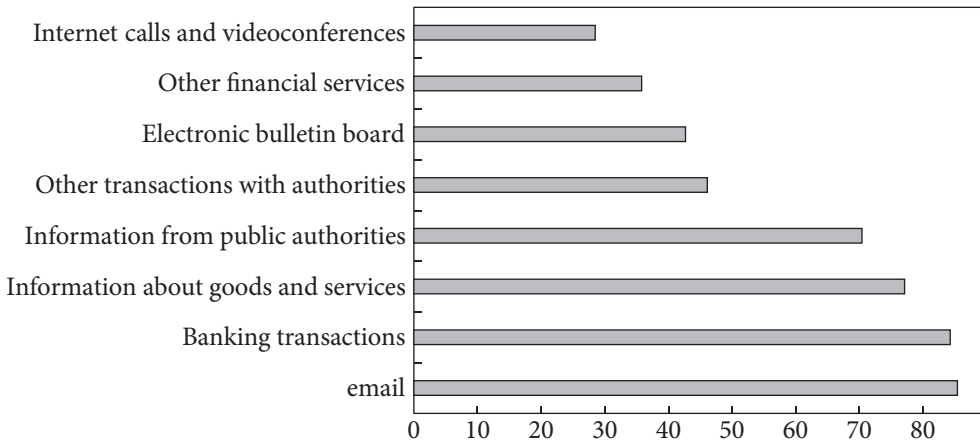


Fig. 3.6. The main fields of ICTs' application by Ukrainian enterprises

Source: State Statistics Service of Ukraine (2020). Application of ICT to enterprises. Retrieved 10 September 2020, from: http://ukrstat.gov.ua/operativ/operativ2018/zv/ikt/arh_ikt_u.html

points, which is below the average for the sample as a whole¹⁹. A detailed analysis of the EPI structure (Table 3.7) indicates that the most critical areas for Ukraine are air and water quality, including due to the underdeveloped wastewater treatment industry. A better result was obtained for the ecological cleanness of agriculture, which is associated with a relatively low level of using mineral fertilizers²⁰. Like in the case of digitalization indicators, Ukraine's EPI is generally lower than that of the reference countries (Germany, France and Poland).

In the context of decarbonization of the energy sector, the situation looks more optimistic. As shown in Fig. 3.7, the volumes of primary energy supply (thousands t o.e.²¹) and the energy intensity of Ukrainian GDP (thousands t o.e. per 1000 international dollars) have been steadily decreasing over the past decade.

Also, since 2015 there has been a steady upward trend in the volume of primary energy supply from renewable sources (Fig. 3.8). However, the share of the produced green energy in its total volume remains insignificant and, therefore, insufficient in the context of ensuring the environmental cleanness of the energy industry. In 2018 74.5% of the energy supply from renewable sources was obtained from biofuels and waste, 20.9% — from hydropower sources and 4.6% — from wind and solar sources²².

¹⁹ Wendling Z. A., Emerson J. W., de Sherbinin A., Esty D. C., et al. (2020). *Environmental Performance Index*. New Haven, CT: Yale Center for Environmental Law & Policy. 2020. Retrieved 10 October 2020, from: <https://epi.yale.edu>

²⁰ Kucher A., Kucher L. (2017). *The use of mineral fertilizers in agriculture. Proposition*, 23.01.2017. Retrieved 02 November 2020, from: <https://propozitsiya.com/ekonomika-ispolzovaniya-mineralnyh-udobreniy-v-selskom-hozyaystve>

²¹ Thousand tons of oil equivalent.

²² State Statistics Service of Ukraine (2020). *Economic statistics. Economic activities. Energetics*. Retrieved 10 September 2020, from: <http://ukrstat.gov.ua>

3. Environmental aspects of digitalization of the economy

Whereas in the hydropower industry as a whole within 2007-2018 the situation did not change, consumption of biofuels and wastes doubled, and the share of wind and solar energy increased by dozens of times.

The final consumption over the reviewed period decreased by 40% (in 2018 compared to 2007), and the energy intensity of final consumption — by almost 32% (Fig. 3.7). The energy costs for transportation and distribution are below 4%, which indicates a relatively high efficiency of the logistic infrastructure.

Table 3.7. Environmental Performance Index of Ukraine and reference countries in 2020

Index/Sub-index	Cluster "Leaders"		Cluster "Catchers"		Ukraine, difference in indicators as compared with reference countries				Ukraine, % of average indicators
	Germany	France	Poland	Ukraine	Germany	France	Poland	Average difference	
EPI, points	77.2	80.0	60.9	49.5	-27.7	-30.5	-11.4	-23.2	68.1
Health of ecosystem	89.6	91.5	5.9	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
Waste management	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	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 (stock status, 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 (prevention work)	71.5	81.9	65.4	69.2	-2.3	-12.7	+3.8	-3.7	94.9
Emissions of pollutants (prevention work)	96	100.0	89.6	76.6	-19.4	-23.4	-1.0	-18.6	80.5
Agriculture (eco-cleaness)	61.9	65.2	57.4	79.5	+17.6	+14.3	+2.1	+18.0	129.3
Water resources (wastewater treatment)	97	88.0	60.9	14.1	-82.9	-73.9	-46.8	-67.9	17.2

Source: Wendling Z.A., Emerson J.W., de Sherbinin A., Esty D.C., et al. (2020). Environmental Performance Index. New Haven, CT: Yale Centre for Environmental Law & Policy. 2020. Retrieved 10 October 2020, from <https://epi.yale.edu>

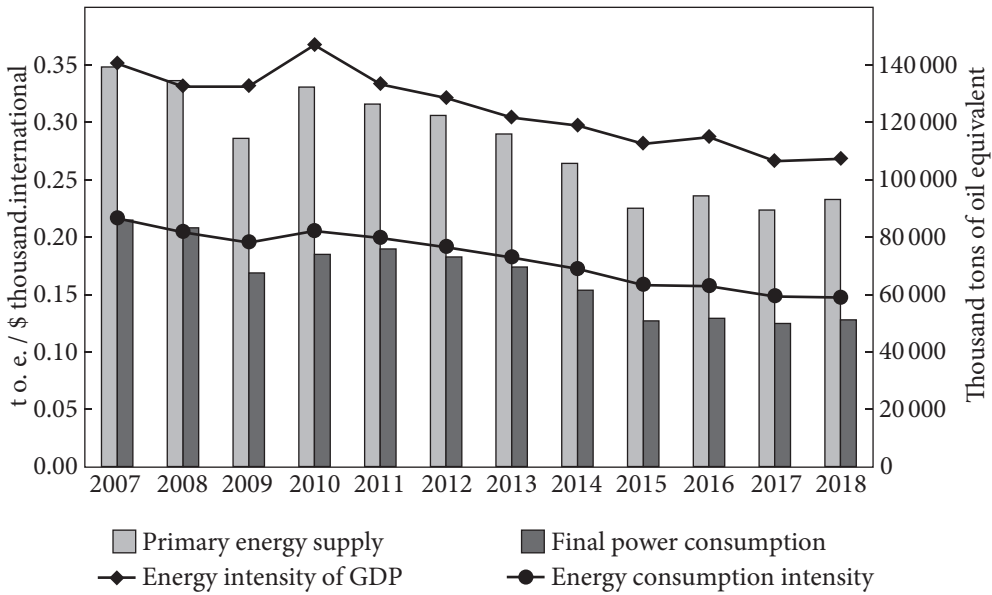


Fig. 3.7. Dynamics of primary energy supply and final energy consumption
 Source: State Statistic Service of Ukraine (2020). Economic statistics. Economic activities. Energetics. Retrieved 10 September 2020, from: <http://ukrstat.gov.ua>

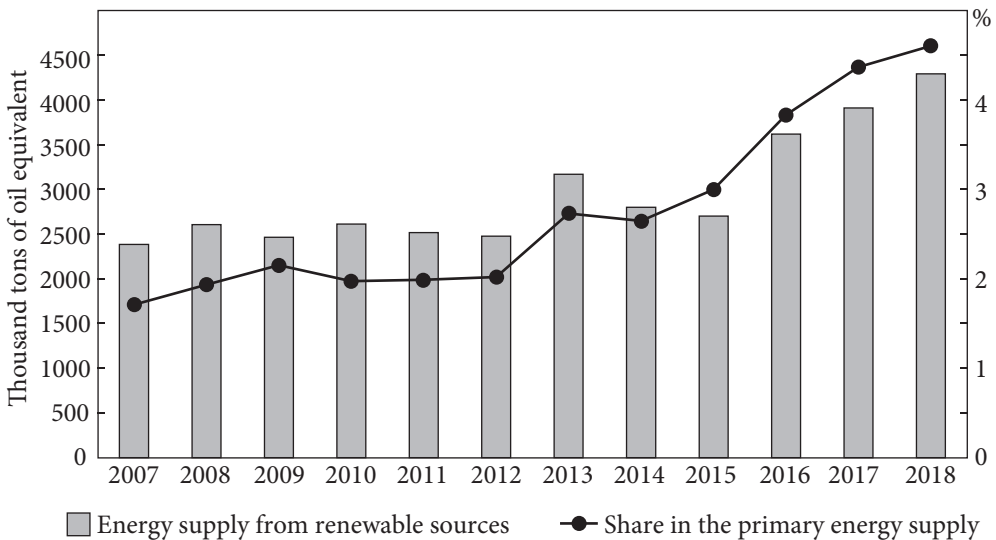


Fig. 3.8. Dynamics of the primary energy supply from renewable sources
 Source: State Statistic Service of Ukraine (2020). Economic statistics. Economic activities. Energetics. Retrieved 10 September 2020, from: <http://ukrstat.gov.ua>

Consequently, despite the absence of statistical information on the direct impact of digital technologies on the dynamics of primary energy supply and final consumption, in the energy industry as a whole there are positive shifts towards its gradual decarbonisation and transition to the principles of a sustainable development. Although, as noted earlier, the overall positive impact remains insignificant against the general background. Judging from the 2018 energy balance, 37% of the produced energy is nuclear, 27% — is energy, obtained from burning natural gas, and 23% — is coal and peat. In the composition of imports, carbon-intensive non-renewable energy resources also dominated: coal and peat (41%) and oil products (30%).

The statistically defined level of greenhouse gas emissions in Ukraine is 126.9-121.3 million tons annually (2004-2019), which corresponds to 13% of the 1990 primary quota established by the "Kyoto Protocol" or 22% of the 2016 new quota within the framework of Ukraine's commitments under the Paris Climate Agreement.

As shown in Fig. 3.9, overall CO₂ emissions demonstrates a downtrend in recent decades, which is mainly due to the decrease in industry production and the number of industrial facilities²³ (Cabinet of Ministries of Ukraine, 2020, pp. 165-166).

In 2017 the GDP, produced per unit of total primary energy supply, corresponded to that of the countries of Eastern Europe, the Caucasus and Central Asia, being significantly inferior to the EU countries (Fig. 3.10).

Within the framework of the Paris Climate Agreement, Ukraine is not to exceed by 2030 the 60% level of greenhouse gas emissions, fixed in 1990²⁴. The implementation of the Agreement also provides for a gradual abandonment of industrial combustion of fossil fuels and, consequently, greenhouse gas emissions into the air. At the same time, according to the statistics for the period 2007-2015, emissions from stationary sources accounted for 83-86% of the total CO₂ emissions in Ukraine. That is, the industrial sector remains the dominant generator of greenhouse gases in the country. Therefore, the expansion of the employment of environmentally efficient digital technologies in industry, including the energy sector, seems to be one of the most important fields of decarbonisation of the Ukrainian economy. However, according to the assessments of individual experts, the prospects for decarbonisation of the Ukrainian industry are not the best because of the high general depreciation of production assets, the lack of sufficient resources to invest into energy-saving projects and weak motivation of economic entities, etc.²⁵

Environment friendly management of electrical and electronic equipment wastes is regulated by the "National Waste Management Strategy in Ukraine until

²³ Since 2014, excluding the temporarily occupied territory of the Autonomous Republic of Crimea, the city of Sevastopol and a part of the temporarily occupied territories in the Donetsk and Luhansk regions.

²⁴ European Commission (2020). *UNFCCC — United Nations Framework Convention on Climate Change*. Retrieved 10 September 2020, from: https://ec.europa.eu/knowledge4policy/organisation/unfccc-united-nations-framework-convention-climate-change_en

²⁵ MIGnews.com.ua. (2011). *Ukraine increased its greenhouse gas emissions*. Retrieved 10 September 2020, from: <https://mignews.com.ua/sobitiya/inukraine/1417924.html>

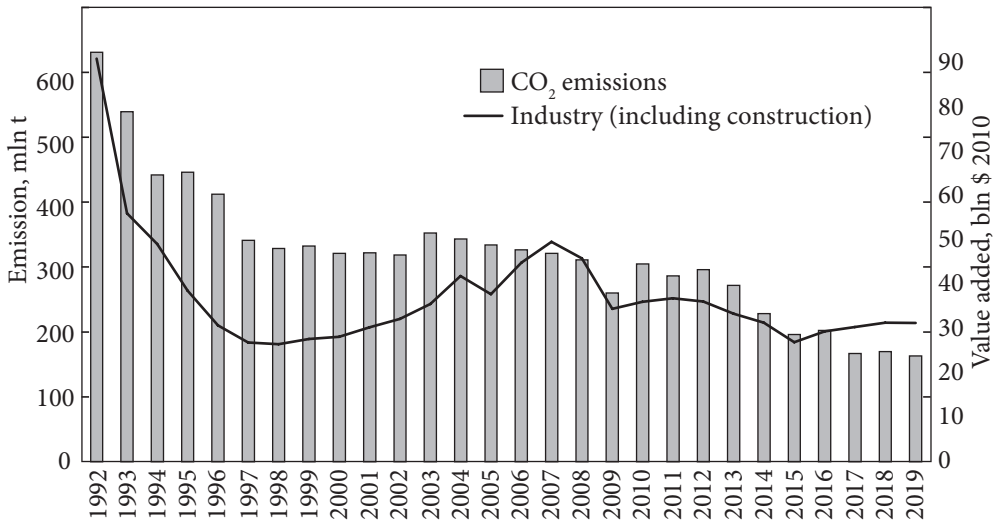


Fig. 3.9. Dynamics of CO₂ emissions in Ukraine

Source: The World Bank Group. (2020). World Development Indicators. Retrieved 10 September 2020, from: <https://databank.worldbank.org/source/world-development-indicators>. Industry

2030" (hereinafter "Strategy 2030")²⁶, the implementation of which is at the stage of harmonization of national legal acts with the European Union ones.

The "Strategy-2030" is acknowledged the urgency of the problems: (1) accumulation of hazardous electronic wastes with a total volume of 5 billion tons (at the current cost of its disposal and storage of about 600 million UAH); (2) low investment activity; (3) lack of the necessary legal base; (4) the absence of clearly defined areas of responsibility for all economic agents. At the same time, it is emphasized that about 70% of substances, hazardous to the environment and human health and present in household wastes, is contained in wastes of electrical and electronic equipment.

The "Strategy-2030" envisages the development of regulations on the electronic information logistics scheme for the extraction and use of natural resources and waste management. Its practical implementation, as well as providing functioning of the information system of e-reporting by business entities in the field of waste management, is planned for 2024-2030. Also, only by this time, it is planned to organize the collection of wastes of electrical and electronic equipment, used batteries and accumulators by utility enterprises. Among the special measures of the "Strategy 2030", it is also planned to develop a targeted draft law, consistent with the Directive 2012/19/EU of the European Parliament and Council of EU of July 4,

²⁶ Cabinet of Ministers of Ukraine (2019). *National strategy for waste management in Ukraine until 2030: Order of the Cabinet of Ministers of Ukraine from February 8, 2017 No. 820-r*. (Edited 12.24.2019). Retrieved 10 September 2020, from: http://search.ligazakon.ua/l_doc2.nsf/link1/KR170820.html

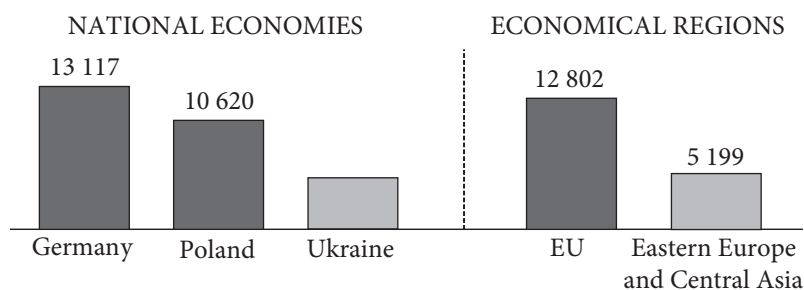


Fig. 3.10. Energy productivity, GDP per unit of total primary energy supply (2010-2017)

Source: Cabinet of Ministers of Ukraine, 2020, p. 166.

2012 on wastes of electrical and electronic equipment (WEEE) and best European practices, including the development of mechanisms for the environment friendly treatment of e-wastes.

For a quantitative assessment of the efficiency of the "Strategy-2030" implementation, the indicator "Creation of centres (units) for wastes collection (primarily wastes of electrical and electronic equipment) for their reuse-aimed processing" is provided. In 2016 (year of the strategy start) there were no such centres in Ukraine.

In 2020, 21 enterprises, located in the cities of Kyiv (8), Kharkiv (4), etc.²⁷, provided services on recycling (processing for reuse) and disposal of various types of electronic wastes in Ukraine. The main types of the most demanded electronic wastes include office and computer equipment, equipment for ICTs and telecommunications (9 enterprises accept); plastic cartridges for laser printers (9 enterprises); used electric accumulators and batteries (4 enterprises).

A special normative document for treatment of electrical and electronic equipment wastes is an order of the Ministry of Regional Development, Construction and Housing-Communal Services²⁸.

However, the current forms of statistical accounting do not make it possible to create a complete structured database on the volume and intensity of accumulation of this type of wastes, their qualitative composition, territorial distribution, efficiency of disposal, etc. That is why the system of accounting for wastes, associated with digital technologies, in Ukraine needs improving.

Hence, as the results of analysis performed show, digitalization of the economy cannot yet be considered as a reliable way to solve environmental problems in Ukraine. Firstly, "digit" alone, without development of national production on the

²⁷ KOMPASS. (2020). *Online reference book of enterprises*. Retrieved 06 September 2020, from: <https://ua.kompass.com/a/recycling-recycling-recycling-services/72510/>

²⁸ Ministry of Regional Development, Construction and Housing-Communal Services of Ukraine (2013). *On approval of methodical recommendations for collecting wastes of electrical and electronic equipment contained in household wastes: instructions from 22 September 2013 number 15*. Retrieved 10 September 2020, from: http://search.ligazakon2.ua/f_d_d/link1/FIN84029.html

innovative basis and implementation of modern manufacturing processes and products, is not efficient enough. And with all this, the country has big problems (Vishnevskiy, Kniazev, 2018).

Secondly, the possible environmental consequences of digitalization of the economy require further in-depth analysis, since long-term positive effects of digitalization in the specific context of the national economy are not obvious (like for many countries among the "Catchers"), whereas the negative effects may be serious. Ukraine, as a country in Eastern Europe, is already part of the e-wastes' receiving region. In addition, the introduction of new digital technologies, including such critical for the Internet of Things as 5G, may have undesired consequences even for countries with a high level of development and strict environmental standards, not to mention Ukraine with its current poor institutional reality. It is impossible to rely only on a profit-driven business in solving this problem. It is therefore required to develop and implement a special national academic program for assessing various aspects of the impact (abiotic, biotic, anthropogenic) of the latest digital technologies on the environment.

Its important element may be the formation of a representative database on the status and parameters of digitalization of the Ukrainian economy, including the intensity of R&D in the digital sector, the density and productivity of digital technologies in industry, the achieved environmental effect (balance of energy consumption and energy saving), carbonization or decarbonisation, the dynamics of accumulation, transport and utilization of e-wastes, etc. It is also advisable to take into account the already existing approaches to the assessment of an economy's digitalization, in particular, the Digital Economy and Society Index (DESI), adopted in the European Union²⁹, which integrates several different indicators of the development of digital Europe and tracks the evolution of the EU countries in terms of their digital competitiveness.

