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UKRAINE'S DIGITAL FRONTIER: A DEEP DIVE INTO ICT SECTOR COMPETITIVENESS

Summary

The research consists of introduction, three chapters, conclusions and references. The first chapter examines Ukraine's ICT ecosystem with the focus on its digital infrastructure and talent pool, analysing various indicators (e.g. broadband penetration, internet connectivity, digital services availability, quality and quantity of human resources in the ICT sector, education and workforce demographics). The second chapter examines the regulatory frameworks governing Ukraine's ICT sector and indicates their impact on technological advancements and R&D activities. Additionally, the second chapter analyses recent technological advancements within Ukraine's ICT sector, highlighting key areas of R&D focus and trends in patent grants. The final chapter suggests strategies to boost Ukraine's ICT sector's competitiveness, including infrastructure development, talent management, regulatory reforms, investment incentives, and international collaboration. These recommendations aim to foster growth, innovation, and sustainability, positioning Ukraine as a hub for ICT innovation, driving economic development, and global competitiveness. The conclusion synthesizes key findings from the research and highlights the importance of addressing challenges and leveraging opportunities within Ukraine's ICT sector.

Introduction

The digital environment in Ukraine has witnessed a profound shift in recent years, propelled by the imperative of digital development and transformation amid the COVID-19 pandemic and the subsequent outbreak of the war in February 2022. Prior to these turbulent events, the ICT sector in Ukraine had been on a trajectory of rapid growth, albeit not yet fully integrated (as a significant component of the economy) with traditional sectors such as trade, heavy industry, and agriculture dominating the GDP share.

The war that engulfed Ukraine impacted all facets of life, including the burgeoning IT industry. Despite the challenges posed by the ongoing war, many stakeholders remain optimistic about the future trajectory of the ICT sector, envisioning it as a pivotal force enhancing Ukraine's resilience and driving its economy to recovery in the post-war period. However, the reality paints a different picture: it is confirmed by the decline experienced by the Ukrainian ICT sector in 2023, marking a departure from its previous status as a key economic driver.

Prior to the war, the Ukrainian ICT sector had garnered international recognition for its significant contribution to GDP, with export revenues rivalling those of traditional sectors such as agriculture and metallurgy. The sector's resilience during the pandemic, facilitated by factors such as mobility, flexibility, and remote work capabilities, had positioned it as a beacon of stability amidst global uncertainties.

Despite initial hopes that the inherent strengths of the ICT sector would shield it from the impact of the war, the industry has faced challenges that have dampened its growth trajectory. The lack of government support and uncertainties surrounding the future have cast a shadow over the once-promising outlook for Ukrainian IT professionals.

In light of these developments, it is imperative to delve deeper into the dynamics shaping the Ukrainian ICT sector's trajectory in the post-war period and explore avenues for sustainable recovery and growth. This research seeks to analyse the evolving landscape of the Ukrainian ICT sector, assess the challenges hindering its progress, and propose strategic interventions to reignite its potential as a cornerstone of the country's economic revitalization.

Chapter 1. Ukraine's ICT Ecosystem: Digital Infrastructure and Talent Pool Insights

The digital landscape in Ukraine has undergone a remarkable shift in recent years, marked by changes in the Internet penetration, mobile connectivity, and Internet connection speeds. The Internet connectivity in Ukraine has expanded significantly, with high-speed Internet being now available in urban and rural areas, which are gradually being connected through government digitalization programmes. Moreover, ICT infrastructure and facilities in Ukraine were developed at a rapid pace due to many different factors, particularly initiatives of local IT clusters, as they attract funding from foreign and Ukrainian companies, thus creating a business environment in their cities.