Thirdly, it is important to make the digitalization program part of the overall strategy for sustainable development of national manufacturing on an innovative basis, including the formation of strong development institutions similar to those already successfully applied in other countries with emerging economies (Kulakova, Koverzneva, 2016).

In this regard, it is important to adapt the European public-private partnership practices, which have proven their ability to select and finance long-term and important for national economies projects.

More than 20 billion euro had already been invested into the EU Single Digital Market by 2020³⁰.

²⁹ DESI was first calculated in 2014; in 2018, in addition to the 28 EU countries, DESI was temporarily expanded to 17 non-European countries (within the framework of the International Digital Economy and Society Index, I-DESI), including the USA, Canada, China, Japan, Brazil, South Korea, Turkey and Russia.

³⁰ European Commission. (2018). *Public Private Partnerships – Shaping Europe's digital future*. Retrieved 06 November 2020, from: <https://ec.europa.eu/digital-single-market/en/public-private-partnerships>

The current EU public-private partnership projects cover such important fields as cybersecurity of the energy, transport and financial sectors, as well as the public health sector, high performance computing; robotics; the fifth-generation mobile communications (5G), development of electronic components and embedded software. It is emphasized that their strategic goal is to help European industry to meet the growing global consumer demands for "greener", more personalized and high-quality products through providing the necessary transition to a demand-driven industry with less wastes and better use of resources³¹. It is obvious that the Ukrainian industry needs similar support as well.

³¹ European Commission. (2018). *Public Private Partnerships — Shaping Europe's digital future*. Retrieved 06 November 2020, from: <https://ec.europa.eu/digital-single-market/en/public-private-partnerships>



4

PROBLEMS OF ASSESSMENT OF DIGITALIZATION PROCESSES AND THEIR IMPACT ON ECONOMIC DEVELOPMENT



4.1. ANALYSIS OF METHODOLOGICAL APPROACHES TO MONITORING AND ASSESSMENT OF DIGITALIZATION PROCESSES

The digital revolution has covered all countries of the world. The digitalization of many sectors of the economy continues, revealing positive and negative consequences for society and business. Therefore, many countries and their associations have been developing and improving their own strategies for the development of the digital economy for many years on the basis of methods for monitoring and evaluating it.

In recent years, several integral indicators (indices) have been developed, which characterize digitalization processes and their impact on the economy. They include, in particular, the following: Digital Economy and Society Index (DESI) and Digital Skills Indicator (DSI) from the European Commission, ICT Development Index (IDI) from the International Telecommunication Union (a specialized division of the United Nations in the ICT), Digital Adoption Index from the World Bank and Microsoft Corporation. Private companies also develop their own indices (for example, such as Digital Economic Opportunity Index from Accenture and Oxford Economics, Enabling Digitalization Index from the insurance company Euler Hermes, Digitization Index (DiGiX) from the banking company Banco Bilbao Vizcaya Argentaria, Digital Country Index from the firms Bloom Consulting and D2-Analytics).

The Digital Economy and Society Index (DESI) is an index that summarizes digital productivity indicators in the European countries. It consists of an assessment of five factors with a different set of indicators:

- Connectivity, measured by the deployment of broadband infrastructure and assessing its quality (8 indicators).
- Human capital — skills needed to take advantage of digital opportunities (6 indicators).

- Use of Internet services – assessment of various actions of people in the network (video content, online shopping, web banking, etc.) (11 indicators).
- Integration of digital technologies — digitalization of business processes and the use of e-commerce (7 indicators).
- Availability and development of digital public services (e-government, digitization of public services) (5 indicators).

More detailed information on the content of these indicators, the number of indicators, subjects and sources of information is presented in the methodological manual "DESI 2020 Digital Economy and Society Index. Methodological note"¹.

The mentioned indicators differ in weight:

- Internet connection — 25%.
- human capital / basic skills — 25%.
- Internet use — 15%.
- Digitalization of business processes — 20%.
- E-government — 15%.

According to the DESI assessment method, Internet connection and digital skills are considered to be the most appropriate measures of digitalization, since they represent the infrastructure of the digital economy and society. Therefore, their impact is rated higher than, for example, the use of the Internet by citizens and digital public services.

The main requirements for collection of data using the DESI method are: regularity (annually or at least with a predetermined frequency); relevancy (indicators should be relevant to specific policy areas); the index should not be redundant (the set of indicators should not be overloaded).

According to the methodological manual for calculation of this index, updates and data corrections are allowed.

For the correct calculation of DESI, the set of indicators, expressed in different units of measurement, is normalized using the "min-max" method, which consists of a linear projection of each indicator with a scale from 0 to 1. For indicators with a positive direction, 0 (zero) in the normalized scale is attached to the minimum value of the indicator, while 1 (unit) — to the maximum.

This index allows one to conduct four basic types of analysis of individual EU member states, namely: overall assessment of the effectiveness of digitalization; analysis of changes in the digitalization scale (geographic diffusion); analysis of the digitalization development over time; comparative analysis of the digitalization stages.

For example, according to the Digital Economy and Society Index-2020, Denmark, Sweden, Finland and the Netherlands have the most advanced digital economies in the EU for several years, while Bulgaria, Romania, Greece and Italy have the lowest scores².

¹ European Commission (2020). *The Digital Economy and Society Index (DESI) Methodological note*. Retrieved 30 November 2020, from http://ec.europa.eu/newsroom/dae/document.cfm?doc_id=67082

² European Commission (2020b). *Digital Economy and Society Index (DESI) 2020 — Shaping Europe's digital future. Thematic chapters*. Retrieved 30 November 2020, from https://ec.europa.eu/newsroom/dae/document.cfm?doc_id=67086

The availability of such information on the development of digitalization in Europe made it possible to reveal that all residents of the EU are provided with basic fixed broadband Internet access, and very high bandwidth networks (VHCN) from 20% (Greece, Great Britain, Cyprus and Austria) to over 90% (Malta, Denmark and Luxembourg). However, only 58% of citizens have basic digital skills, and business experiences a shortage of ICT specialists.

In the field of digital technologies integration, the leader in using Big Data is Malta (24% of companies), in implementing cloud services – Finland (50% of companies). At the same time, the report notes that there is a significant gap between the digitalization of large enterprises and small businesses.

E-government has been successfully implemented in Estonia, Spain and Denmark (digital public services were in demand by over 90% of Internet users), while Greece and Italy have low ratings in the EU (below 40% of Internet users). The quality of public services to enterprises for starting business and conducting regular business transactions, available online, has been improved in almost all EU member states.

Thus, having information about the level of digitalization in the EU countries, each EU member country or a country, wishing to join the EU, can make decisions on the development or improvement of certain issues of national programs and strategies in the field of digital economy development.

The Digital Skills Indicator (DSI) was developed to measure the extent of digital competence in Europe as one of the Digital Agenda events for Europe. This index was created on the basis of the Digital Competence Framework through analysing the use of ICT by households and individuals.

DSI covers four fields of digital competency, namely: information literacy, communication, content creation and problem solving through the use of digital technologies:

"Information literacy" includes the ability to formulate requests in the Internet, find digital data, information and Internet content, distinguish between verified and false information, store and use digital data, information and content.

"Communication" reflects the ability to interact, communicate and collaborate by means of digital technologies (including through the provision of public and private digital services), manage digital identity and reputation.

"Creation of digital content" characterizes the level of the population's skills in creating and editing digital content, improving and integrating information into the existing stock of knowledge and understanding the way of copyrights, licenses, etc.

"Security and problem solution" is an indicator of protecting devices, personal data and privacy in a digital environment, the ability to identify needs and problems, as well as to remove problematic situations³.

According to the manual, due to the fact that the nature of the analysis of ICTs does not allow assessing the level of qualification of each action, three skill levels ("absent", "basic" and "above basic") were selected and calculated for each of the four

³ European Commission (2015a). *The Digital Competence Framework 2.0. EU Science Hub*. Retrieved 24 September 2019, from at: <https://ec.europa.eu/jrc/en/digcomp/digital-competence-framework>

parameters, and the overall composite indicator was calculated using a similar logical approach. This methodology was first applied in 2015. The results of calculating the general DSI are used by the European Commission as part of the Digital Economy and Society Index (DESI, see above), and are also presented in the visualization tools of the digital program. For more information on the methodology for calculating this index, see "Digital Skills Indicator derived from Eurostat survey on ICT usage by individuals. Methodological note 2015" (European Commission, 2015b).

Preferred sources of information for calculating indices, elaborated by experts of the European Commission, as well as monitoring the advance of policies, related to the strategy for the development of a single market for digital technologies in Europe, are as follows: Eurostat studies on the ICTs' application in households and by individuals, as well as on the ICTs' in e-commerce at enterprises; statistical studies of Eurostat in the field of ICTs; telecommunications market data, provided by national regulatory authorities; periodic studies, carried out by order of the European Commission on fields, indicators (where there is no official statistics) and separate researches on specific issues.

Analysis of methods for assessing digital transformations in the EU via the two abovementioned indices showed that the lack of data (indicators) in some countries or the absence of data for a certain period of time can be attributed to the shortcomings and problems of these assessments, which significantly affects the completeness and the possibility of correct use of calculations results.

In recent years, experts from the European Commission have been paying significant attention to the organization and systematization of data on the development of digital technologies in the EU member countries. For example, the online system Digital Agenda Scoreboard key indicators⁴ has already been developed, where more than 200 indicators (at the end of 2020) have been selected, divided into thematic groups that illustrate some of the key aspects of the development of the European information society: telecommunications sector, broadband coverage, Internet speed and prices, mobile market, the Internet, audiovisual and media content, Internet services, e-government, e-commerce, e-business, digital skills, ICT experts, ICT usage in the education and healthcare systems, security and digital privacy, ICT sector development, EU digital research and development programs, women in the digital space.

Also, a methodological base for the correct use of the resource has been developed: information has been collected on the sources, definition and scope of using each indicator, as well as additional information, for example, about indicators or common variables, removed from the program. The program allows visualizing the dynamics of indicators and indicators throughout the countries, compare them and their dynamics, build tables of country ratings by the thematic group of indicators, etc.

Another index — the ICT Development Index — made by the UN specialized department in the ICT field, unites 11 indicators. It was used to monitor and compare

⁴ European Commission (2019a). *Digital Agenda Scoreboard key indicators — Digital Scoreboard — Data & Indicators*. Retrieved 24 September 2019, from https://digital-agenda-data.eu/datasets/digital_agenda_scoreboard_key_indicators/indicators

the level of ICT development among countries from 2009 to 2017. This index was formed from a limited set of data, collected by countries of the world at all levels of ICT development.

Analysis of the methodology for calculating this index "The ICT Development Index (IDI): conceptual framework and methodology"⁵, showed that to assess the level of digitalization of a country's economy indicators, similar to those, proposed by the European Commission, were used with minor variations.

The advantages of the IDI calculation method include the fact that this index is used by many countries as a statistical tool for measuring the level of accessibility and use of ICTs, assessing the effectiveness of sectoral policy and comparing the country's competitiveness in the context of digitalization, which allows comparative analysis and assessment of each country's development.

A disadvantage of this methodology is the fact that the system of indicators does not include indicators of financial accountability, that is, indicators that reflect income and expenses, related to the ICT use (for example, investments in the ICT sector), which can be used to define the economic efficiency of digitalization in each country, households' expenses on the use of digital technologies, etc. For example, according to the Suncorp Bank report "Cost of Being Digitally Savvy", Australians (18-64 years old) spent about \$ 37 billion per year on technological services and digital devices. This amounts to almost \$ 2.5 thousand per person⁶.

In 2017, the set of ICT Development Index indicators was revised and supplemented with a number of new ones. However, the release of the new ICT Development Index was hindered by problems with the availability and quality of data for individual indicators. In 2020, the reference document "ICT Development Index 2020: A proposal" was developed, in which the problems of this index were analysed, and proposals were made for changes in the methodology for its calculation, which minimize statistical inconsistency and increase the reliability of the results⁷.

The Digital Adoption Index is an index from the World Bank, designed to measure the level of prevalence of digital technologies in three segments of the economy: society, business and government. Accordingly, it is based on three sub-indices, related to population, business and government, which have the same weight. Each sub-index is the average of some normalized indicators, which measure the levels of ICT adoption by the corresponding groups, such as increasing productivity and accelerating business growth, empowering and improving the welfare of people, as well as increasing efficiency in the provision of public services that became possible due to the use of digital technologies (for example, the indica-

⁵ ITU (2018). *The ICT Development Index (IDI): conceptual framework and methodology*. Retrieved 24 September 2019, from <https://www.itu.int/en/ITU-D/Statistics/Pages/publications/mis2017/methodology.aspx>

⁶ Suncorp (2019). *Tech-savvy Australians spending billions*. Retrieved 24 September 2019, from <https://www.suncorp.com.au/about-us/news/media/tech-savvy-australians-spending-billions.html>

⁷ ITU (2020). *ICT Development Index 2020: A proposal*. Retrieved 5 December 2020, from https://www.itu.int/en/ITU-D/Statistics/Documents/events/egti2020/IDI2020_BackgroundDocument_20200903.pdf

tors "share of enterprises with websites", "number of protected servers", "download speed", "public online services", "access to the Internet at home", etc.)

The Digital Adoption Index was originally developed in the frame of the "World Development Report 2016: Digital Dividends" and subsequently updated on the basis of the 2016 data. At present, the calculations of this index are available only for 2014 and 2016, efforts are made to attract interested organizations to improving the Digital Adoption Index methodology⁸.

Analysis of the methods and calculation results for the abovementioned indices made it possible to identify the reasons, why many of them did not receive further development and application. Although most of the collected indicators were used in reviews and reports on digitalization (in the world and in individual countries, fields of activity, studies on the potential and development of ICTs, the modern digital market and trends in the development of digital technologies), there have remained many unresolved issues, regarding the completeness of databases and periodicity of such assessments.

The formation of the new direction of statistical researches proceeds in a rapidly changing conditions: every year the digital economy receives new advanced tools that significantly transform approaches and methods for measuring the impact of digitalization on the economic performance. Therefore, the Declaration of G20 Digital Economy Ministers Meeting from 22 July 2020 endorses the G20 Roadmap for the creation of a common measurement system for the digital economy, which will help close measurement gaps, improve comparability of indicators and strengthen statistical capacity in the G20 countries and beyond. The Declaration also notes that new business models, based on digital transformation, pose various measurement challenges, related to data, digital services and digital platforms. Therefore, the participants of the G20 Digital Economy Ministers Meeting call for discussion and study of indicators to take into account various measurement problems, provide guidance on measurement where possible and recognize efforts to integrate the digital economy into national accounts and other statistical systems where needed⁹.

The main disadvantage of indices and indicators of the development of digitalization from individual organizations is order for work (researches), which leads to specificity of information collection, since, in addition to publicly available statistical data, its sources are also the results of questionnaires and special studies from private analytical companies. This reduces the possibility of performing comparative analysis and assessment across countries of the world, conducting long-term observations of the development of the digital market, etc.

In general, the analysis showed that, on the one hand, the developed digital transformation indices make it possible to comprehensively analyse the degree and

⁸ The World Bank (2016). *Digital Adoption Index*. Retrieved 10 December 2020, from <https://www.worldbank.org/en/publication/wdr2016/Digital-Adoption-Index>

⁹ G20 Information Centre (2020). *G20 Digital Economy Ministers Meeting. Ministerial Declaration*. Retrieved 5 December 2020, from http://www.g20.utoronto.ca/2020/G20SS_Declaration_G20_Digital_Economy_Ministers_Meeting_EN.pdf

dynamics of the development of digital opportunities of various countries' economies. On the other hand, there are significant difficulties in monitoring and measuring the level of development of the digital economy. Despite the presence of digitalization indicators in industry, education and employment, finance and science, the calculation of indicators of new technologies, skills, abilities and competencies requires further improvement, which could provide correct comparisons among countries. Problems also remain with the analysis of the scale of use and assessments of the power of influence on the dynamics of value added of such digital technologies as machine learning and artificial intelligence, the Internet of Things, 3D printing, robotics, blockchain, Big Data analytics, both in the economy as a whole and in its individual sectors.

Some of the analysed methods do not contain indicators, related to the export of digital economy products (ICTs, software, equipment for using and analysing Big Data, blockchain technology, etc.), which are important in the context of re-globalization of economic processes and the formation of new international chains and networks.

The use of various non-unified sources of information makes the use of individual calculation results limited or impossible.

A common disadvantage of many of the analysed methods for defining the level and development of the digital economy is that the calculation results do not sufficiently take into account the dynamics of the general indicators of the social and economic development of countries, their demographic, cultural and institutional characteristics.

Obviously, this new direction of economic researches is just being formed, and, therefore, it takes some time to create initial items and developments that have operational significance and may be brought in line with the requirements of a correct comparative analysis of social and economic systems and recognized principles of economic comparative studies (Voskresenskaya, 2017).

4.2. EVOLUTION OF MATHEMATICAL MODELS OF ICT IMPACT ON ECONOMIC DEVELOPMENT

The issue of defining the impact of digital technologies and ICTs on economic development (economic growth and labour productivity) is not new. ICTs and digital technologies, their development in a broad sense can be considered as one of instances of scientific and technological progress (STP). Attempts to assess the power of the influence of STP and investment in it on the economic development were undertaken in R. Solow's researches, which have already become classical.

In 1956, R. Solow proposed to expand the Cobb-Douglas production function by taking into account neutral technological changes (Solow, 1956).

As known, the Cobb-Douglas production function has the form

$$Y = F(K, L), \tag{4.1}$$

where Y is the manufacturing of products; K is the accumulated capital; L is the labour, involved in the manufacturing.

In such a model, the change in the production volume occurs by increasing (decreasing) the volume of one of the production factors (labour or capital) or two factors simultaneously.

R. Solow in (Solow, 1956, p. 85) noted that, in addition to these two factors, technological changes and STP can affect the volume of manufacturing as well. In accordance with this, the classical Cobb-Douglas function (F. 4.1) changes its form to

$$Y = A(t)F(K, L), \quad (4.2)$$

where $A(t)$ is a variable, reflecting the impact of STP on production (technological variable).

The technological variable may change exponentially and, accordingly, can be described as

$$A(t) = e^{gt},$$

where t is the time factor; g is an indicator of the technological change rate.

In the proposed extension of the Cobb-Douglas model, R. Solow notes that, in his opinion, some arbitrary changes in engineering and technologies will not create a significant influence on manufacturing, and, therefore, they may be ignored. The direct influence of STP on an economy (the simplest case) is gradual, smooth and can be defined simply by multiplying the traditional Cobb-Douglas function by the scale factor, as presented in F. 4.2.

Hence, R. Solow put forward a hypothesis about the neutral influence of STP on the manufacturing. He also notes that his modifications of the Cobb-Douglas production function were developed within the framework of neoclassical economic theory based on the premise that there is full employment in an economy. This means that even when one of the production factors changes, some balance will be established over time between them (Solow, 1956, p. 91).

In 1957, in his following paper (Solow, 1957), R. Solow made an attempt to define the power of the STP impact on economic development, in particular — to calculate the fluctuations in output per employee, caused by technical changes. At the same time, he again took as a basis the modified Cobb-Douglas production function, which takes into account technological changes. But, unlike his previous paper, R. Solow used econometric tools to find the production function coefficients and assess the impact of STP on the labour productivity.

To solve the problem, R. Solow differentiated F. 4.2 and divided this equation by Q^{10} . As a result of these changes, F. 4.2 was transformed into

$$\frac{\dot{Q}}{Q} = \frac{\dot{A}}{A} + \frac{\partial f}{\partial K} \frac{\dot{K}}{Q} + A \frac{\partial f}{\partial K} \frac{\dot{L}}{\dot{Q}}. \quad (4.3)$$

¹⁰ In the original paper (Solow, 1957), Y was replaced by Q , therefore, the original Solow's designations will be used in the text below. That is, we accept that $Y = Q$ and the rest of the designations in F. 4.2 remain unchanged.

For the calculations, statistical data were used that characterize the US economy for the period 1909-1949: output per unit of labour, capital per unit of labour and the share of capital in the total cost of property.

In F. 4.3, the output is understood as a gross national product (GNP). The original statistics and, accordingly, calculations were limited to non-state economic activity excluding agriculture.