Based on results of 2021, communication segment of Ukraine's ICT sector is represented by: (1) three major wireless operators, Kyivstar, Vodafone Ukraine, and Lifecell, covering 99.9% of the population with mobile-cellular technology and 91.6% with at least 3G mobile network; (2) the "big six" fixed broadband companies (Ukrtelecom, Kyivstar, Volia, Triolan, Vega, and

PJSC Datagroup); (3) fiber and capacity leasing companies (PJSC Ukrtelecom, Omega Telekom, Atracom, PJSC Datagroup, VEGA, and ETT); (4) dark fibre wholesale companies (Atrakom LLC, Eurotranstelecom LLC, Naftogaz and Ukrtelecom), providing extensive optical fibre backbone infrastructure for continuous network operation; (5) state-owned enterprises and municipalities registered as wholesale operators (JSC Ukrainian Railways, the Ukrainian Sea Ports Authority, the Ukrainian Sea Port „Yuznyi", National Nuclear Energy Generating Company, etc.) with over 10,000 km of unutilized non-commercialized fibre infrastructure.

It should be noted that Ukraine has made significant progress in building a high-quality and accessible ICT infrastructure in 2010–2021 (Table 1). In accordance with the recommendations of the Universal and Meaningful Connectivity project [1], which aims to provide a level of connectivity that allows users to have a safe, satisfactory, enriching and productive experience on the Internet at an affordable price. Specifically, half of the goals set by the program have been fully achieved to improve the quality and accessibility of digital infrastructure for individuals, households, and educational institutions. The second half, as of 2021, was accomplished at a high level, but still needed to be brought up to the program standards related to the use of ICT by businesses and gender inclusion.

The average cost of home broadband in Ukraine is relatively affordable compared to other European countries. Consumers can expect to pay between UAH 150 and UAH 500 per month (approximately USD 5 to 17) for speeds ranging from 100 Mbps to 1 Gbps (however, prices may vary depending on the region and the level of competition between service providers). On the other hand, the mobile Internet segment has a different pricing structure. The main mobile operators in Ukraine provide 4G services with packages that include both data and voice services. Prices for these packages start at UAH 60 (approximately USD 2) for a basic plan, which scales up based on data usage and additional features.

In 2018–2022, the average cost of Internet connection services was (Table 2):

1) USD 4.92 per month for fixed-broadband basket (5GB);
2) USD 3.67 per month for data-only mobile-broadband basket (2 GB);
3) USD 4.01 per month for mobile-cellular low-usage basket (70 min + 20 SMS) and for mobile data and voice low-consumption basket (70 min + 20 SMS + 500 MB);
4) USD 4.33 per month for mobile data and voice high-consumption basket (140 min + 70 SMS + 2 GB).

Table 1

Achieving Ukraine's ICT development goals by 2030

Indicator	Target value	Value	Progress Score
Achieved targets			
High-speed fixed broadband	at least 95%	98,9	98
Fixed broadband cost	The goal is considered to be achieved if expenditures do not exceed 2% of monthly GNI per capita.	1,87%	95
Data-only mobile broadband basket, % GNI per capita		1,26%	96
Primary schools connected to the Internet, %	The goal has been achieved if at least 95% of HEIs are connected.	100	100
Lower-secondary schools connected to the Internet, %		100	100
Upper-secondary schools connected to the Internet, %		100	100
Secondary schools connected to the Internet, %		100	100
Mobile phone ownership gender parity	1	1,01	100
Unachieved targets			
Individuals aged 15+ using the Internet, %,	at least 95%	79.2%	79
Households with Internet access at home, %		82,7 %	82
Individuals who own a mobile cellular telephone, %	at least 95%	90,70%	90
Business with 0+ staff using the Internet, %	at least 95%	86,60%	86
Business with 10+ staff using the Internet, %		86,6 %	86
Internet use gender parity, %	The goal is considered to be achieved if the gender parity index is at least 0.98.	0,937	93

Source: compiled from [1]

During the period of adverse global economic conditions attributable to the COVID-19 pandemic, the telecommunications sector experienced a notable increase in its revenues. This growth was characterized by five prominent market trends:

1) The expansion of 4G coverage across Ukraine utilizing radio frequency bands of 1800 MHz and 2600 MHz;

2) The reformation and deployment of 4G networks within the 900 MHz radio frequency band by mobile operators to deliver contemporary telecommunication services in rural regions and along Ukrainian highways;

3) A surge in the scope of services provided and the user base accessing the Internet;

4) A rise in the utilization of modern electronic services, particularly in government services, e-commerce, e-health, and educational domains;

5) An escalating demand for machine-to-machine and Internet of Things services within sectors like banking, security services, housing and communal services, as well as transport and logistics companies.