R. Solow believed that such an approach allows bypassing the problem of defining the output by the public sector of the economy and make the initial statistical data more homogeneous. Thus, in the Solow model (F. 4.3), in fact, an assessment of changes in GNP under the influence of STP was performed relatively to man-hours of labour, spent in the private sector of an economy (except for agriculture), that is, an assessment of changes in labour productivity under the influence of STP in the private sector of the US economy.

R. Solow noted that the statistical data, necessary for constructing his model, were rather rough, and some were absent at all. Therefore, he corrected and changed the available information for his own needs. That is, as the author himself noted, was "...undoubtedly wrong" (Solow, 1957, p. 314).

Upon performing all the calculations, R. Solow revealed that STP has some positive effect on manufacturing growth: on average, over 40 years (1909-1949) technological progress contributed to the increase in labour productivity in the private sector of the US economy by 1.5% per year. However, global crises (World wars, the Great Depression) made their own adjustments. Taken together, the abovementioned allowed R. Solow to draw a conclusion that STP has neutral effect on production.

R. Solow's papers (Solow, 1956; Solow, 1957) undoubtedly became an important milestone on the way to the defining of the STP impact on production, moreover, one of the first in this direction. However, if we evaluate them from the standpoint of modern economic science and statistics, we can highlight a number of shortcomings, which should be taken into account, when this model is used in current conditions.

(1) R. Solow noted that he faced very approximate statistical information, which he had to adjust for his needs, and when calculating the share of capital in the total cost of private sector property, he did not take into account depreciation, because neither the corresponding statistical information, nor conventional methods for defining the depreciation level were available at that time.

For over 60 years that have passed since the publication of R. Solow's articles, the methods for collecting and processing statistical data, as well as their accuracy, have been significantly improved, which creates preconditions for obtaining more accurate results in modelling real economic situations.

(2) In the models, used by R. Solow, the inflation factor was not taken into account and the statistical information for the model was given not in comparable, but in current prices. Accordingly, this can exert a significant effect on the simulation results, since the influence of the inflation factor can grow over the simulation period.

(3) R. Solow chose a rather long period of time for modelling, namely 40 years. From the statistics standpoint, such a long period should ensure a better match of the

simulation results to reality than a shorter period. However, real life and processes of national economies' development differ significantly from mathematical and statistical models. So, during this period, the United States faced the consequences of the First and the Second World Wars, the Great Depression, the Spanish influenza pandemic, which significantly affected the number of employees, the ability of the private sector to invest in capital and the total volume of production by the private sector. The influence of these force majeure circumstances was partially reflected in the simulation results, obtained by R. Solow. However, in order to prevent the accumulation of statistical errors, it seems more appropriate for modelling to choose periods with a relatively stable situation.

(4) The R. Solow model is based on the assumption that technologies and STP evolve gradually. But, as known from the history, for example, of the First Industrial Revolution, this assumption is not always true (not for all the initial premises): technologies and STP as a whole can develop in leaps¹¹.

Since the model deals with the economy of a country as a whole, and not with an individual industry or even branches, these abrupt changes can be partly smoothed out due to the simultaneous existence of many technological curves in economic sectors. However, as R. Solow notes (Solow, 1957), within 1943-1949 there was a sharp (compared to the rest of the period) growth in manufacturing, which he explained by poor-quality statistics or excessive use of capital during World War II. At the same time, such a shift in the production curve may also indicate a transition to a new technological curve of the country's entire economy.

In 1987, the rapid development of information technologies and digital equipment led to another surge of scientific interest in modelling the impact of STP, in particular — electronics and software products, — on the production. Once again, the initiator of these studies was R. Solow.

In his review for the book by S.S. Cohen and J. Zysman "Manufacturing Matters: Myth of the Post-Industrial Economy" (Cohen, Zysman, 1987), R. Solow fairly reproaches the authors that they at first put forward unsubstantiated hypotheses, and then groundlessly accept them as correct. One of these hypotheses is the assertion that the development of electronic equipment and technologies and their spread stimulates an increase in labour productivity. Unfortunately, this was not observed in the United States. Although, as the authors of the book emphasize, the indicated techniques and technologies themselves contributed to such an increase. That is, we can conclude that, by the authors, the problem with insufficient growth in the level of productivity lies rather in something else than in hardware and software.

R. Solow objects to this: "You can see the computer age everywhere, but in the productivity statistics" (Solow, 1987, p. 36). This expression, somewhat taken out of

¹¹ In the book "Innovation: The Attacker's Advantage", published almost 30 years after R. Solow's article (1957), its author – R. Foster – described a gradual technological development as a movement along an S-shaped technological curve, and an abrupt, uneven development as a technological gap and transition to another S-shaped technological curve (Foster, 1986, pp. 87-112). Further, when analysing models, the terminology of technological development proposed by R. Foster will be used.

context, later was named "Solow paradox" and became a kind of trigger that caused a surge of scientific publications, the authors of which, using statistics and economic and mathematical models, tried to confirm or refute R. Solow's opinion and assess the impact of ICTs, computer and other digital equipment on a country's economy as a whole or on certain aspects of its development (GDP growth, value added, labour productivity, etc.). Some of these works will be analysed further.

4.3. ANALYSIS OF MODERN MODELS OF ICT IMPACT ON ECONOMIC DEVELOPMENT

First of all, it should be noted that, in addition to economic and mathematical models, the authors of which tried to verify, refute or confirm the Solow paradox, there are works that, from the standpoint of logic, explain, why statistics on productivity does not always reflect the positive impact of investments in the ICT sector development on productivity.

A serious research in this direction was carried out by J. Triplett, who explained how the unaccounted factors, indicated by him, affect results of economic and mathematical modelling by a number of other authors and prolong the life of the Solow paradox (Triplett, 1999).

This author, in particular, pointed out the following.

1. *You do not see computers "everywhere," in a meaningful economic sense.* Since the end of the 90s (when the paper by J. Triplett was published) till today the manufacturing of computers and other electronic equipment for information processing has accounted for a relatively small share of GDP, and they themselves occupied a small part of fixed assets. The author notes that according to some estimates, the share of computers and electronic equipment in fixed assets of US enterprises in 1993 was less than 14%. Therefore, when creating economic and mathematical models, they simply "dissolved" in the total assets, which did not allow obtaining correct results (Triplett, 1999, pp. 311-313).

2. *You only think you see computers everywhere.* J. Triplett noted that in the statistical reports released by the US government, at least until 2000, the price index was declining too quickly, therefore, when defining computer production, a distorted impression about its rapid growth is formed (Triplett, 1999, pp. 315-318).

3. *You may not see computers everywhere, but in the industrial sectors where you most see them, output is poorly measured.* Examples of such TEAs were primarily insurance and financial institutions. In these TEAs, hardware and software were used actively and in large amount, but at the same time, the exact concept of products in these activities was barely defined (Triplett, 1999, pp. 318-321).

4. *Whether or not you see computers everywhere, some of what they do is not counted in U.S. Department of Labour economic statistics* (Triplett, 1999, pp. 321-322). Much of today's hardware and software innovations are focused on making them easier to use. However, such user-friendly innovations (at least in software) usually require more power of the electronic devices, on which they are installed: more RAM

and hard disk capacity, more operations per unit of time, performed by the processor, etc. All these characteristics are not displayed, at least in that part of economic statistics which concerns labour productivity. It is also quite difficult to assess in reality how useful such "convenient" innovations are, how they contribute to an increase in labour productivity, whether the time and money spent on their creation are justified in terms of the impact on labour productivity, how much time and effort are needed to master them by employees, etc.

In addition, there is one more aspect to consider. In the context of ICTs' global spread, enterprises have ample opportunity to transfer manufacturing, as well as parts of financial transactions, to other countries in order to reduce tax liabilities and other expenses.

Therefore, the costs of innovations in the ICT field, as well as the results, obtained with them, can be reflected in the statistics of other countries, where production or financial transactions are actually carried out, and not in a country, where the parent company is located, which directly manages the financial processes of such innovations and production. Since neither national statistical services nor economic and mathematical models for assessing the impact of ICTs on the economic development of individual countries, as a rule, take into account such behaviour of enterprises, this can also affect the reliability of the results obtained.

5. *You do not see computers in the productivity statistics yet, but wait a bit and you will* (Triplett, 1999, p. 310). When describing the situation with the latest technologies and their reflection in statistics, it should be borne in mind that, firstly, new processes take time to refine them and bring them to the stage of a really useful product. Accordingly, at this stage of their life cycle (that is, when the technology is at the S-curve bottom), one should not expect a high return on investments or a strong positive impact on economic indicators. After some time, when the ascending section of the S-curve begins, the economic results from new equipment and technology become more evident, which can be reflected in statistics.

Secondly, like any new phenomenon, since the emergence of the newest ICT product and even for a certain period of time (different in various cases), not only there has been developed no methodology for collecting and analysing statistical data concerning it, but even no corresponding terminology. A typical example is the definition of the concepts "ICTs", "ICT sector", etc., which was mentioned earlier. Accordingly, the correct modelling of the impact of those processes, in relation to which there are so many uncertainties, is a very difficult task. Currently, in the field of ICTs and digital development, the situation with terminology and statistical data is clearer and more understandable than 10-20 years ago (but the problems remained). Therefore, we can expect that modern economic and mathematical models for assessing the impact of ICTs on economic development will be more elaborated, especially if the time lag between the development of a new technology and its widespread use will be taken into account.

6. *There is no paradox: some economists are counting innovations and new products on an arithmetic scale when they should count on a logarithmic scale.* In fact, the former

gives us the ability to account for the number of "new things". Therefore, comparing the current situation with the situation in the past, some researchers get the impression that newer products were created earlier with less expenses, so the Solow paradox is confirmed. However, it is important to take into account the real rate of technological changes, which can be done by constructing logarithmic dependences. In this case, the assessment of the situation can be reversed (Triplett, 1999, pp. 326-328).

The above considerations were reflected, to one or another extent, in newer economic and mathematical models, which will be discussed later.

One of the most famous (at least, if to judge by citation statistics) among the economic and mathematical models of defining the impact of ICTs and ICT equipment on economic development is the econometric model, proposed by D. Jorgenson, M. Ho and K. Stiroh (Jorgenson, Ho, Stiroh, 2003; Jorgenson, Stiroh, 2000).

The basis of this model is the Cobb-Douglas production function, modified by R. Solow. The further modification by authors consisted in a greater detailing of the constituent parts of the production function and its logarithmization. In particular, these scientists represented the volume of output (Y_t) as a function of investment (output of investment goods) in a particular year (I_t), the accumulated capital (K_t), labour, involved in production (L_t), and consumption (output of consumer goods) (C_t) (Jorgenson, Stiroh, 2000, p. 6). By Jorgenson-Stiroh, the resultant production function is as follows:

$$\overline{w_{I,t}} \Delta \ln I_t + \overline{w_{C,t}} \Delta \ln C_t = \overline{v_{K,t}} \Delta \ln K_t + \overline{v_{L,t}} \Delta \ln L_t + \Delta A_t, \quad (4.4)$$

where A_t is variable, related to the effect of ICTs on production output (technological factor); $\overline{w_{I,t}}$ is average share of investments per nominal yield; $\overline{w_{C,t}}$ is average share of consumption per nominal yield; $\overline{v_{K,t}}$ is average share of capital per nominal yield; and $\overline{v_{L,t}}$ is average share of labour input per nominal yield; $\overline{w_{I,t}} + \overline{w_{C,t}} + \overline{v_{K,t}} + \overline{v_{L,t}} = 1$; symbol Δ denotes the first derivative.

With this model, D.W. Jorgenson and K.J. Stiroh assessed the impact of labour, capital, information and other technologies on the US economic growth. The calculations were performed for the period 1973-1998 and the country's economy as a whole. The cost of software and hardware was included in the cost of capital as a whole. Statistical information was brought to a comparable form (1996 is basic) (Jorgenson, Stiroh, 2000, p. 8).

Upon transforming F. 4.4, the following equation for the average labour productivity was obtained:

$$\Delta \ln y_t = \overline{v_{K,t}} + \overline{v_{L,t}} (\Delta \ln L_t - \Delta \ln H_t) + \Delta A_t, \quad (4.5)$$

where H_t is labour input for period t , $y_t = \frac{Y_t}{H_t}$ is total yield (the total of investments and consumption) per labour input, and, $k_t = \frac{K_t}{H_t}$ is capital per labour input.

As a result of the calculations performed, it was found that in 1973-1995 computers, software and hardware contributed to economic growth on average by 0.34% per year, and within 1996-1998 — by 0.99%.

It was also defined that in the period from 1990 to 1999, the average labour productivity in the United States grew, and the growth in the cost and volume of capital, contributed to this, was by 0.49 percentage points (p.p.), while the ICTs' use in production grew by 0.63 p.p. (Jorgenson, Stiroh, 2000, p. 19).

Compared to previous researches of the authors, which were criticized, in particular, by J. Triplett (Triplett, 1999, p. 312), in the new model proposed in 2000, software and hardware were taken into account in the cost of capital, and also statistical data were updated, a significant part of which at the time of the previous model creation (1994-1995) was absent. Therein, the authors obtained more optimistic results than earlier. In the new model, the contribution of computer technologies to the production growth in 1990-1996 was estimated to be by 0.19% per year, whereas in the previous works of these authors it was only 0.12% per year (Jorgenson, Stiroh, 2000, p. 312).

In 2003 D.W. Jorgenson, M.S. Ho and K.J. Stiroh once again updated the model and extended the calculations not only to the United States, but also to a number of other OECD member countries (Australia, Canada, Finland, France, Germany, Italy, Japan, Great Britain). They also made forecasts of the economic development of these countries through the use of ICTs. The new model also included computer engineering, hardware and software as part of the capital (Jorgenson, Ho, Stiroh, 2003, p. 6). In addition, the authors took into account in the updated model the dual nature of ICTs: firstly, they are products produced by this sector (although also a part of its fixed assets), and, secondly, for other sectors of the economy they are a part of the capital (Jorgenson, Ho, Stiroh, 2003, p. 5).

According to the forecasts for the period from 2003 to 2013, production in the considered OECD countries (USA, Australia, Canada, Finland, France, Germany, Italy, Japan, Great Britain) should have grown on average by 2.78% per year, herein 1.78% due to progress in the ICT sector and investments in ICT hardware and software, made by other sectors of the economy (Jorgenson, Ho, Stiroh, 2003, p. 15).

Despite the improvements of the 1994-1995 model, a number of shortcomings can still be identified in the updated model.

1. The authors chose for the analysis a long period of time (1973-1998), within which economic instability in the United States was observed, not related to the development of technologies in the ICT sector (for example, two waves of the Energy Crisis in the middle and at the end of 1970s). Such force majeure circumstances could affect the formation of dependences between the indicators: over a long-analysed period, the error could accumulate and, as a result, this could affect the accuracy of the model.

2. The Jorgenson-Stiroh model, as well as the R. Solow model, does not take into account the time lag between the period of investment in ICTs and ICT equipment and the period, when these devices and technologies begin to give a noticeable return.

3. The life cycle of technologies (presence of technological S-shaped curves) is not taken into account, which causes a decrease in the real (not balance sheet) cost of

products of the ICT sector and fixed assets, related to software and electronic equipment. The model itself takes into account price indices for products of the ICT sector, but they refer only to new products, but not to those that are already in use.

4. From item 3 of this list another drawback of the Jorgenson-Stiroh model follows: it actually does not take into account that, due to the emergence of new generations of technologies, there is a significant moral and physical depreciation of the related to ICTs part of the capital. As a result, the cost of capital in the model can be higher than the real one, which affects the results of calculations.

For the ICT sector and its products, both taking into account the factor of the technologies' life cycle and the presence of S-shaped technology curves are very important. So, based on the Moore's law and his assessments, in the period 1970-2000 only processors underwent no less than 14 major technological changes (Moore, 2003, p. 22). First of all, they concerned their productivity, miniaturization and, accordingly, technologies of their production. It can be assumed that other components of digital technologies, other hardware and software also undergone significant changes during that time, which affected their cost and the relative cost of their predecessors.

Another important feature of the Jorgenson-Stiroh model was emphasized on by the Russian scientist V. Platonov (Platonov, 2007). He noted that the econometric studies of Jorgenson-Stiroh panel data gave an even more paradoxical result than the Solow paradox: they showed that information technology positively affects economic growth and labour productivity, but negatively affects the overall efficiency of production factors (i.e., capital and labour) in the USA. Such a contradiction can be explained by the imperfection of the methodology of quantitative studies carried out at that time, in particular (as noted above in item 1 of the list of shortcomings of this model) due to the non-stationarity of time series (Platonov, 2007, p. 31).

An important step in the development of analysis in this field was the study, carried out by M. O'Mahony and M. Vecchi (O'Mahony, Vecchi, 2003). In their research, they took the existing modifications of the Solow model as a basis (including Jorgenson-Stiroh model). For modelling, the period 1976-2000 was selected, data on 31 types of economic activity (TEA) in the USA and 24 TEAs in the UK. Agriculture was not taken into consideration.

The goal of M. O'Mahony and M. Vecchi was to establish the influence of ICTs not only on economic development and labour productivity, but, first of all, on the overall productivity of production factors (parameter A in the model of Solow and others).

First of all, the authors took into consideration the fact that enterprises, which belong to different TEAs, can invest different amounts of funds in ICTs, which means that the share of ICTs in their capital structure differs. For example, in the manufacturing, the share of ICTs in capital may be higher than in the mineral industry.

Output (Y in the Solow model) in the O'Mahony-Vecchi model does not mean gross output, but value added, since at the time of this model's creation in UK there was no reliable statistical information on gross output.

The authors divided the capital into ICT capital (computers, software and other hardware) and non-ICT capital (the rest of the capital). At the same time, in contrast

to the previous models, M. O'Mahony and M. Vecchi tried to take into account the depreciation of fixed assets and the fact that ICT capital becomes obsolete faster than non-ICT capital. The latter was taken into account by introducing ICT price indices in the model.

M. O'Mahony and M. Vecchi note that, when analysing such a significant period of time (25 years) and the number of TEAs (55 in two countries), it is not advisable to employ the traditional least squares method, which is often used by other authors, in particular in the models (Jorgenson, Ho, Stiroh, 2003; Jorgenson, Stiroh, 2000; Solow, 1957). This is due to the fact that this method assumes the stationarity of all the studied variables and the homogeneity of enterprises, which is not observed in reality. Therefore, they proposed a different methodology for conducting research, taking into account the heterogeneity of time series with preliminary checking of data for stationarity and cointegration (O'Mahony, Vecchi, 2003, p. 4).

The authors showed that, when using the standard calculation and modelling methods, based on the data they collected, it is possible to obtain results, close to the estimates of D. Jorgenson and K. Stiroh: in the USA and Great Britain in the period 1976-2000 due to investments in ICTs, the growth of averaged value added was 2.28% per year, while the total productivity of production factors grew by 1.22% per year (O'Mahony, Vecchi, 2003, p. 8).

However, when using a more advanced modelling methodology, other estimates were obtained. If we take the entire growth in the value-added indicator as 100%, then in the USA and Great Britain in 1976-2000 40% of this growth was due to investments in ICTs (not 20%, as was found in previous models) (O'Mahony, Vecchi, 2003, P. 19). The marginal return on investments in ICT capital for the two countries as a whole was 22%, and for the rest of the capital — only 12% (O'Mahony, Vecchi, 2003, p. 20). Moreover, in the USA, where they started investing in ICTs earlier and in larger amounts than in the UK, the marginal return on ICT capital was over 50%, while in the UK it was only 20% (O'Mahony, Vecchi, 2003, p. 21).

At the same time, the authors note that the results of their calculations may seem too optimistic due to the fact that they have selected few enterprises and TEAs. Nevertheless, a significant positive moment of the conducted research (O'Mahony, Vecchi, 2003) was the justification that an incorrect modelling methodology can negatively affect the final results in the subject under consideration. Therefore, in mathematical modelling and econometric analysis of statistical information, it is imperative to use more accurate tools. In addition, M. O'Mahony and M. Vecchi demonstrated that the paradoxical results, obtained by D.W. Jorgenson and K.J Stiroh, are explained by the absence of accounting of the time lag between the period of investing in ICTs and the time, when these investments begin to really work and are reflected in the statistics accordingly.

At the same time, as V. Platonov noted (Platonov, 2007, p. 32), the research of M. O'Mahony and M. Vecchi is not without drawbacks either.

In particular, the limitations of the approach they used consists in the following. It:

(1) cannot explain causality (that is, it is impossible to identify, which of the observed phenomena is the cause and which is the result);

(2) does not make it possible to analyse the channels and mechanisms of ICTs' impact on productivity;

(3) does not allow identifying the peculiarities of innovative development, as it is based on neoclassical theory.

The last drawback is due to the fact that the authors did not take into account the existence of S-shaped technological curves and the abrupt jump nature of the change in technologies, which, as mentioned above, is also inherent for the previously analysed models. At the same time, when it comes to ICTs, taking into account the factor of technological gaps and stages of the technology life cycle is important for obtaining more substantiated estimates of the impact of ICT sector products and investments in ICTs on the labour productivity and economic development.

Nevertheless, despite the indicated shortcomings of the O'Mahony-Vecchi model, it does not lose its scientific significance. At the same time, contrary to the justification by these authors of the expediency of applying more correct methods for analysing statistical data, the Jorgenson-Stiroh models and the approaches, employed in them, are still used in practice, including due to the lower complexity of the calculations.

The research of D. Acemoglu, D. Autor, D. Dorn, G. Hanson and B. Price and the model, they proposed, are indicative in this sense (Acemoglu, Autor, Dorn, Hanson, Price, 2014).

The authors set out the aim for themselves to establish, whether spreading and implementation of ICTs and electronic devices in the USA enterprises exclude human labour. To do this, they proposed some, in their words, "...simple, descriptive regressions that chart the relationship between IT investment and industry-level outcomes for the time period 1980–2009" in the United States (Acemoglu, Autor, Dorn, Hanson, Price, 2014, p. 395):

$$\log Y_{jt} = \gamma_j + \delta_t + \sum_{i=81}^{09} \beta_i \times IT_j + e_{jt}, \quad (4.6)$$

where Y is the production output; γ is the vector of fixed effects in industry; δ is the vector of dummy time variables; IT is a static measure of the intensity of ICTs' use in industry, which the authors of the model measure as the ratio of ICT costs to total capital costs; β is the coefficient of normalization, which indicates the ICT level in each following year (1981, 1982...2009) relative to the basic year (1980); e is an error.

First of all, proceeding from F. 4.6, one can assume that the authors performed the calculations for each industry in the United States. However, in (Acemoglu, Autor, Dorn, Hanson, Price, 2014, p. 395), there is no more specific information on this matter, but only diagrams are provided that illustrate some dependences in industries not related to the ICT sector and in the ICT sector itself. In view of the existing uncertainty concerning which TEAs are included in the ICT sector (as noted in the previous sections, its composition may differ in different countries), these results of the model need to be clarified.

Furthermore, a question arises about the advisability of using in one equation the logarithm, the vector of fixed effects of an industry and the vector of dummy

time variables. This point requires detailed argumentation both from the standpoint of economic and mathematical modelling, and from the standpoint of the economic meaning of this equation.

Based on the modelling results, it was concluded that in certain sectors of the USA industry there is different labour productivity depending on the intensity of ICTs' use, but to a greater extent its change was due to the decline in manufacturing and employment, which was observed from the late 1990s. At the same time, the authors did not give an unambiguous answer to the question of whether ICTs really displace human labour in the USA, but instead gave the judgment that, based on their research, it is too early to consider the Solow paradox to be solved, and additional research is needed.

In addition to economic and mathematical models, targeted at defining and assessing the impact of ICTs on the economy as a whole, economic development and labour productivity at the level of a country or a group of countries, there are a number of models that solve similar problems, but only at the level of individual enterprises. They include, in particular, the model of E. Brynjolfsson and L. Hitt (Brynjolfsson, Hitt, 2003).

This paper analyses the impact of computerization on the output and labour productivity on the basis of information about the activities of 527 large US enterprises for the period 1987-1994. In other words, the authors moved from the level of the entire economy of the country (or several countries) and individual industries to the micro level (activities of enterprises) and studied a period of 7 years. This is markedly less than in the considered above researches of R. Solow (40 years), D. Jorgenson and K. Stiroh (25 years), M. O'Mahony and M. Vecchi (25 years), D. Acemoglu, D. Autor, D. Dorn, G. Hanson and B. Price (30 years).

The Brynjolfsson-Hitt model is based on modifications of the Cobb-Douglas production function, in which they, in turn, explicitly divided all capital into computer-related and the rest, and also noted that the factor of the industry affiliation of enterprises affects the result (for example, the share of computer capital in the overall capital structure will differ in the ICT sector and textile production). The model itself, like those considered earlier, was developed within the framework of neoclassical economic theory and belongs to the class of econometric models.

In general, the Brynjolfsson-Hitt model looks like this:

$$Q = A(i, j, t) K^{\beta_K} L^{\beta_L} C^{\beta_C}, \quad (4.7)$$

where Q is the gross value added of the enterprise; K is the cost of common (not ICT) capital; C is the cost of ICT capital; L is the labour; t is a time variable, $t = \overline{1987, 1994}$; i is an index, reflecting the number of the analysed enterprises, $i = \overline{1, 527}$; j is a branch of an industry (TEA), which the enterprise belongs to; A is a variable, reflecting the difference in the amount of value added between enterprises over time, not associated with changes in the use of input resources (labour, ICT capital and non-ICT capital); β is the elasticity parameter of non-ICT capital (β_K), labour (β_L) and ICT capital (β_C).

To carry out the analysis, in the model authors changed the actual values for their levels, for which they transformed F. 4.7 into a logarithm form. To simplicity,

they denoted the new variables with lowercase letters ¹², and the indices, denoting the company (i), time (t) and branch of an industry (j), were omitted (except they are indeed necessary for clarity):

$$q = a(i, j, t) + \beta_K k + \beta_L l + \beta_C c. \quad (4.8)$$

To perform the calculations, all data were brought to a comparable form, and also corrected for price indices. In addition, the authors took into account that statistical data may not be accurate or reliable enough. Therefore, the possibility of error was included in the calculations. They also noted that, despite such preliminary measures, the calculation methodology, used by them, largely depends on the reliability of statistical information. If this condition is not met, the scientific correctness of their model and conclusions is reduced.

Comparing changes in the values of indicators over time, E. Brynjolfsson and L. Hitt came to the following conclusions:

1. Computers (ICT capital) significantly correlate with the growth of labour productivity: with an increase in the time interval (from a year to 7 years), this relationship is strengthened, which can be explained by the adaptation of new technologies in the organizational structure of the enterprise.

2. TEA, to which the enterprise belongs, and the period, during which ICT capital is used, also affect the contribution of computerization to increasing labour productivity.

3. Whatever the type of economic activity is, computers increase the labour productivity in it.

4. Investment in ICT capital at an enterprise level for the period under consideration (7 years, 1987-1994) led to an increase of value-added creation by 0.25-0.5%.

5. The state of fixed assets, difference in the existing technological infrastructure, approaches to investments in ICTs, historically formed at a particular enterprise, can significantly affect the desire of its management to invest in new ICT capital or on the possibility of quickly putting such capital into operation at a particular enterprise.

E. Brynjolfsson and L. Hitt emphasize that their calculations of the impact of ICT capital and computerization on the labour productivity reflect the situation only in the private sector of the economy, and that they cannot define, whether this impact is more or less on the country's economy as a whole.

If we analyse the shortcomings of the E. Brynjolfsson and L. Hitt model, it should be noted that this model is built on the principles, used in the Jorgenson-Stiroh model, with the exception of greater detailing of economic units (since the level of industries and enterprises is analysed, rather than the economy of the country as a whole), a short period of modelling and comparison of the results of calculations between different years and different enterprises. Of the new, the authors have added a correlation-regression analysis to the econometric tools they used, in addition to the least squares method.

¹² That is, in the notation of E. Brynjolfsson and L.M. Hitt, log K looks like k .

In general, from the methodological point of view, the Brynjolfsson-Hitt model inherited the shortcomings of the Jorgenson-Stiroh model. In addition, although the authors brought the statistical data to a comparable form and adjusted them for price indices, as done in the Jorgenson-Stiroh model, they do not take into account the factor of depreciation of fixed assets, as well as the existence of technological cycles, the effect of which can partially explain the conclusion about the increase of the computerization impact on productivity over time. The authors relate this result to the presence of time lags between investments in ICTs and return on it, as well as to organizational improvements in enterprises (Brynjolfsson, Hitt, 2003, pp. 805-806).

Another group of economic and mathematical models is devoted not so much to defining the impact of digitalization on a country's economy or the activities of enterprises, as to establishing the size and development trends of the digital economy itself. In the context of the problems under consideration, such a statement of the question also makes sense, since the fact of an accelerated growth of the digital economy is an indirect evidence of the modern ICTs' effectiveness. In particular, this group includes the model presented in the paper (Herrero, Xu, 2018)¹³.

The authors note that it is necessary to define the size of the digital economy and the trends of its development in order to further establish its impact on the country's GDP, as well as to compare the scale of the digital economy in different countries and make recommendations on the directions of its further growth (Herrero, Xu, 2018, pp. 2-3). At the same time, the very concept of "digital economy" is defined as a synonym for the ICT sector.

In fact, the A.G. Herrero and J. Xu model is a variation of the Cobb-Douglas production function, but not in the form of the exponential or logarithmic functions, which are usually used (including in the analysed papers of R. Solow, D.W. Jorgenson and K.J. Stiroh and others), but as a linear relationship.

The function itself uses the proportions and shares of input factors (labour, capital, technological development), which, as a result, allows the authors to obtain a certain index, designed to characterize the development of China's digital economy. The model looks like this:

$$IDE = \alpha L + \beta C + (1 - \alpha - \beta) TI, \quad (4.9)$$

where *IDE* is the index, characterizing the development of the digital economy; *L* is the labour; *C* is the capital; *TI* is technological innovations; α , β are coefficients, characterizing the share of input parameters in the resulting indicator.

In turn, the input parameters have a complex structure. The indicator "labour" includes: "the average wage of employees in the ICT sector relative to that in the country as a whole" and "the number of available jobs in the ICT sector relative to that in the country as a whole". The indicator "capital" includes: "share of venture capital in the ICT sector", "share of capital to be sold", "share of the registered capital

¹³ As the authors note, this model was proposed by the Beijing media group Caixin (Caixin Media Company Ltd.) — an influential organization that provides financial and business news, using the media and online channels.

of the enterprise" and "share of new registered capital in the ICT sector". The indicator "technological innovation" includes "share of researchers in the ICT sector", "share of new inventions and patents in the ICT sector", "level of implementation of the patented inventions in practice in the ICT sector". The coefficients, characterizing the shares of the input parameters in the resulting indicator, were calculated by Caixin independently (the method was not disclosed). Their values are 40% for the indicator "labour", 40% for the indicator "capital" and, as follows from F. 4.9, 20% for the indicator "technological innovation".

As noted by A.G. Herrero and J. Xu, almost all of the statistical information for their model and calculations were obtained through Big Data analysis from Caixin in collaboration with an anonymous online recruitment platform.

As a final result of all calculations, it was defined that in China from January 2016 to April 2017, the digital economy grew by 176% (Herrero, Xu, 2018, p. 8).

Despite the importance of the obtained assessments of the development of China's digital economy, A.G. Herrero and J. Xu note that it is impossible to make comparisons with other countries on their basis, since the list of TEAs that Caixin referred to the ICT sector differs, for example, from that used by the OECD. That is, proceeding from this, a comparative analysis may be carried out incorrectly.

Moreover, Caixin does not disclose in detail the methodology of collecting and processing statistical information and calculating coefficients, characterizing the share of input parameters in the resulting indicator (in F. 4.9). Also, it is not indicated, whether these calculations took into account the depreciation of fixed assets, the inflation factor and changes in prices for products of the ICT sector due to changes in technology, for what period the data were collected and dependences were established. Given this, it is rather difficult to draw conclusions about the reliability of the model, proposed by Caixin.

Also, as noted by J. Triplett (Triplett, 1999, pp. 326-328) and R. Solow (Solow, 1957, p. 318), the modification of the Cobb-Douglas production function, which has the form of a linear relationship, frequently leads to inaccurate results.

Summarizing the above analysis of economic and mathematical models for assessing the ICT impact on economic development (of countries, individual enterprises, ICT sector), the following can be noted.

1. The fact that such mathematical modelling is carried out and evolves indicates the importance of ICTs for economic development. The current industry, the entire economy, the sphere of public administration, etc. are already unthinkable without the Internet, mobile devices, digital data and platforms, etc. (and in this sense, the Solow paradox has already lost its practical significance). The main issue, which the authors of models usually try to solve, is the assessment of the power and scale of the ICT impact, the results of which can form a basis for the elaboration of policy measures for their further development and promotion.

2. Economic and mathematical models for assessing the impact of ICT on economic development are mostly based on the Cobb-Douglas production function with the modifications proposed by R. Solow.

3. A significant drawback of many of the analysed models is the lack of taking into account the factors of capital depreciation, the life cycle of technologies and technological gaps, which affects the reliability of the results obtained.

4. In a number of the analysed models the outdated data analysis methodology, applied way back ago by R. Solow, was used despite the fact that over 60 years since he published his calculations on the impact of technical progress on economic development (Solow, 1957) has past, it has been improved and, on its basis, more elaborated calculations have been performed (O'Mahony, Vecchi, 2003).

5. Many of the analysed models assess the ICT impact on economic development within one country. However, such an approach makes it a hostage of specific institutions, technologies, infrastructures and the population of individual countries¹⁴, which all together define the peculiarities of national development and implementation of ICT sector's products in the activities of enterprises and the daily life of people and societies. Therefore, in order to substantiate more significant conclusions and expand the scope of their application, it is advisable to assess the ICT impact on economic development through comparison among countries and their clusters, taking into account the group regularities of development in space and time and constructing the corresponding complexes of models.

¹⁴ For more details, see (Voskresenskaya, 2017).



5

TRANSFORMATION POTENTIAL OF DIGITALIZATION AND WAYS TO INCREASE NATIONAL COMPETITIVENESS



5.1. CONSTRUCTION DEPENDENCE FUNCTION OF REAL RESULTS AND DIGITAL COSTS

In the context of the Fourth industrial revolution, digitalization of an economy is one of the main driving forces for global transformations of the modern world, which is important not so much in itself, but as an integral element of the development of industrial cyber-physical systems. "Digit" has acquired special significance in the formation of a new mode of production and related systems of institutions. This statement is clearly demonstrated in Fig. 5.1.

As shown in the Fig. 5.1, many developing countries are ahead of the advanced ones, for example, in such an indicator as the specific number of mobile cellular subscribers (per 1000 people). However, from the standpoint of national competitiveness, this is not a decisive advantage. A more important is a contribution of digital technologies to the innovative development of national manufacturing. According to this component, judging by such an important indicator as the share of high-technology exports per capita in its total value, the advanced countries are far ahead of the developing economies, shown in the figure.

It should be emphasized that, firstly, cyber-physical systems are very complex and very diverse objects, which cannot be adequately described by one or two indicators. Therefore, in the further analysis, we use complexes of interrelated indicators that characterize various aspects of the problem under study.

Secondly, the links between digital expenses and real results of activity, mediated by the development of cyber-physical systems, cannot be considered universal, that is, be the same for all times and peoples. In particular, this is due to the fact that the effects of digitalization depend on the performance of material software media, conditionally called hardware. That is, it is one thing, when digital technologies are used to improve the efficiency of modern means of production, which

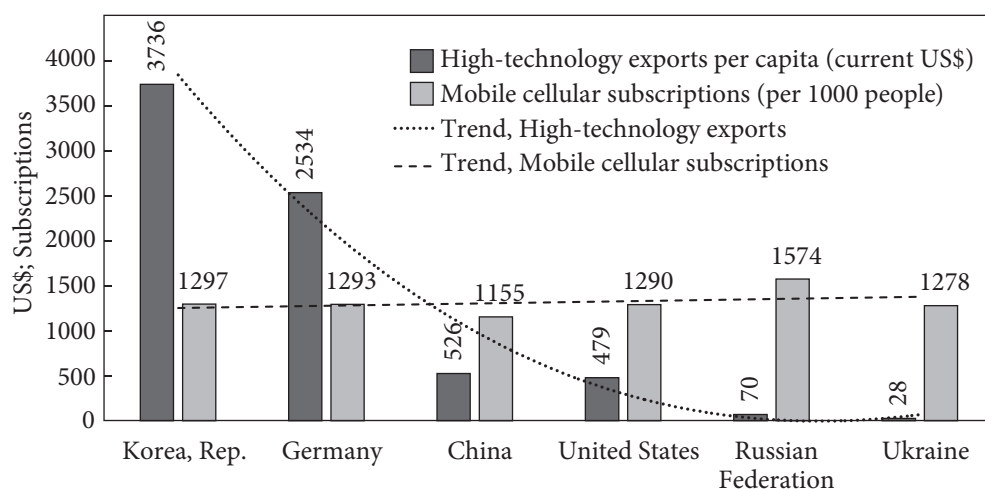


Fig. 5.1. Indicators of the development of digital and real sectors of the economy in selected advanced and emergent economies (2018)

Source: The World Bank (2020). World Development Indicators. DataBank. Retrieved 14 November 2020, from <https://databank.worldbank.org/source/world-development-indicators>

embody disruptive production technologies "in hardware" (McKinsey & Company, 2013), and it is quite different thing, when digitalization is combined with equipment and technologies, the physical capabilities of which are significantly limited in comparison with the best new samples.

Therefore, if in different countries (groups of countries) different social and economic structures dominate, then the effect of digitalization there will be different as well (Fig. 5.2).

As noted before (see Chapter 4), the relationship between costs and results in a technology life cycle can be represented with an S-curve (Foster, 1986). Its meaning lies in the fact that at first, when the technology is just beginning its life cycle, efforts to promote it tend to yield modest results. But as the technology unfolds its potential, the efforts (costs) begin to bring increasing returns, which is shown as an increase in the slope of the S-shaped curve. Finally, at the stage of maturity, further efforts to improve the technology yield only marginal results in terms of its physical performance (the curve slope becomes small). This indicates that the potential of this technological solution has been largely exhausted.

However, it is at the stage of physical maturity that well-developed technologies bring high financial returns. It is therefore profitable to sell mature technologies to other countries, as that brings good dividends. At the same time, those economies that accept them (localize and adapt), although they can, due to this, significantly increase the overall level of national production, will always lag behind the countries-innovators, which, via using money flows from the exploitation of mature technologies, invest in the development of new generations of engineering solutions. It is clear that in the be-

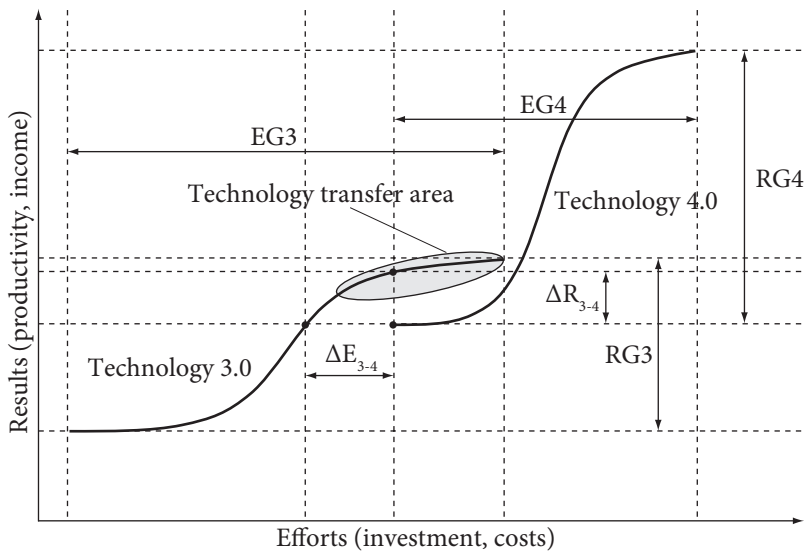


Fig. 5.2. Life cycle of technology; technological and financial gaps: EG — Efforts Gap; RG — Results Gap

ginning, the transition from old to new technologies can be associated with significant losses in productivity and income (ΔR_{3-4} in Fig. 5.2). In addition, mastering new solutions is more expensive than developing old ones: in the case of developing new technologies, the achievement of the same level of productivity requires higher initial costs (ΔE_{3-4} in Fig. 5.2). But when the made decisions turn out to be successful, they begin to bring much greater returns than technologies of the previous generation (as shown on Fig. 5.2, losses from the ΔR_{3-4} transition are bigger than compensated by the benefits from using the potential RG_4). This is demonstrated by the midpoint of the 3.0 S curve, which is much lower than that of the 4.0 S curve, and therefore the cost/benefit ratio is significantly improved $RG_4/EG_4 \gg RG_3/EG_3$).