Table 2

Dynamics of ICT services affordability in Ukraine, USD per month*

ICT Price Baskets	Years					Absolute Change			
	2018	2019	2020	2021	2022	2019-2018	2020-2019	2021-2020	2022-2021
Fixed-broadband basket	3.49	4.04	4.77	5.44	6.84	0.55	0.73	0.67	1.4
Data-only mobile-broadband basket	1.84	2.76	4.59	4.53	4.61	0.92	1.83	-0.06	0.08
Mobile-cellular low-usage basket (70 min + 20 SMS)	2.83	2.83	4,81	4.75	4.82	0	1.98	-0.06	0.07
Mobile data and voice low-consumption basket (70 min + 20 SMS + 500 MB)	2.83	2.83	4.81	4.75	4.82	0	1.98	-0.06	0.07
Mobile data and voice high-consumption basket (140 min + 70 SMS + 2 GB)	2.83	2.83	5.36	5.29	5.33	0	2.53	-0.07	0.04

Source: compiled from [2]

** presented latest available data*

According to available data [3], Ukraine hosts a total of 1663 product IT companies, indicating a thriving environment for the development of software products. Additionally, there are 554 service-oriented IT companies, highlighting the country's capability in offering a range of IT-related services to clients worldwide. Moreover, the presence of 90 R&D centres underscores Ukraine's commitment to innovation and technological advancement. The geographical distribution of IT companies and R&D centers provides

valuable insights into the regional hubs of technological innovation within Ukraine. In terms of product companies, Kyiv leads the pack with 1437 offices, followed by Lviv, Kharkiv, Odesa, Dnipro, Vinnytsia, and Zaporizhzhia. Similarly, in the service sector, Kyiv dominates with 357 offices, followed by Lviv, Kharkiv, Dnipro, Odesa, Zaporizhzhia, and Vinnytsia.

It is noteworthy that the key segments of ICT services in Ukraine include: IT support and outsourcing (integration and customization of IT products developed by other companies), custom software development (full or partial software development cycle to meet customer needs), IT consulting and digitization (a mixture of software development and classic digitalization consulting), and business process R&D outsourcing (a mixture of IT consulting and custom software development).

Furthermore, the global trend toward the digitalization of all spheres of social activity continues to make it possible for IT companies to cooperate with clients from various industries, including e-commerce (wholesale and retail), banking and fintech, healthcare and medicine, media and advertising, transportation and logistics, education, agriculture, etc. (Table 3).

Table 3

Main product segments of Ukraine's ICT sector in 2024*

Industry	Types of products	Companies in Tech Ecosystem
1	2	3
Martech & Media	marketing automation platforms, content management systems, customer data platforms, social media management tools, analytics and reporting tools, etc.	314
Business productivity software	project management tools, office suites, collaboration and communication platforms, cloud storage and file sharing, time tracking and employee monitoring software, workflow automation tools, etc.	236
Fintech & Insurtech	integration of AI in chatbots, online lending, insurance, and financial instrument comparison, along with the use of blockchain for data processing and customer identification	199
Healthtech & Wellness	telemedicine and telehealth platforms, health and fitness wearables, digital health apps, wellness and lifestyle management programmes, etc.	144
Hardware & IoT	IoT solutions for asset tracking systems, vehicles, warehouse automation, remote security, patient monitoring, smartphone navigation, smart home systems, smart cars	138

(End of Table 3)