The concept of the life cycle of technologies and an abrupt transition from old technological solutions to new ones can and should be extended to the sphere of comparative technical and economic analysis of countries that possess dominant technologies of different levels of development. That is, the movement to the right between the points of the same S-shaped curve can be interpreted as a transition from one country to another, which has achieved more in unlocking the potential of the dominant technologies of this level, e.g., technologies 3.0, representing the Third Industrial Revolution. If these or those countries have switched to the mass use of technologies 4.0, presenting the Fourth Industrial Revolution, they will be located on another, of higher level, S-shaped curve. Herein any, even the largest, investments in improving 3.0 technologies cannot provide such productivity as investments in the advance of 4.0 technologies, and, therefore, gaps between countries with different dominant technologies will not narrow but widen. This standpoint constitutes a key hypothesis and a starting point for further research.

In other words, we propose considering the effects of digitalization not within the framework of one country, whose economy is predicably affected by the action of various factors, including unknown, but taking into account the comparative analysis and the actual outcomes of digital transformations in those countries that have already advanced or lagged behind in this regard. This makes it possible to forecast relatively reliably not only backward (i.e., on the basis of comparison with the actual data of one country), but also forward, when the results of expected changes can be distilled from the analysis of development indicators of other countries.

It should be noted that it is necessary to take into account not only technical and technological, but also institutional factors. Indeed, in the final analysis, the effectiveness of new technologies' employment is also defined by the extent, to which formal and informal norms of behaviour prevailing in a particular society are favourable for innovations. A society that does not accept innovators and technological innovations will not be successful in using modern digital technologies.

Given the above, the scientific and methodological approach to the analysis of indicators characterizing the effects of digitalization (Table 5.1) consists in the following.

1. In accordance with the economic meaning of the compound expression "cyber + physical", all indicators are divided into two large groups: the first one characterizes the digital (cybernetic) side of the studied phenomenon (indicators of development of the digital sector of the economy), and the other characterizes the physical side (indicators of the technological development of the real sector of the economy).

2. In accordance with the conceptual statement on the diversity of digitalization effects depending on the cybernetic, technical, economic and institutional conditions in individual countries (or their groups), the indicators were collected for many countries over several years (2014-2018 is the latest period, for which the necessary data are available and taking into account the fact that during these years there were no strong shocks in the world economy). Only those countries were excluded from the sample for which the necessary data on development of digital and manufacturing technologies were absent, as well as countries with a population of up to 1 million people (since they cannot be considered typical objects of international comparison), plus specific countries, whose abnormally high economic results are due to the appropriation of rent from the sale of carbon raw materials (these are, first of all, the countries of the Middle East, such as Qatar, Saudi Arabia, etc.). 90 countries meet these criteria ¹.

¹ The sample includes: Albania, Algeria, Argentina, Armenia, Australia, Austria, Azerbaijan, Belarus, Belgium, Bosnia and Herzegovina, Botswana, Brazil, Bulgaria, Burundi, Canada, Chile, China, Colombia, Costa Rica, Croatia, Cyprus, Czech Republic, Denmark, Ecuador, Egypt, Arab Rep., El Salvador, Estonia, Ethiopia, Finland, France, Georgia, Germany, Ghana, Greece, Guatemala, Hong Kong SAR, China, Hungary, India, Indonesia, Israel, Italy, Japan, Jordan, Kazakhstan, Kenya, Korea (Rep.), Kyrgyz Republic, Latvia, Lithuania, Madagascar, Malaysia, Mauritius, Mexico, Moldova, Mongolia, Morocco, Mozambique, Namibia, Nepal, Netherlands, New Zealand, Nicaragua, Norway, Pakistan, Paraguay, Peru, Philippines, Poland, Portugal, Romania, Russian Federation, Serbia, Singapore, Slovak Republic, Slovenia, South Africa, Spain, Sri Lanka, Sweden, Switzerland, Tanzania, Thailand, Tunisia, Turkey, Uganda, Ukraine, United Kingdom, United States, Uruguay, Zambia.

Table 5.1. List of indicators characterizing the digital and technological development of the world countries

Legend	Digital development indicators	Legend	Technological development indicators
b'	The share of value added of the ICT sector, % GDP	c'	High-technology exports (% of manufactured exports)
b''	Value added of the ICT sector, \$ per capita, PPP	c''	High-technology exports, % GDP
		c'''	High-technology exports, international \$, per capita
b_1	Internet access in schools, 1-7 (best)	c_1	Industry (including construction), value added (% of GDP)
b_2	ICT goods imports (% total goods imports)	c_2	Manufacturing, value added (% of GDP)
b_3	ICT service exports (% of service exports)	c_3	Manufacturing, value added, \$ per capita, PPP
b_4	International Internet bandwidth, kb/s per user*	c_4	Gross fixed capital formation (% of GDP)
b_5	Mobile broadband subscriptions/100 pop.*	c_5	Gross fixed capital formation (international \$ per capita)
b_6	Fixed telephone subscriptions (per 100 people)	c_6	PCT patents, applications/million pop.*
b_7	Mobile cellular subscriptions (per 100 people)	c_7	Expenditures for R&D, % of GDP, 2005-2015
b_8	Individuals using the Internet (% of population)	c_8	Expenditures for R&D, \$ per capita, PPP, 2005-2015
b_9	Fixed broadband subscriptions (per 100 people)	c_9	Company spending on R&D, 1-7 (best)
		c_{10}	R&D expenditure by source of funds (%), business enterprise
		c_{11}	R&D expenditure, business enterprise, \$ per capita, PPP

The indicators given in Table 5.1 were subdivided into two groups: resultant indicators (b' , b'' and c' , c'' , c''') and influencing factors (b_1 - b_9 and c_1 - c_{11}). The aim of this division is to identify those variables that exert the greatest impact on the results of development of the digital and physical fields of national economies, and then to use these factors in further analysis.

To reach the aim, a standard statistical analysis was applied (a matrix of paired linear correlation coefficients was built, which were also checked for multicollinearity).

Then, to calculate the size of the digital economy in countries of the world, the common in economic researches multiplicative exponential function with three factors was used:

$$b'_i = B \cdot b_{xi}^l \cdot b_{yi}^m \cdot b_{zi}^n, \tag{5.1}$$

where b'_i is the share of value added in the ICT sector, % of GDP; B is the scale factor; b_{xi} , b_{yi} , b_{zi} are factors x, y, z influencing the sizes of the digital economy in the i country; l, m, n are power coefficients.

Through conducting a number of calculation experiments (including optimization by the criterion of the minimum deviation of the actual value of the resultant indicator from its calculated value using the MS Excel solution search tool), it was found that for modelling the specific size of the digital economy (the share of value added of the ICT sector, %) it is advisable to use the following indicators: (a) ICT service export per capita, PPP (constant 2017 international \$); (b) secure Internet servers (per 1 million people); (c) individuals using the Internet (% of population) (Table 5.2).

The calculations, the results of which Fig. 5.3 illustrates, were performed using data from OECD countries only (rather than for the entire sample). This is due to the fact that for these countries there is reliable statistical information characterizing the size of the digital economy as the sum of gross value added by types of economic activity according to ISIC REV.4 (D26: Computer, electronic and optical products; D582: Software publishing; D61: Telecommunications; D62T63: IT and other information services) ².

The constructed model ³

$$b'_i = 1.6781 \cdot b_{2i}^{0.0321} b_{3i}^{0.2135} b_{6i}^{0.0106} \quad (5.2)$$

was used to define the calculated size of the digital economy in other non-OECD countries of the world.

Then, by conducting a regression analysis, we found that the size of the specific (per capita) volume of exports of high technologies is mostly affected by the following indicators: (a) manufacturing, value added, \$ per capita, PPP (constant 2017 international \$); (b) gross fixed capital formation, \$ per capita, PPP (constant 2017 international \$); (c) expenditures for R&D, \$ per capita, PPP (constant 2017 international \$).

Thus, in total, six influencing factors were selected that define the digital (cybernetic) and physical (the degree of technological development in material production) sides of the phenomenon under study:

- ICT service export per capita, PPP (constant 2017 international \$);
- Secure Internet servers (per 1 million people);
- Individuals using the Internet (% of population);
- Manufacturing, value added, \$ per capita, PPP (constant 2017 international \$);
- Gross fixed capital formation, \$ per capita, PPP (constant 2017 international \$);
- Expenditures for R&D, \$ per capita, PPP (constant 2017 international \$).

These indicators were used for clustering the world countries (a multidimensional statistical procedure, which, on the basis of analysis of information on the sample objects, arranges the objects into relatively homogeneous groups).

² OECD.Stat (2020). *STAN Database for Structural Analysis*. Retrieved 4 January 2021, from <https://stats.oecd.org/Index.aspx?QueryId=4414>

³ Here in after, the Fisher criterion was used to assess the quality of the obtained models.

Table 5.2. Results of calculation of the specific size of the digital economy in the OECD countries, depending on the influencing factors

Country	The share of value added of the ICT sector, 2014-2018, %	ICT service export per capita 2014-2017 PPP (constant 2017 international \$)	Secure Internet servers (per 1 million people)	Individuals using the Internet (% of population)	Calculated value	Error
	B	l	m	n		
	1.6781	0.0321	0.2135	0.0106		
Australia	4.34	88.5	72.8	85.4	5.08	0.17
Austria	4.01	799.5	34.0	84.9	4.63	0.15
Belgium	3.61	1 151.1	29.0	86.6	4.53	0.25
Canada	4.04	225.3	73.8	89.8	5.25	0.30
Czech Republic	6.14	562.9	83.2	77.2	5.54	0.10
Estonia	7.46	758.1	94.1	87.5	5.75	0.23
Finland	6.13	1 452.3	69.9	87.4	5.51	0.10
France	4.57	302.1	45.0	80.7	4.76	0.04
Germany	4.98	461.7	109.9	86.4	5.84	0.17
Greece	3.10	143.9	10.8	68.5	3.42	0.11
Hungary	7.33	411.9	38.6	76.1	4.65	0.37
Ireland	5.36	16 634.8	125.9	84.1	6.75	0.26
Italy	3.67	186.3	22.4	62.5	4.03	0.10
Japan	6.56	32.1	22.6	89.8	3.83	0.42
Latvia	4.26	473.9	31.6	79.7	4.48	0.05
Netherlands	6.46	969.4	212.1	92.3	6.89	0.07
Norway	3.96	343.2	50.1	96.7	4.90	0.24
Poland	3.55	283.2	26.9	72.3	4.25	0.20
Portugal	3.61	219.3	33.1	70.4	4.41	0.22
Slovak Republic	5.81	357.4	24.9	80.1	4.22	0.27
Slovenia	4.29	442.9	62.0	75.8	5.16	0.20
Spain	3.40	351.1	22.8	81.2	4.14	0.22
Sweden	7.30	1 458.6	45.8	92.1	5.03	0.31
Switzerland	8.51	1 344.0	130.1	88.4	6.27	0.26
Turkey	2.69	7.7	9.7	59.8	3.04	0.13
United Kingdom	4.80	425.2	64.8	93.6	5.21	0.09
United States	5.85	119.2	119.1	80.1	5.69	0.03
Standard deviation	1.54	3 131.18	46.45	9.28	0.93	
<i>Average</i>	5.03	1 111.33	61.67	81.83	4.94	0.19
Coefficient of variation	0.31	2.82	0.75	0.11	0.19	

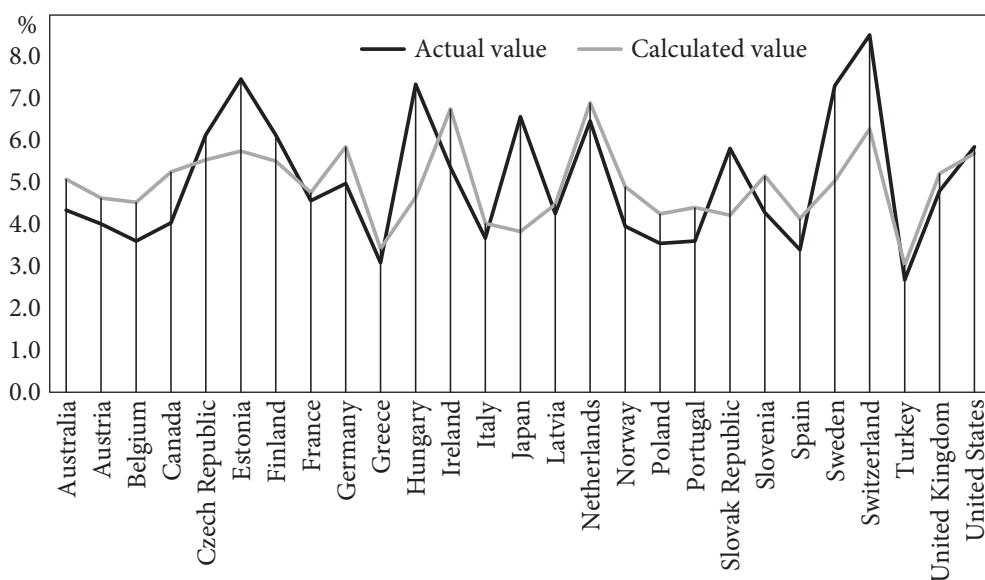


Fig. 5.3. Actual and calculated values of the size of the digital economy (% of GDP) in a number of OECD countries

For this, such a well-known tool as a hierarchical clustering according to the Ward's method (where analysis of variance is used to estimate the distances between clusters, i.e., the increment of the sum of squares of the object – centre of cluster distances obtained as a result of the union) was used together with the Euclidean metric (Euclidean distance) (Fig. 5.4).

As shown in Fig. 5.4, the ordering of objects allowed for the formation of four distinctly separated groups of countries, which were interpreted as countries of Industry 4.0 (cluster A), Industry 3.0+ (cluster B), Industry 3.0 (cluster C) and Industry 2.0 (cluster D). This interpretation is related to the meaningful analysis of the indicators that characterize the clusters (Table 5.3).

As shown in the table, the average values of indicators for clusters indeed significantly (by several times) differ. If we take, e.g., such a digital indicator as the export of ICT services per capita, then in the first cluster (A) it is over \$ 1,000, in the cluster (B) it is already less than \$ 500 and in the cluster (C), which includes Ukraine, it is below \$ 100. That is, ten times lower than in cluster A. A similar situation is observed in terms of technological indicators. For example, the cost of manufacturing products per capita in cluster A amounts to 8.6 thousand dollars, in cluster B — 4.5 thousand dollars, or approximately twice less, in cluster C — 2.2 thousand dollars, i.e., four times less, not to mention the outsider cluster D — 0.7 thousand dollars, or 13 times less than in cluster A.

As follows, cyber-physical indicators indicate the presence of such significant quantitative gaps between clusters, which can be interpreted qualitatively as a transition between separate scientific and technical level's stages. In addition, the very

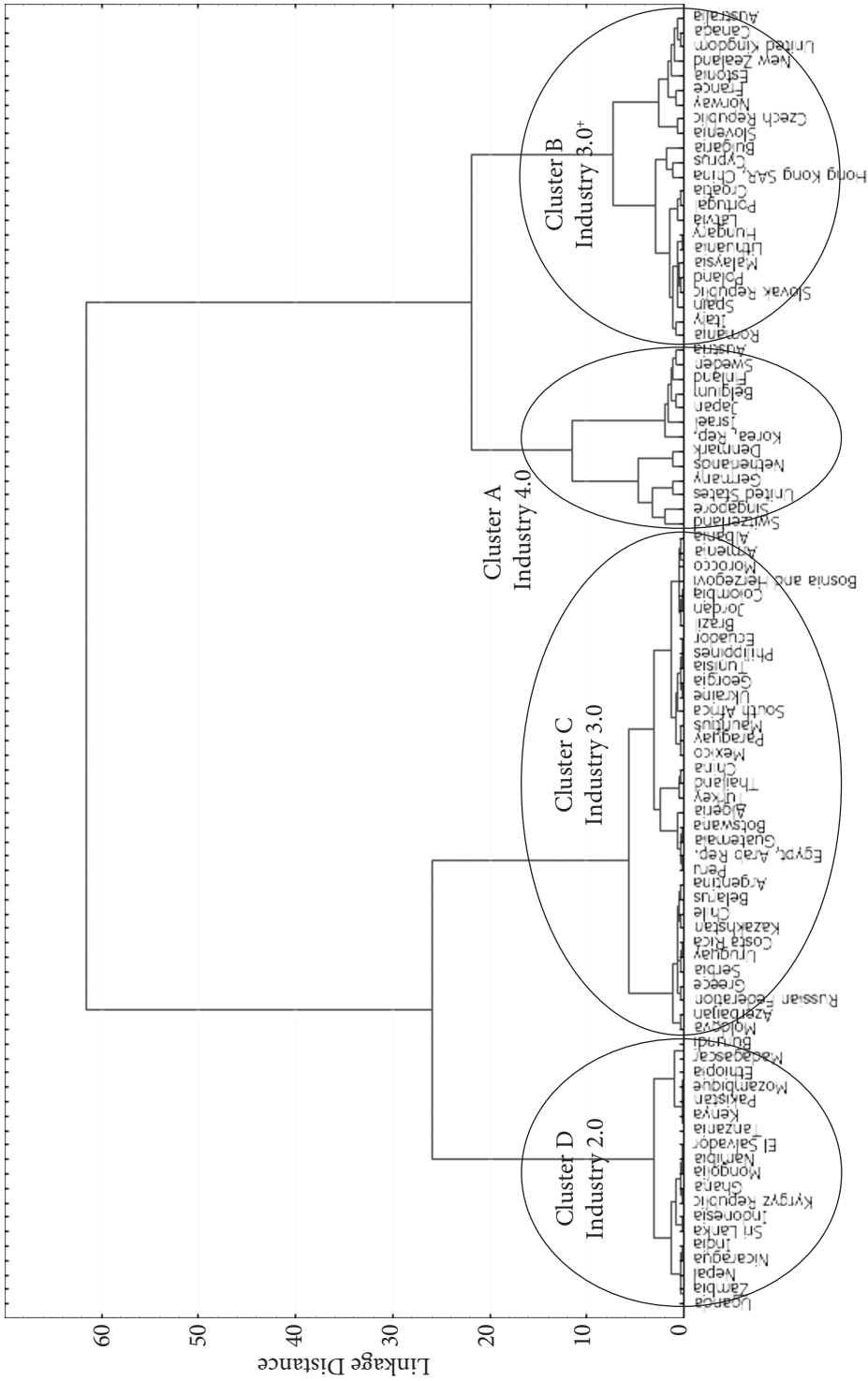


Fig. 5.4. Results of clustering of the world countries according to the selected indicators of development of cybernetic and technological subsystems

Table 5.3. Economic indicators characterizing the formed clusters of countries of the world

Clusters	Digital development indicators			Technical development indicators		
	ICT service export per capita 2014-2017 PPP (constant 2017 international \$)	Secure Internet servers (thousands per 1 million people)	Individuals using the Internet (% of population)	Manufacturing, value added, \$ per capita, PPP (constant 2017 international \$)	Gross fixed capital formation, \$ per capita, PPP (constant 2017 international \$)	Expenditures for R&D, \$ per capita, PPP (constant 2017 international \$)
A	1026	90	88	8621	12 418	1609
13 countries ^a	100%	100%	100%	100%	100%	100%
B	421	46	78	4 488	7 816	500
23 countries ^b	41.1%	51.2%	89.4%	52.1%	62.9%	31.1%
C	89	5	59	2 166	3 556	88
35 countries ^c	8.71%	5.07%	66.8%	25.1%	28.6%	5.49%
D	34	1	21	666	1 348	14
19 countries ^d	3.27%	0.62%	23.6%	7.73%	10.9%	0.85%

^a Austria, Belgium, Denmark, Finland, Germany, Israel, Japan, Korea (Rep.), Netherlands, Singapore, Sweden, Switzerland, United States; ^b Australia, Bulgaria, Canada, Croatia, Cyprus, Czech Republic, Estonia, France, Hong Kong SAR, China, Hungary, Italy, Latvia, Lithuania, Malaysia, New Zealand, Norway, Poland, Portugal, Romania, Slovak Republic, Slovenia, Spain, United Kingdom; ^c Albania, Algeria, Argentina, Armenia, Azerbaijan, Belarus, Bosnia and Herzegovina, Botswana, Brazil, Chile, China, Colombia, Costa Rica, Ecuador, Egypt, Arab Rep., Georgia, Greece, Guatemala, Jordan, Kazakhstan, Mauritius, Mexico, Moldova, Morocco, Paraguay, Peru, Philippines, Russian Federation, Serbia, South Africa, Thailand, Tunisia, Turkey, Ukraine, Uruguay; ^d Burundi, El Salvador, Ethiopia, Ghana, India, Indonesia, Kenya, Kyrgyz Republic, Madagascar, Mongolia, Mozambique, Namibia, Nepal, Nicaragua, Pakistan, Sri Lanka, Uganda, Tanzania, Zambia.

composition of cluster A includes few countries, which today are the evident technological leaders of the world (USA, Germany, Korea, Japan, etc.), where Industry 4.0 is now intensely developing.

As for Ukraine, in all respects it clearly "falls short" of cluster B. It can be quite fair considered as a typical representative of cluster C, i.e., the group of countries which is defined as Industry 3.0. This is evident, since according to Ukrainian experts, most of the production technologies in the country now belong to the third and fourth technological modes (based on mass and serial production), i.e., to those, which period of dominance in the world ended in the 20th century (Liashenko, Kotov, 2015, p. 23-26).

These circumstances should be taken into account, when assessing the impact of the digital sector on the economy as a whole.

5.2. ASSESSMENT OF THE TRANSFORMATION POTENTIAL OF THE ECONOMY'S DIGITALIZATION

Traditionally, labour and capital are among the main factors of production that define the size and dynamics of national output. They are frequently used for mathematical modelling of GDP through multiplicative exponential functions (such as the classical Cobb-Douglas function). In the conditions of the digital revolution, these factors are usually supplemented with certain indicators reflecting the impact of digitalization of the economy and development of the ICT sector (Dasiv, Madikh, Okhten, Turlakova, 2019). Moreover, it is important to take into account that for modelling, such indicators should be selected for which there is available statistical data over several years in the context of selected for analysis countries of the world.

In view of this, to define the size of a country's (i) GDP per capita (Y_i), a model was proposed, in which, along with indicators of gross fixed capital formation (d_{xi}) and average monthly payment of employees (d_{yi}), an indicator characterizing the size of the global economy by value added of the ICT sector, \$ per capita, PPP (d_{zi}) is used:

$$Y_i = Dd_{xi}^r d_{yi}^s d_{zi}^t, \quad (5.3)$$

where D is the scale factor; r , s , t are power coefficients.

The starting data for the calculations are presented in Table 5.4.

To define the parameters by applying the least squares method, function (5.3) was transformed into a linear form by taking logarithms:

$$\ln Y_i = \ln D + r \ln d_{xi} + s d_{yi} + t d_{zi}^t. \quad (5.4)$$

As a result of the calculations, the parameters D , r , s , t were defined and the following equation was derived:

$$Y = 55.0 d_{xi}^{0.368} d_{yi}^{0.312} d_{zi}^{0.125}. \quad (5.5)$$

As shown in Fig. 5.5, the results of GDP calculation using function (5.5) agree well within its actual values. The relatively high value of the parameter $t = 0.125$ indicates that the digital component is indeed an important factor in economic growth.

In general, judging by the data presented, the graphs look like an illustration of a "smooth" evolution: the countries that have a large ICT sector, as a rule, generate a large value added. Thus, one could conclude that the key to the economic growth is an accelerated development of the digital economy.

However, this is a premature conclusion and a deceptive impression that hides internal contradictions of real economic processes.

In this regard, it should be mentioned that, firstly, technologies, including digital ones, are characterized by their own life cycles, at the end of which the transition from the previous technology generation to a new one is always a break in continuity (at least in certain aspects) and a leap that is difficult to accomplish. Obviously, no incremental improvements, e.g., in the development of the legendary Nokia 3310, can convert it into an iPhone 12. Secondly, digital technologies do not develop in isolation from tangible mediums.

5. Transformation potential of digitalization and ways to increase national competitiveness

In the current conditions, newly introduced machines and equipment that determine the technical level of manufacturing, as a rule, are already well "digitized", that is, they include digital tangible and intangible assets. This is on the one hand. And on the other hand, it is modern material production that is a generally recognized driver of innovation, including in the digital field (European Commission, 2018).

Table 5.4. The results of calculation of the GDP size depending on the influencing factors for the world countries

Country	GDP per capita, PPP (constant 2017 international \$) 2014-2018	Value added of the ICT sector, \$ per capita determine it, PPP, 2014-2018	Gross fixed capital formation, \$ per capita, PPP (constant 2017 international \$) 2014-2018	Average monthly earnings of employees	GDP per capita, calculated value	Error, %
<i>Cluster A</i>						
Austria	54 080	2170.5	12 539.3	3250.0	48 412	10.5
Belgium	50 044	1806.7	11 607.5	3617.5	44 860	10.4
Denmark	54 135	2444.2	11 179.6	3887.6	49 979	7.7
Finland	46 377	2842.0	10 439.9	3284.1	50 628	9.2
Germany	52 116	2594.2	10 634.5	5232.4	52 166	0.1
Israel	38 409	1650.7	7 836.4	2324.4	36 297	5.5
Japan	40 137	2633.6	9 552.7	2665.0	46 651	16.2
Korea, Rep.	39 926	4886.2	11 943.1	3527.0	65 026	62.9
Netherlands	54 312	3508.4	10 882.8	2880.6	54 531	0.4
Singapore	92 187	6253.5	24 006.4	3945.5	89 977	2.4
Sweden	51 943	3793.9	12 623.0	3400.0	60 028	15.6
Switzerland	66 878	5690.4	16 074.8	5409.0	79 628	19.1
United States	59 276	3467.2	12 111.1	4025.2	58 531	1.3
<i>Average</i>	53 832	3365	12 418	3650	56 670	5.3
<i>Cluster B</i>						
Australia	48 552	2109.0	12 301.9	4623.9	49 852	2.7
Bulgaria	20 472	1092.5	3 999.5	1398.8	23 691	15.7
Canada	48 169	1946.0	11 202.9	3202.4	44 906	6.8
Croatia	25 551	1163.5	5 054.3	1887.3	27 090	6.0
Cyprus	36 111	1711.9	6 033.2	2790.9	34 647	4.1
Czech Republic	37 101	2277.0	9 417.2	2251.2	43 115	16.2
Estonia	32 605	2432.6	7 946.1	2028.8	41 334	26.8

5.2. Assessment of the transformation potential of the economy's digitalization

Continuation of Table 5.4

Country	GDP per capita, PPP (constant 2017 international \$) 2014-2018	Value added of the ICT sector, \$ per capita determine it, PPP, 2014-2018	Gross fixed capital formation, \$ per capita, PPP (constant 2017 international \$) 2014-2018	Average monthly earnings of employees	GDP per capita, calculated value	Error, %
France	44 217	2018.6	9 775.1	3558.8	44 170	0.1
Hong Kong SAR, China	58 519	2730.0	12 949.3	2383.6	51 320	12.3
Hungary	28 567	2094.8	6 366.9	2103.4	36 648	28.3
Italy	41 112	1510.7	7 083.7	2780.1	34 795	15.4
Latvia	27 514	1172.0	5 908.0	1591.8	27 938	1.5
Lithuania	32 382	1473.6	6 405.4	1704.9	31 441	2.9
Malaysia	25 687	910.5	6 506.1	1658.0	26 385	2.7
New Zealand	41 096	1919.9	9 420.7	2971.6	41 917	2.0
Norway	62 298	2466.8	15 148.4	4198.8	55 721	10.6
Poland	29 070	1031.7	5 439.7	2266.5	27 135	6.7
Portugal	32 125	1158.7	5 163.8	1303.8	26 015	19.0
Romania	25 577	1144.5	5 898.6	1915.3	28 323	10.7
Slovak Republic	30 119	1750.4	6 460.2	1881.6	33 995	12.9
Slovenia	35 369	1515.6	6 553.2	2645.9	33 783	4.5
Spain	38 390	1306.2	7 052.0	2741.3	32 881	14.3
United Kingdom	45 371	2176.5	7 683.2	2962.6	41 143	9.3
<i>Average</i>	36 781	1701	7816	2472	36 445	0.9
<i>Cluster C</i>						
Albania	12 628	270.4	3 066.2	945.2	12 429	1.6
Argentina	23 397	646.1	3 522.7	1321.9	18 638	20.3
Armenia	11 695	238.2	2 160.1	660.4	10 161	13.1
Azerbaijan	14 460	264.8	3 609.2	1200.2	13 375	7.5
Belarus	18 472	579.6	5 161.4	1638.5	20 747	12.3
Bosnia and Herzegov.	13 318	359.9	2 438.3	958.7	12 865	3.4
Botswana	17 197	256.1	5 326.0	1145.5	14 852	13.6
Brazil	14 873	386.6	2 469.9	939.7	13 229	11.1
Chile	23 731	851.6	5 349.4	1223.0	23 308	1.8
China	13 537	246.7	5 745.3	1372.4	15 342	13.3

5. Transformation potential of digitalization and ways to increase national competitiveness

Continuation of Table 5.4

Country	GDP per capita, PPP (constant 2017 international \$) 2014-2018	Value added of the ICT sector, \$ per capita determine it, PPP, 2014-2018	Gross fixed capital formation, \$ per capita, PPP (constant 2017 international \$) 2014-2018	Average monthly earnings of employees	GDP per capita, calculated value	Error, %
Colombia	14 268	299.5	3174.5	836.4	12 850	9.9
Costa Rica	18 548	512.3	3381.6	1377.8	16 982	8.4
Ecuador	11 741	205.3	3049.9	453.8	10 242	12.8
Egypt, Arab Rep.	10 820	130.3	1550.4	1482.7	8 104	25.1
Georgia	13 134	370.0	3240.7	1099.5	14 459	10.1
Greece	28 883	893.9	3415.9	1351.5	20 852	27.8
Guatemala	8 207	119.6	1164.4	583.9	6 394	22.1
Jordan	9 930	150.5	1876.1	1364.7	8 982	9.5
Kazakhstan	24 653	598.7	5425.2	1339.1	20 802	15.6
Mauritius	20 682	689.8	8077.0	1176.0	24 449	18.2
Mexico	19 519	1083.3	4320.1	596.0	21 777	11.6
Moldova	11 128	365.5	2648.6	974.5	13 307	19.6
Peru	12 336	209.9	2730.9	1223.7	11 274	8.6
Philippines	7 723	117.7	1869.3	658.1	7 490	3.0
Russian Federation	25 989	861.9	5522.4	1565.0	24 380	6.2
Serbia	16 138	592.0	2823.0	754.0	15 702	2.7
South Africa	12 752	481.5	2475.9	529.2	13 366	4.8
Thailand	16 895	368.2	4013.9	1350.6	15 839	6.2
Turkey	26 719	717.7	7903.9	2040.0	26 375	1.3
Ukraine	11 878	497.9	1818.5	1008.2	13 295	11.9
Uruguay	20 990	556.2	3911.9	1182.6	17 984	14.3
<i>Average</i>	16 330	449	3653	1108	15 479	5.2
<i>Cluster D</i>						
El Salvador	8 303	126.1	1324.8	617.4	6 837	17.7
Ethiopia	1 891	9.9	715.6	185.0	1 905	0.8
India	5 817	96.6	1675.6	210.5	5 845	0.5
Indonesia	10 558	249.1	3428.0	410.1	11 266	6.7
Kyrgyz Republic	4 924	76.4	1575.5	693.7	6 095	23.8

The end of Table 5.4

Country	GDP per capita, PPP (constant 2017 international \$) 2014-2018	Value added of the ICT sector, \$ per capita determine it, PPP, 2014-2018	Gross fixed capital formation, \$ per capita, PPP (constant 2017 international \$) 2014-2018	Average monthly earnings of employees	GDP per capita, calculated value	Error, %
Mongolia	11 234	283.9	2776.5	1079.3	12 466	11.0
Namibia	10 191	165.3	2497.5	1047.3	9 848	3.4
Nepal	2 999	47.4	876.9	583.6	4 161	38.8
Nicaragua	5 717	85.7	1531.4	1071.7	6 649	16.3
Pakistan	4 436	62.5	634.6	566.2	4 145	6.6
Sri Lanka	12 211	237.2	3227.2	542.8	11 240	8.0
Uganda	2 440	23.6	812.9	446.5	3 043	24.7
Tanzania	2 069	19.6	505.7	267.0	2 297	11.0
Zambia	3 474	38.9	1246.0	951.0	4 594	32.3
<i>Average</i>	6 162	109	1 631	619	6 457	4.8
<i>Overall average</i>						11.6

Sources: The World Bank (2020). World Development Indicators. DataBank. Retrieved 14 November 2020, from <https://databank.worldbank.org/source/world-development-indicators>; International Labour Organization/ (2021). Statistics and databases. Retrieved 14 November 2020, from <https://www.ilo.org/global/statistics-and-databases/lang--en/index.htm>

In this context, it becomes obvious that the development of ICTs in isolation from the physical sector of the economy is not very promising. For example, in order to achieve a high level of income in the country belonging to cluster C, it is not enough to develop the digital economy itself, but it is necessary to have a high basic level of equipment and technologies and at the same time to rise investments in fixed assets, bringing them to the level of more developed countries. This is much more serious funds (see Table 5.4, the indicator "Gross fixed capital formation, \$ per capita, PPP (constant 2017 international \$) 2014-2018" by groups of countries) and problems that go beyond the digital economy itself and require solving a complex set of interrelated tasks, such as: maintaining a high level of development of national fundamental and applied science, building a modern system for training scientific and engineering personnel, creating a favourable innovation and investment climate for investing in the real economic sector, pursuing appropriate monetary and fiscal policies, developing mechanisms for transforming savings into investments, supporting a highly competitive environment, reducing transaction costs, including those associated with monopoly and corruption, etc.

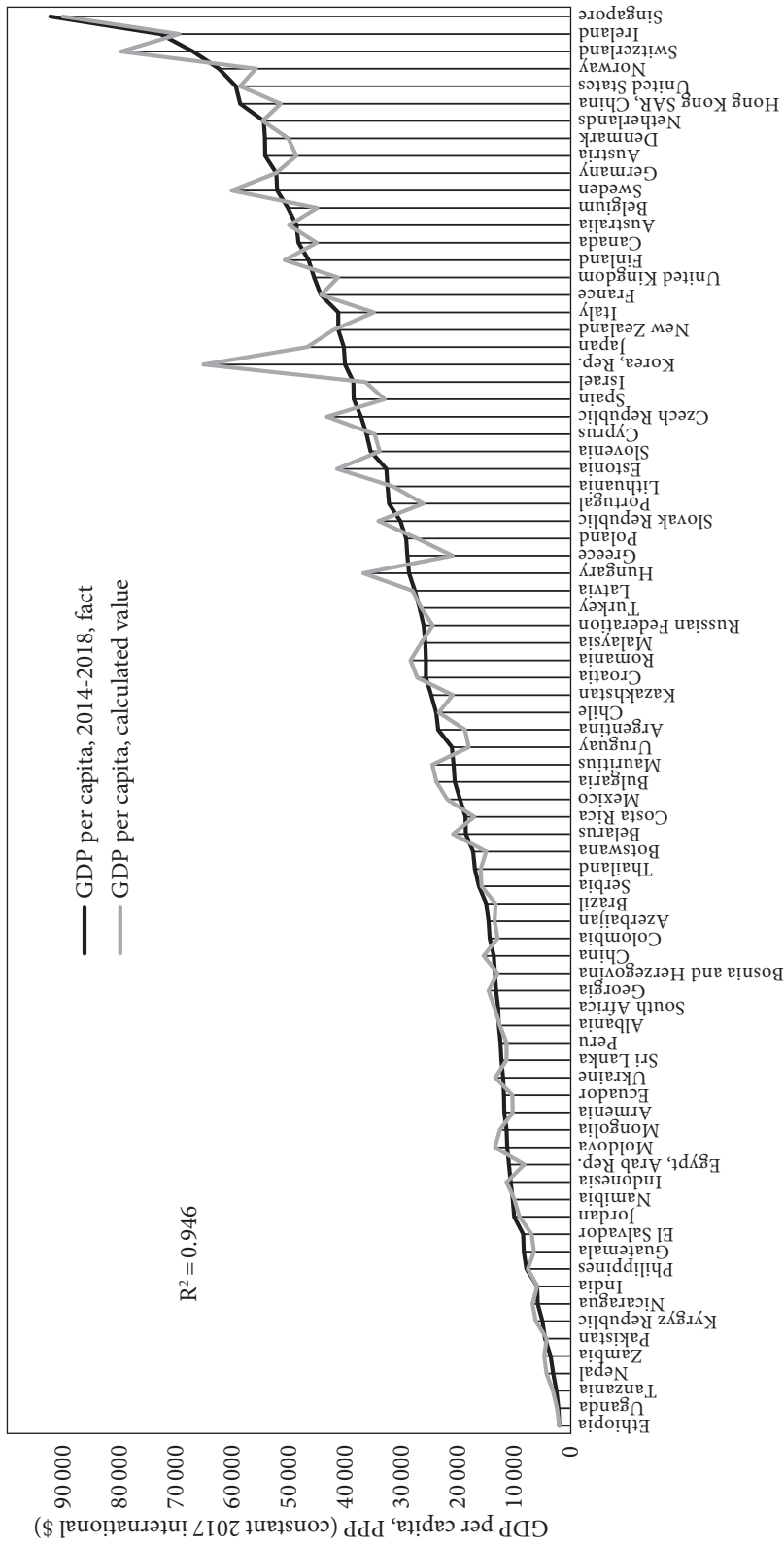


Fig. 5.5. Factual and calculated values of GDP of the analysed countries of the world

In connection with the abovementioned relationship between tangible and digital components of development, in order to assess the impact of "digit" on the economy, it is advisable to use the concept of technologies' life cycles (S-shaped curves).

Let us consider three countries: Ukraine as one of the former industrial leaders (1970-1980) (Cluster C) and the current industrial leaders Czech Republic (Cluster B) and Germany (Cluster A) — two EU members, to which Ukraine aspires to accede.

As known, today's Ukraine is characterized by a relatively low level of technological development. The industry that now forms the basis of its industrial potential (this is, first of all, branches of power and metallurgical complexes) are technologies of level 3.0 or lower. The opposite is the industry of the EU leader — Germany, — which by many features can be attributed to Industry 4.0 (cluster A). The Czech Republic, which traditionally belongs to the group of industrially developed countries, occupies an intermediate position. So, its industry can be conventionally called Industry 3+.

According to the concept proposed above, we assume that in each national economy, productivity (results) is a function of efforts in the form of investments in tangible and digital capital (so that tangible capital could not be increased without investments in digital capital) and the general level of R&D of the country. The result will be labour productivity (GDP per unit of the country's labour force) and expenses (efforts) will be capital-labour ratio (residual value of fixed assets per person). In fact, this is the classic dependence of labour productivity on the capital-labour ratio.

Herein each country develops its dominant technologies, so that large expenses (efforts) (x) are followed by large results (y), but this dependence is not linear, rather S-shaped, which is described by the logistic curve formula:

$$y = \frac{A}{1 + 10^{a - (1 + \mu)x}} + C, \quad (5.6)$$

where A is a parameter that defines the lower boundary of the logistic curve; C is a parameter that determines the difference between the upper and lower limits of the logistic curve; a is a parameter that defines the influence of R&D (the relationship between R&D expenses and labour productivity); μ is a parameter characterizing the tangible/digital capital ratio.

The parameterization of function (5.6) was performed by means of the MS Excel tool. For this, information on the analysed countries for 2005-2018 was used (except for the 2008-2009 period because of the global financial crisis, which caused sharp fluctuations in economic indicators). In this case, the parameter a was calculated with the aid of a correlation-regression analysis of variables characterizing expenses on R&D and labour productivity in the world countries of the (Fig. 5.6), and the parameter μ was defined adapting data from McKinsey & Co⁴. The rest of the model parameters were found via the MS Excel add-in "Search for solution".

⁴ Bughin J., Manyika J. (2013). *Measuring the full impact of digital capital*. McKinsey Quarterly. Retrieved 14 November 2020, from: <https://www.mckinsey.com/industries/technology-media-and-telecommunications/our-insights/measuring-the-full-impact-of-digital-capital#>

The calculation results are presented in Figs. 5.7 and 5.8. As shown in Fig. 5.7, even if Ukraine achieves the same capital-labour ratio as in the Czech Republic and Germany, in principle, it will not be able to catch up with them in terms of labour productivity, if only the development trends inherent in the last decade remain. Since technologies 3.0 are dominant in Ukraine, even the massive introduction of innovations, including those based on purchased technologies (the sphere of technology transfer in Fig. 5.2), will not be able to solve the problems of competitiveness of the national economy and its transition from the state of "raw materials appendix" of the developed countries" into the state of "a new industrial tiger" with dominant technologies 3.0+ and 4.0. The technological gap, measured by the lag in labour productivity at the same level of capital-labour ratio (\$ 0.1 million per person, if Ukraine reaches it), is: in comparison with the Czech Republic — productivity is about 5 times smaller (the gap is about \$ 30 thousand per person) and compared with Germany — about 10 times smaller (the gap is about \$ 65 thousand per person).

A more visual comparison of the countries mentioned in the paradigm of S-shaped technological curves is shown in Fig. 5.8, in which the interval of changes in the capital-labour ratio is significantly expanded compared with their real values, which makes it possible to clearly represent the upper and lower boundaries of the development of each generation of technologies (3.0, 3.0+ and 4.0).

As shown in the figure, the potential of technologies 3.0 (Δy_{3+}) is significantly lower than that of 3.0+ technologies, and, moreover, of 4.0 (Δy_4) technologies. At the same time, according to the concept of abrupt transitions from one technological curve to another, new generations of technologies start from relatively low indicators of economic activity, so that, at first, innovations may be unprofitable (line b_0 is located lower than line a_0 , and line c_0 is lower than line b_1). But then, over time, they are able to reach multiple returns on initial risky, low-profit or even unprofitable investments.

This means that fundamental decisions about national development should be made not only from consideration of current cash flows but taking into account long-term public interests that go beyond the scope of current economic recoupment problems. That is, strategic imperatives and long-term policy of social and economic development cannot be built relying only on market incentives and mechanisms, but it is also necessary to use the potential of democratic procedures and public institutions, enhanced by Big Data analysis, artificial intelligence and other modern scientific tools, which allows a glimpse into a risky high-tech future.

Another remark: the simulation results shown in Fig. 5.8 set relatively large intervals for the growth of labour productivity (e.g., for technologies 4.0 it is about three times higher than the real values). However, in fact, this is not very much, and the order of values obtained from the parameterization results can be considered normal. To support this statement, historical data on labour productivity in Germany over the past half century can be cited (Fig. 5.9).

During the observed period (1970-2018), labour productivity increased by almost 2.5 times. Therefore, taking into account the factor of accelerating scientific-technological progress and the exponential growth of productivity of modern key

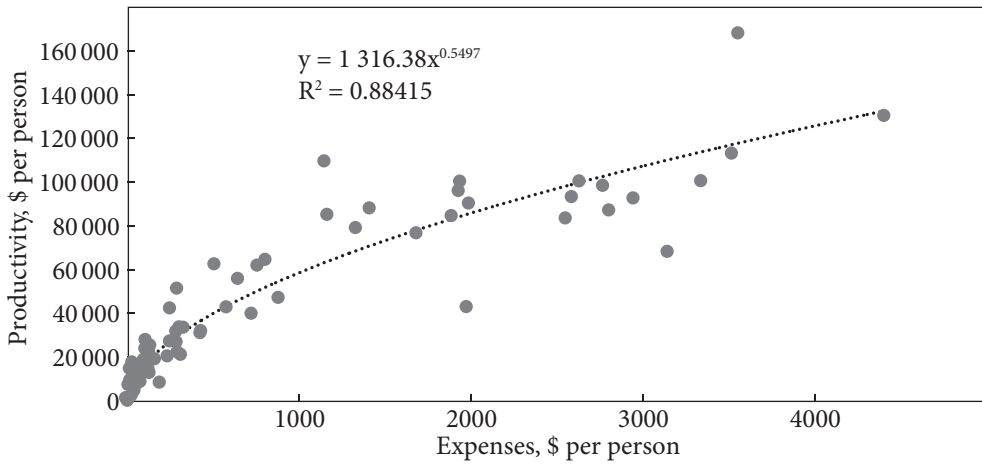


Fig. 5.6. Dependence of labour productivity on the R&D expenses by the world countries
 Source: The World Bank (2020). World Development Indicators. DataBank. Retrieved 14 November 2021, from <https://databank.worldbank.org/source/world-development-indicators>

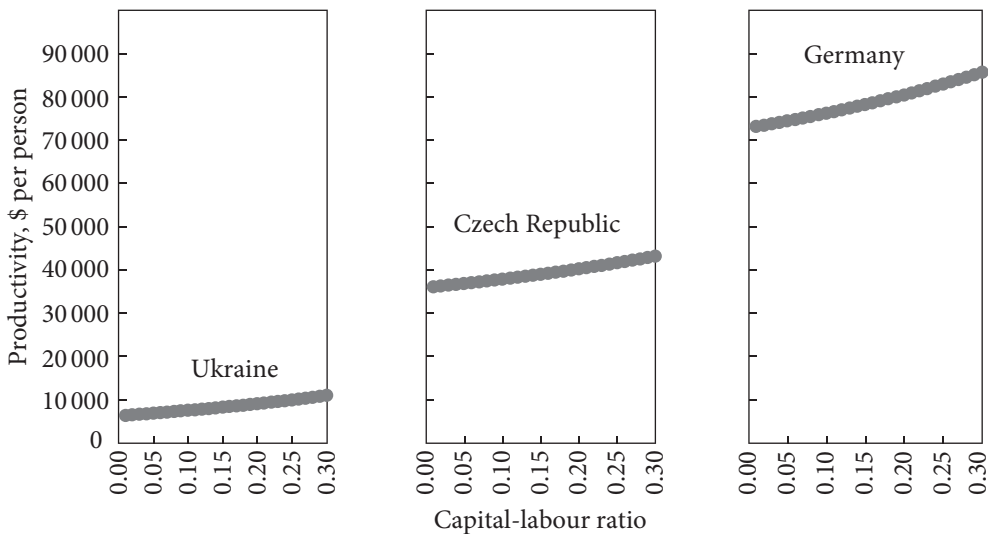


Fig. 5.7. The relationship between the capital-labour ratio and labour productivity in Ukraine, Czech Republic and Germany (the factual capital-labour ratio in Ukraine is \$ 0.007-0.010 million per person, in the Czech Republic \$ 0.12-0.17 million per person, in Germany \$ 0.23-0.30 million per person)

technologies, the figures obtained via economic-mathematical calculations (F. 5.6) can be considered even somewhat pessimistic.

Of course, one can argue that the trends calculated using historical data do not say anything about how the situation may change in the future, if the country makes a "jump" and moves from one technological curve to a new one. This can happen.

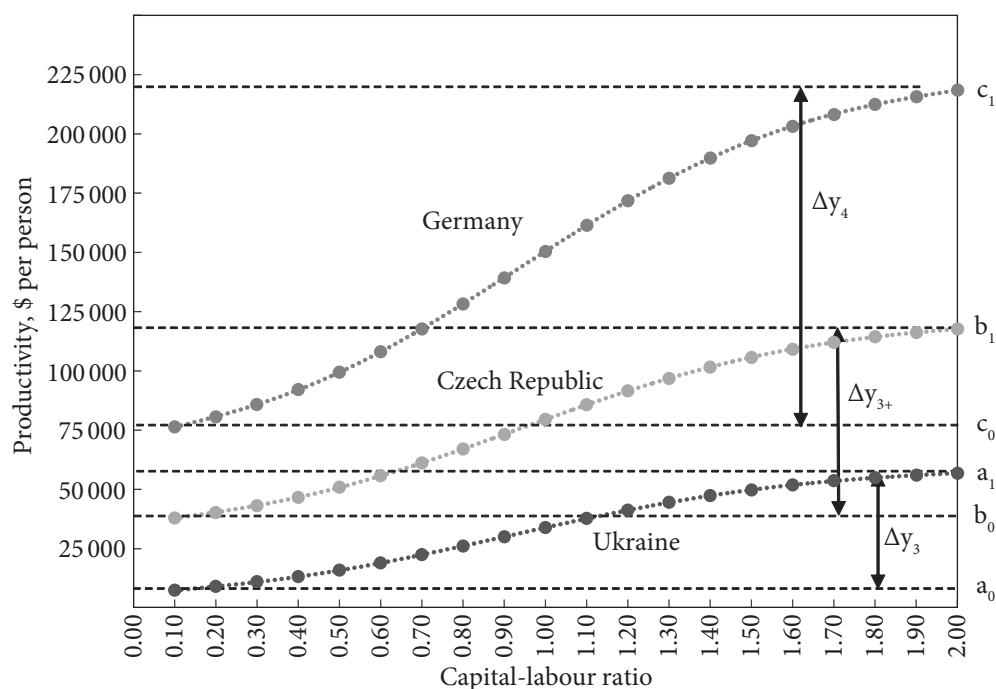


Fig. 5.8. S-shaped technological curves for Ukraine, Czech Republic and Germany

But at the same time, it is important to understand that such a transition is a very complex problem, which cannot be considered as only an engineering, or as only a financial one (since the problem of technological gaps cannot be solved by "pouring" money). It is also of fundamental importance to take into account the peculiarities of the institutional environment, formed under the influence of geographic, socio-cultural and other factors, that is, it is required to consider the problem in the context of the historical process of development of national industrial ecosystems (Soldak, 2019) with all their pros and cons.

5.3. WAYS TO ENHANCE THE TRANSFORMATION POTENTIAL OF THE NATIONAL ECONOMY'S DIGITALIZATION AND COMPETITIVENESS

As shown by the analysis performed, digital technologies are an important factor in the national economic growth in conjunction with the development of the national industry. In this sense, the issue of increasing their transformational potential is part of a more general problem of choosing ways to overcome the technological lag of the national industry and the economy as a whole in the new digital reality.

In view of the concepts of technologies' life cycles and technological and financial gaps, transfer of technologies from abroad is not a reliable mean of solving this

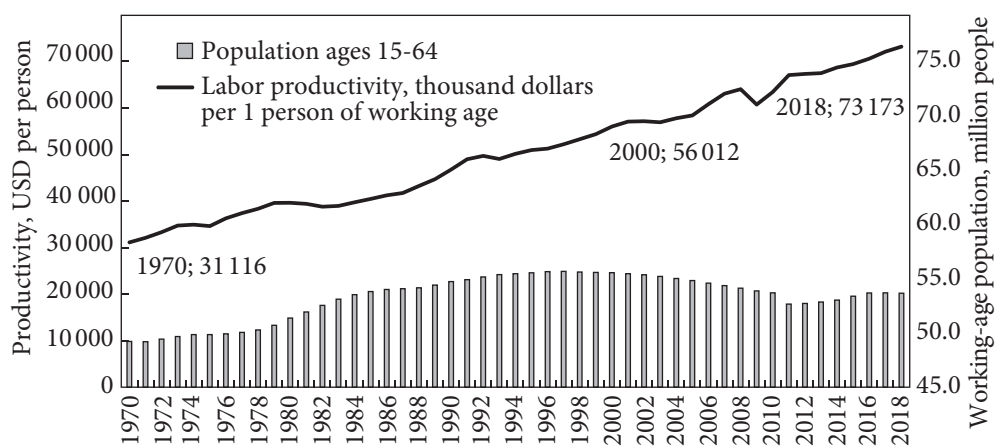


Fig. 5.9. Working- age population and labour productivity in Germany over the period 1970-2018
 Source: The World Bank (2020). World Development Indicators. DataBank. Retrieved 14 November 2021, from <https://databank.worldbank.org/source/world-development-indicators>

problem, since, as shown in Fig. 5.2, transfer technologies usually have a limited potential for physical performance gains and contain a built-in lagging mechanism. Obviously, in order to significantly raise the national engineering and technological level, a country needs its own science integrated with production, that is, an accelerated development of the national R&D sphere (both to carry out own scientific and technical developments, and to adapt borrowed ones).

As noted in (Vishnevsky, Knjazev, 2018), at the current stage of development of Ukraine, taking into account the global trends towards increasing the scientific capacity in the advance of all fields of public life, the national science, perhaps, is the weakest link in the chain of existing problems. In the complex of measures to improve the quality of institutions, to promote the development of digital and production technologies (which will be discussed further), special attention should be paid to the national science.

The total (government and business) R&D expenses in Ukraine for the period 2010-2018 amounted to only 0.47% of GDP, when the world average level at the same period was 2.22% (i.e., by 4.7 times higher than in Ukraine) (Table 5.5).

Keeping in mind that Ukrainian GDP (in terms of PPP) also lags behind the world average value by about 1.4 times, the real expenses on R&D in the state are almost 7 times less than the world average. The situation is somewhat better, but not much, in reliance on number of researchers: this specific indicator is slightly less than the world average (Ukraine: 1.0 thousand researchers, the world: 1.4 thousand per million population).

Nevertheless, Ukrainian researchers produce much more products per unit of current and capital expenses than their colleagues in the world on average, and even more than their colleagues in the industrial leaders such as the United States, China and Germany. This, however, does not mean that the national science as a

whole works satisfactorily. The indicators given in the table per person employed in R&D can hardly be called outstanding. Although even these results, when recalculated for \$ 1 million expenses, can be considered relatively high (except for the indicator of high-tech exports). For example, per \$ 1, a Ukrainian researcher publishes about 4.6 times more scientific articles than researchers in the world on average. This means that the country's expenses (public and private) for 1 scientific article prepared by Ukrainian specialists are approximately 4.6 times lower than the world average.

In other words, Ukrainian researchers still maintain a relatively decent level of results without receiving adequate funding. For such financing, science does not work either in the USA, or in Germany, or in China. And this is a real problem. In the end, cheap science is costly to society. This is first.

Second, relatively good (taking into account the funding factor) results of Ukraine in the field of scientific and technical reserve are poorly introduced in current production. China, e.g., uses its R&D much more efficiently. In this country, for example, high-tech exports per 1 industrial design are almost 5 times higher than in Ukraine. This means that the existing national scientific potential works largely for foreign, rather than for national industry.

Another problem, which is clearly manifested in the light of international comparison, is related to the fact that in the most technologically advanced countries of the world, the main source of funding R&D is not the state, but business. For example, in Germany the share of private capital in the sources of R&D funding is 67.7%, in the USA — 71.5%, Japan — 77.8%, the Korea Republic — 78.2%⁵. It is the demand from business (dominantly industrial) that allows maintaining a high level of R&D in these countries. That is why the modern industry is considered to be a driver of innovations. And if there is demand, then supply appears. In Ukraine, science is mainly financed by the state (46%), plus a significant part comes from abroad (22%) (as on 2018). Business, in comparison with the leading industrial countries, finances science very little (30%). This indicates an evident weakness in private demand for high-tech developments. A similar picture is observed in the Russian Federation⁶, although there the situation in the field of science financing looks better.

Of course, it can be noted that proposals from the national science also leave a great deal to be desired. And this is true. However, the fundamental issue, apparently, is still not in science. With any, even the best offer, a steady demand for science products from business requires a long planning. If it is short (limited by

⁵ UNESCO Institute for Statistics (2020). How much does your country invest in R&D? Retrieved 12 December 2020, from <http://uis.unesco.org/apps/visualisations/research-and-development-spending/>

⁶ As Russian experts note, "...despite significant investments in Russian science by the state, this area remains insufficiently productive, does not form its own scientific and technological basis for creating and implementing priorities responding to the "big challenges" facing society and state and does not act as a driver for socio-economic development" (Konstantinov, 2021, p. 51).

Table 5.5. Indicators of science and technology development in selected countries of the world (2010-2018, on average)

Indicator	World	USA	China	Germany	Russia	Ukraine	Ratio Ukraine / World, %
Researchers full-time equivalent per million people	1438	4245	1225	5003	2822	988	68.7
Expenditures for R&D, % of GDP	2.22	2.79	2.15	3.02	1.11	0.47	21.2
Total number of researchers, thousand people	10919	1387	1706	415	408	44	0.4
Expenditures per researcher, PPP, \$ millions	0.256	0.403	0.263	0.324	0.107	0.056	21.7
<i>Return per 1 researcher</i>							
Scientific and technical journal articles, units	0.234	0.305	0.310	0.252	0.200	0.236	100.7
Patent applications filed by residents, units	0.210	0.206	0.817	0.112	0.061	0.048	22.8
Industrial design applications filed by residents, units	0.095	0.016	0.404	0.094	0.009	0.119	125.3
High technology Exports, \$ millions	0.246	0.113	0.429	0.507	0.025	0.028	11.5
<i>Return on expenses per 1 researcher</i>							
Scientific and technical journal articles, units per \$1 million rld	0.91	0.76	1.18	0.78	1.88	4.24	463.2
Patent applications filed by residents, units per \$1 million	0.822	0.510	3.101	0.347	0.573	0.860	104.7
Industrial design applications filed by residents, units per \$1 million	0.373	0.041	1.533	0.289	0.088	2.148	576.2
High technology Exports, \$ per 1\$	0.962	0.279	1.628	1.564	0.234	0.509	52.9

Source: The World Bank (2020). World Development Indicators: Science and technology. Retrieved 24 December 2020, from <http://wdi.worldbank.org/table/5.13#>

the length of the political cycle), then the costs of innovations simply do not have enough time to be paid back. It is therefore more profitable for the dominant business owners in Ukraine to satisfy economic interests not at the expense of risky

innovations, but by using the resources of the power and obtaining rent, which is often observed in practice.

The described situation in the field of R&D has settled not due to the fact that Ukrainian scientists, relying on the long-standing traditions of scientific schools in various fields of knowledge, work and are organized so poorly (although organizational innovations here are required as well), but rather due to poor funding of science. The reasons for this are rooted not so much in the insufficient attention of the state to this area, but in the weak demand for scientific and technical developments from the business side. Such demand, in turn, is associated with a short planning distance, within which business prefers not long-term innovations, but quick results due to the use of power resources and rent-seeking behaviour. The short planning horizon is induced by the strategic instability of development under the influence of political factors. A society that lives in the rhythm of short-term cycles of revolutionary transformations of politics and property cannot be stable and rich. Thus, the circle is complete.

In order to break it, it is drastically important to bring the development of the economy and its driver — industry, which is now experiencing a period of another upsurge and restructuring in the world, beyond the framework of short-term political cycles that generate instability and social inequality. For this, first of all, it is necessary to create: i) long guarantees of property rights, including on intellectual property; ii) long public-private development strategies, including in the field of the digital economy and new cyber-physical production; iii) long development institutions based on the principles of independent regulatory agencies (Shapiro, 1997), which changes in the rules of functioning and management should go beyond permissions of the following political power.

All this again underlines the importance of the thesis that technologies do not develop in a vacuum, but in the current socio-cultural and institutional environment. This is also evidenced by the latest achievements of institutional and evolutionary theory in economics, which argue that for successful development, institutions of a predominantly inclusive, not extractive, type are important (Acemoglu, Robinson, 2016) alongside with developed cultural capital (Harrison, 2014), organizational routines that meet the requirements of high-tech (Hodgson, 2003), which in the complex can be called an innovation-oriented industrial ecosystem. It is that very ecosystem Ukraine has to urgently create, in line with other countries of emergent economies (Fig. 5.10).

The main idea of this approach lies in the frame of the tech-ecosystem paradigm. The desired transition to Industry 4.0 (vector \vec{P}_4), in addition to technologies of the appropriate level, requires a simultaneous transformation of human capital, technologies and institutions, which cannot be achieved immediately. As J. Diamond rightly noted, one cannot just share the experience of efficient institutions with poor countries and expect them to apply the knowledge gained and, as a result, catch up with the United States or Switzerland in terms of GNP per capita. Efficient institutions always grow as a result of a long chain of historical accomplishments, from

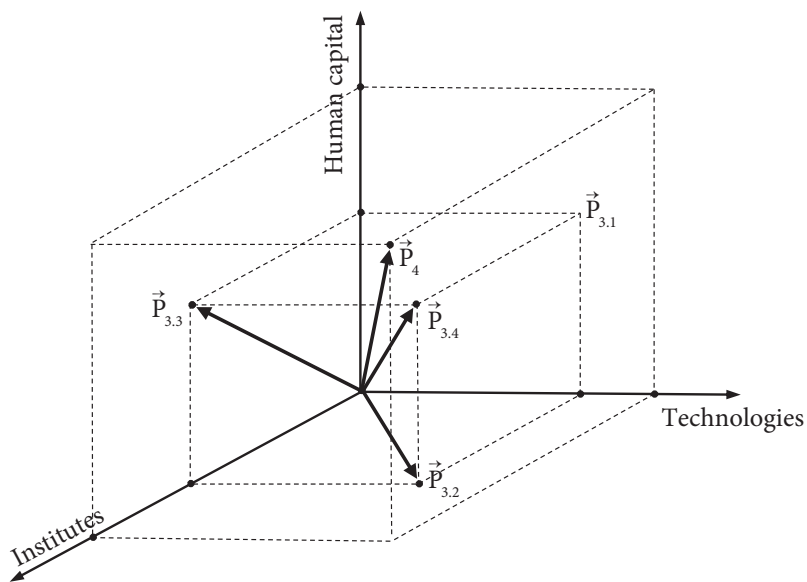


Fig. 5.10. Graphic illustration of the basic vectors of industrial ecosystem development

initial factors of geographic nature to direct factors derived from them, among which there are institutional ones (Diamond, 2010, p. 561).

At present the most realistic vectors of development for Ukraine are vectors of development of the Industry 3.0 technologies ($\vec{P}_{3,1}$, $\vec{P}_{3,2}$, $\vec{P}_{3,3}$, $\vec{P}_{3,4}$), although it is clear that with such formulation of a question, Ukraine remains within the category of a technological gap (i.e., where countries are located on different technological curves), rather than within a more desirable category of lagging technology (where countries are on the same technology curve). Moreover, to accelerate the development of these technologies and reduce the current lagging behind the industrially developed countries, a number of steps must be taken, considering the abovementioned vectors.

5.3.1. Vector of technology development

Defining the list of key technologies. First of all, Ukraine should make decision at the government level on the fundamental list of key technologies that can form the base of new industrialization, taking into account the peculiarities of the current state of the national industry as well as socio-cultural and institutional environment. For this, it is necessary to carry out a critical analysis of the well-known strategies of innovative, scientific-technological and industrial development in the world, primarily in Europe; to conduct a SWOT analysis and foresighting of the development of the Ukrainian industrial system; to develop and periodically update the list of key technologies, which provide the base for innovations in a number of products and proc-

esses in industries; to create for this, following the example of the EU, a High-Level Panel on Key Technologies⁷.

Rise funding for R&D. Funding for Ukrainian science is now unsatisfactory. This is one of the main reasons for the multiple reduction in number of scientists⁸ and the general difficult situation in the national R&D sphere. Therefore, it is very important to ensure a gradual increase in R&D expenses to a level above the average for countries of cluster C (Fig. 5.4). To reach this, it is necessary, e.g., at the first stage (2021-2023) to increase R&D expenses to 0.7% of GDP, at the second stage (2023-2026) — up to 1.1% of GDP and at the third stage (2027-2030) — up to 1.5% of GDP, including at least half at the expense of the private sector. This, in turn, requires the creation of an efficient system to stimulate business participation in R&D, with taking into account European experience⁹.

Promotion of accelerated development of digital technologies. A key for accelerating the technological development of Ukraine on the basis of modern ICTs are:

the government assistance in the development of avant-garde digital technologies, in particular — 5G, on which the Internet of Things is based;

intensification of work on improving coverage of previous generation technologies and improving the quality of mobile communication;

help with the implementation of international technological standards in the field of advanced digital technologies.

Currently, there are several institutions in the world that develop standards in this field. Given this situation, the State Committee of Ukraine on technical issues and consumer policy should activate the work on adapting the ICT standards widespread in the world into the system of national standards of Ukraine. It is also advisable to define how Ukraine can be involved in the creation of international standards. Such a proposal is not something unique or impracticable in an emergent economy. An example is the Republic of Belarus, where in 2018 the National Technical Committee for Standardization "Digital Transformation" was created to determine the directions of ICT development and develop standards in accordance with the

⁷ European IP Helpdesk. (2020). *High Level Expert Group on Key Enabling Technologies: final report*. Retrieved 14 December 2020, from <https://www.iprhelpdesk.eu/news/high-level-expert-group-key-enabling-technologies-final-report>

⁸ In 1991, there were about 450 thousand scientific workers in Ukraine (approximately 1% of the population, which corresponded to the average for Europe), of which 295 thousand were researchers. 17.1% were employed in academic science, 66.8% in industrial science, and 16.1% in university and factory science. In 2018, according to the State Statistics Service, the total number of researchers was already less than 60 thousand people (5 times lower than in 1991), of which about 30 thousand people worked in the public sector. See: Dzerkalo Tyzhnia (2019). Over thirty years in Ukraine entire scientific areas have disappeared - surveyor. Retrieved 06 December 2020, from https://dt.ua/UKRAINE/za-tridcyat-rokiv-v-ukrayini-znikli-cili-naukovi-galuzi-oglyadach-332274_.html

⁹ For example, in countries such as Austria, Belgium, Canada, Denmark, France, Ireland, Netherlands, Spain and the United Kingdom, a business is provided with a payable R&D credit, by which it receives money from the state, even if it has tax losses (i.e., when the total deductions that an entity may claim for the reporting period exceed the amount of taxable income) (PwC, 2017).

international trends and needs of the national economy, within which officials work closely with technical specialists and scientists in this field¹⁰.

5.3.2. Vector of human capital development

Government assistance in human development. Bridging gaps in human development in the context of meeting the needs of new industrialization and digitalization involves, inter alia, reforming the current education system, primarily — higher education, expanding opportunities for retraining and obtaining education throughout life for the constant updating of knowledge and skills in line with the developing advanced technologies.

During the period 2015-2019 total expenses on higher education in Ukraine decreased by almost 50%, predominantly via government's funding, which led to reduction in the number of institutions and teachers of higher education (Chekina, Vorhach, 2020). Against this background, there is still observed a certain inertial growth in the share of highly qualified personnel in its total number. This trend contradicts the economic theory and practice of many European countries, where, in connection with the Fourth Industrial Revolution, it is relevant to increase funding for higher education in order to solve the problem of STEM personnel shortage.

To a certain extent, the current situation in Ukraine is related to not only the moderate quality of higher education (judging by the rating of universities) (World Bank, 2020), especially in the field of STEM personnel training, but also the shadow economy factor.

To solve these problems, which are typical for many emergent economies, additional efforts are required in order to:

- Provide a state priority for the development of STEM education for a new workforce that is entering the labour market, including through a state order for a list of specialties and directions of training in the higher education system that are critical for the development of smart industry.
- Develop a national system of advanced training and retraining of labourers already involved in production (in particular, with the participation of high-tech national companies in the development of vocational education system, in the training and advanced training of specialists for industry with subsequent employment in these companies).
- Promote government actions directed to labour mobility and development of alternative forms of employment, including the creation of digital platforms for talented people and development of public economy, that is, networks, in which people can work without a formal labour agreement, as well as in the remote access mode, the importance of which has become obvious in the context of the coronavirus pandemic problems.
- Support incomes and arrange financial aid and other forms of assistance in finding new decently paid jobs and transferring employees from one job to another.

¹⁰ Gosstandart (2018). Read in the journal "Standardization", № 5-2018. Retrieved 14 December 2020, from: <https://gosstandart.gov.by/read-in-the-journal-standardization,-no-5-2018>

Business investment in the development of STEM personnel. Solving the problem of accelerating human development requires attracting sponsor opportunities to support public digital educational platforms for STEM learning within the framework of non-formal and informal (outside the standard educational environment) education, organizing events to promote STEM education and lifelong learning. An important direction in this field is financing by business of crowdfunding educational platforms and educational centres that expand opportunities for STEM education and lifelong learning aimed at constantly updating skills, including digital ones. To increase the interest of business in cooperation with educational institutions, as well as in training, retraining and advanced training of personnel, appropriate economic incentives can be used (Chekina, Vorhach, 2019).

5.3.3. Vector of institution development

Creation of industrial development management bodies. In solving the strategic problem of overcoming the current negative trends in the field of industrial development, one cannot rely only on the market mechanism and economic incentives, which do not always work well in an emergent economy. To do this, it is advisable to create a special governing body and endow it with the necessary powers and resources, so that it could be authoritative for both government officials and private businesses (which now controls most of the Ukrainian industry). It is also important to move its activities beyond the current political environment (owing to the special status established by a special law), since long strategic, rather than short politically motivated decisions, are needed to develop industry on an innovative basis. An example of such a governing body is the world-famous Ministry of International Trade and Industry (MITI) in Japan, which once played a significant role in accelerating the technical and economic development of this country¹¹.

Improvement of fiscal institutions. There is no provision in the Ukrainian budgetary and tax legislation that define a long-term policy in this field. Obviously, the Ukrainian state should formulate and legislatively consolidate more fundamental and broader concept of the development of taxes as an integral system, in which priority areas and explicit fiscal rules for its development will be defined¹². The main direction of tax policy in the long term should be the creation of favourable conditions for industrial development by shifting the emphasis from taxation of production results (which are easily deducted from taxation through digital transactions) to technically improved sales taxation, as well as used in production

¹¹ An important component of MITI's achievements was the high qualifications of officials, since the ministry was able to hire the best managers in the country. It was a veritable "think tank" that controlled planning and regulated industrial and energy policy, national production, international trade and part of finance, especially tax policy and capital supply (Johnson, 1982, p. 319).

¹² Currently, there is a trend towards an increase in the number of explicit fiscal rules for permanent restrictions on fiscal policy expressed in terms of simple quantitative restrictions for budget aggregates (Fiscal Affairs Department, 2016, p. 4).

resources, primarily natural. Important steps in this direction can be the development of a digital mechanism for administering VAT¹³, as well as replacing the corporate income tax with a tax on withdrawn capital (Vietska, 2018), which easily undergoes digital algorithms.

Improvement of monetary institutions. An important condition for an accelerated development of industry based on digital technologies is the availability of enterprises' access to long and cheap money. In many developed countries the cost of loans is now at a historically low level. In Ukraine interest rates are also gradually decreasing. However, first, they are still much higher than in many other, including emergent, economies. Second, bank financing is inherent in failures, which must be corrected, including with the help of such well-known institution as development banks. Such banks help to counter the procyclical nature of the privates financial system. They can provide financing for innovative enterprises and infrastructure projects, credit support for small producers, environmental projects, etc.¹⁴ To create such a development bank in Ukraine, it is necessary to develop an appropriate law, which will define, in addition to the basic provisions on the mission and functions of this entity, the procedure for monitoring the results of the bank's activities and responsibility for failure in fulfilment of the tasks assigned to it (Matyushin, Aborchi, 2016).

The implementation of the above recommendations and suggestions will contribute to the improvement of the progress of policy in the field of technological development and increasing the efficiency of national industry. However, due to the fact that Ukraine is a low-tech export-oriented economy, which is highly dependent on external conditions, it will be very difficult to implement the proposed recommendations in practice, since simultaneously with overcoming technological gaps, Ukraine has to respond to (1) fluctuations in prices for such important items of national exports as iron ore and metals, which occur, inter alia, due to the uneven recovery of global economic growth after the crisis caused by the COVID-19 pandemic; (2) expected rise in prices for imported hydrocarbons; (3) fluctuations in the exchange rate of the dollar, on which the Ukrainian monetary system and the economy as a whole critically depend; (4) growth of protectionist measures because of increased competition due to the global redistribution of industrial capacities.

¹³ An example is the Russian Federation, which is ahead of many foreign jurisdictions in terms of the level of digital VAT administration (Mishustin M. (2019). People take an example from Russia and come to study. *Kommersant*, No. 214 of November 21. Retrieved 15 February 2020, from <https://www.kommersant.ru/doc/4165008>). In Russia in the field of tax administration, websites, web portals and personal electronic services were first created. Currently, work continues on mobile applications and individual proactive services. In the near future, tax administration is to turn into an adaptive digital platform that is functioning exclusively with digital data and electronic entities.

¹⁴ Griffith-Jones S., Ocampo J.A. (2019). *Why the World Needs National Development Banks. Project Syndicate*. Retrieved 06 November 2019, from <https://www.project-syndicate.org/commentary/national-development-banks-sustainable-growth-by-stephany-griffith-jones-and-jose-antonio-ocampo-2019-05>



CONCLUSIONS

The digital revolution lasts for several decades, especially intensely since the time, when the amount of digital information in the world exceeded the amount of analogue data (early 2000s). Nevertheless, many problems remain unsolved, and even more new issues have appeared. Therefore, it is so important to draw a certain line under researches carried out on problems of the digital economy in the framework of developing and emerging countries, as well as outline the directions of further search for their solutions. In this regard, let us highlight some scientific provisions that can serve as an object for criticism and a starting point for further analysis.

1. Based on studies of the current technical and economic processes in the era of the digital revolution, as well as structural and etymological analysis of known definitions, it is proposed to interpret ICTs as a whole complex of methods and processes of information production, storage, processing, transmission and perception by humans or special devices alongside with scientific description of such methods and processes.

It is also proposed to expand the definition of the concept of ICT infrastructure by including the system of training and re-training of personnel in the field of ICTs and computer literacy of a country's population. In accordance with this approach, the ICT infrastructure is considered to be a combination of a computer technology, telecommunication equipment, data transmission channels and information systems, means of switching and managing information flows, organizational structures with legal and regulatory mechanisms ensuring their effective functioning, as well as systems for providing computer literacy of the population, professional training and retraining of specialists in the ICT sector.

2. On the basis of analysis of the categorical apparatus of the digital economy and taking into account the advanced rates of development of digital technologies, it has been established that the digital economy is an economic activity based on digital ICTs and a wide network of connections between individuals

and legal entities, material and intangible objects, production and non-production processes created with the help of these technologies.

It is proposed to distinguish the digital economy in the narrow and broad sense. From the viewpoint of the coverage of types of economic activity, the digital economy in the narrow sense represents the value added created in the sectors of ICT industry and ICT services, whereas the digital economy in the broad sense is the value added created in all sectors of the economy with employment of ICTs and ICT infrastructure.

3. It was shown that introduction of up-to-date digital technologies in various fields of public life exerted a deep and multifaceted impact (both positive and negative) on the environment. At the same time, at the global level, it is generally characterized by a positive tendency: the higher the level of digitalization, the more environment friendly national economies are, other things being equal.

Furthermore, it was also established that the environmental efficiency of digitalization depends on the level of production technologies (i.e., physical) and the general economic development of the country. In groups of less developed countries, including Ukraine, the spread of digital technologies exerts clearly weaker positive impact on the environment as compared with clusters of more developed countries. Therefore, long-term positive effects of digitalization in emergent economies are not obvious, whereas negative ones can be serious. To minimize environmental risks, it is necessary to intensify researches in the field of comprehensive assessment of various aspects (abiotic, biotic, anthropogenic) of the impact of the latest digital technologies on humans and the environment.

4. As a result of the analysis of economic and mathematical models of the ICTs' impact on economic development, it was found that such models are mostly based on the Cobb-Douglas production function modified according to R. Solow. These models allowed obtaining a number of very different and contradictory assessments of ICTs' impact on the economy, but in general, the main conclusion that can be drawn from them is that, contrary to the "Solow paradox", digitalization is of great economic significance.

The results of the performed analysis made it possible to suggest building an assessment of the transformation potential of digitalization of the economy on the following principles:

- The digital economy is important not so much in itself, rather as an integral part of cyber-physical production systems, which form a new mode of production, and related systems of institutions and socio-economic relations; therefore, effects of digitalization depend on the hardware performance.
- Relationship between digital expenses and performance results, mediated by development of cyber-physical systems, cannot be considered universal and uniform for all times and people. Therefore, if diverse technological modes dominate in different countries (groups of countries), then the consequences of digitalization in these countries (groups of countries) will vary as well.
- To define the effects of digitalization, it is advisable to use the concept of the technologies' life cycle, described by S-shaped curves and abrupt (rather than

smooth) transitions from one curve to another owing to changes in the dominant technologies in a particular country.

- It is necessary to take into account not only technological, but also institutional factors, because, all in all, the efficiency of new technologies' introduction is also defined by the extent, to which formal and informal norms of behaviour dominating in a particular society are favourable for innovations.

5. Through the employment of the multiplicative exponential function of specific (per capita) GDP for 82 countries of the world over the 2014-2018 period depending on the factors of capital, labour productivity and the level of digital development, it was established that the digital economy indeed significantly influences the economic growth, but its impact is smaller than that of traditional factors of production. Herein, the power of the impact differs depending on the technological and general level of development of countries.

The last statement was confirmed by the cluster analysis, which resulted in the forming four groups of countries, interpreted as the countries of Industry 4.0 (group A, 13 countries), Industry 3.0+ (group B, 23 countries), Industry 3.0 (group C, 31 countries) and Industry 2.0 (group D, 14 countries). In the clusters of lagging behind countries (C and D), some indicators of the digital economy development look decent, whereas the gap in the development of high-tech production is very large.

6. In the frame of the economic theory of the life cycle of technologies, a refined concept of the technological gap between countries from different clusters is proposed, which is associated with a jump-like transition from one technological curve (representing the dominant level of technology in a given country) to another.

To assess the size of technological gaps between countries, it is proposed to use a logistic function, which defines the relationship between the labour productivity and the capital-labour ratio, taking into account the interdependence of physical and digital capital. Through its application, technological gaps between Ukraine and industrially developed European countries was ascertained, which were measured by multiple lags in the labour productivity.

Based on the analysis performed, a conclusion was drawn that in order to reduce technological gaps between emergent and advanced economies, it is necessary to create a new, innovation-oriented, business ecosystem at the expense of simultaneous improvement in developing technologies, human capital and institutions, taking into account the path-dependence.

* * *

The developed conceptual statements and findings can be used to deepen understanding of the digital economy problems and to form plans for the digital transformation of developing economies.



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LIST OF ACRONIMES

GNI	—	Gross National Income
GVA	—	Gross value added
ICT	—	Information and communication technology
IMF	—	International Monetary Fund
IoT	—	Internet of Things
IIoT	—	Industrial Internet of Things
ISIC	—	International Standard Industrial Classifications of All Economic Activities
IT	—	Informational Technologies
NRI	—	Networked Readiness Index
OECD	—	Organization for Economic Co-operation and Development
R&D	—	Research and Development
STEM	—	Science, Math, Engineering and Technology
STP	—	Scientific and technological progress
TEA	—	Type of economic activity
UNEP	—	United Nations Environment Programme
VA	—	Value added
WB	—	The World Bank

Досліджено особливості процесів цифровізації економіки і цифрових інформаційно-комунікаційних технологій, визначено чинники впливу процесів цифровізації на результати економічної діяльності, проаналізовано методичні підходи до моніторингу й оцінки ефективності цифровізації, побудовано функції залежності цифрових витрат і реальних результатів економічної діяльності, оцінено трансформаційний потенціал цифровізації національних економік й обґрунтовано рекомендації з підвищення їхньої конкурентоспроможності.

Для наукових співробітників, викладачів, аспірантів, студентів, усіх тих, кого цікавлять проблеми цифровізації економіки, промислових революцій та інноваційного розвитку.

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