1	2	3
E-Commerce & Retail	Big Data is utilized for forecasting demand, sales, pricing policies, and assortments, while automation and robotization optimize business processes, and virtual and augmented reality models clothing and other products	133
Esports & Gaming	live streaming and content creation platforms, development of mobile games, esports platforms, etc.	128
Edtech	learning management systems, online course platforms, virtual classroom software, educational content and tools, student information systems, etc.	121
AI	machine learning platforms and frameworks, AI-powered analytics and business intelligence tools, and other AI-powered solutions	70
Militarytech	use of robotics, including aerial reconnaissance drones and kamikaze drones, automated data collection software, and virtual and augmented reality for combat simulation and training	69
Cybertech	antivirus and antimalware software, intrusion detection and prevention systems, firewall, secure web gateways, etc.	51
Cleantech	smart grid technologies, energy management systems, etc.	45
Agtech	farm management systems (automate agricultural production processes), precision farming (uses GPS, remote sensing, and yield assessment) and land bank management	41
Communication	unified communications solutions, contact centre and customer experience solutions, etc.	40

Source: compiled from [3]

** presented latest available data*

In recent years, Ukraine has made significant progress in the development and dissemination of skills in the field of information and communication technologies (Table 4). A 2023 survey showed [4, p. 18] that 93% of the Ukrainian population has digital skills, and the share of people with above-average digital skills increased by 12% to 38%, indicating a deeper development of digital skills among Ukrainians.

In the regional context, Ukraine ranks third among the key ICT exporters in Eastern Europe in terms of the number of users with advanced ICT skills (437 thousand users), giving priority to only Poland (1.89 million) and the Czech Republic (535 thousand) [7, p. 48].

Table 4

Progress in the development and dissemination of ICT skills (by type of skill) in 2019–2021*

Type of ICT skill	2019		2020		2021		Absolute change	
	%	*mln.*	*%*	*mln.*	*%*	*mln.*	*%*	*mln.*
Changing privacy settings	-	-	2,3	0,997	2,0	0,877	-0,3	-0,1
Connecting and installing new devices	8,5	3,8	15,9	7,031	20,5	8,977	4,6	5,2
Creating electronic presentations with presentation software	5,4	2,4	8,2	3,630	9,7	4,256	1,5	1,8
Finding, downloading, installing and configuring software	4,1	1,8	8,6	3,78	9,6	4,225	1,1	2,4
Sending e-mails with attached files	26,5	11,8	36,4	16,07	40,5	17,737	4,1	6,0
Transferring files between a computer and other devices	19,7	8,7	25,1	11,095	28,6	12,542	3,5	3,8
Using basic arithmetic formula in a spreadsheet	5,0	2,2	9,7	4,259	11,8	5,186	2,2	3,0
Using copy and paste tools to duplicate or move information within a document	25,5	11,3	34,2	15,079	38,2	16,723	4,0	5,4
Writing a computer program using a specialized programming language	0,5	0,2	1,0	0,427	1,2	0,530	0,2	0,3

Source: compiled from [5–6]

** presented latest available data*

A separate trend in the development of digital literacy in Ukraine is the tendency of people with advanced digital skills to continue developing or improving these skills. In addition, the predominant social groups that report progress in mastering digital skills include students, the working population, young people aged 18–29, people with incomplete higher or complete higher education, people with above-average incomes.

One of the main factors behind Ukraine's success in ICT (information and communication technologies) is the availability of highly qualified IT professionals in the country (Figure 1). In 2023, the number of IT specialists registered as individual entrepreneurs in Ukraine amounted to 271.7 thousand people, which is 13% more than in 2022 [8]. It is worth noting that the format of IT individual entrepreneurs (IT FOPs) is the most popular model of

cooperation in the domestic IT sector – 87% of Ukrainian IT professionals; the second place was taken by official hiring in accordance with the Labor Code – 6%; the third place was taken by the format of gig contractors – 1%.

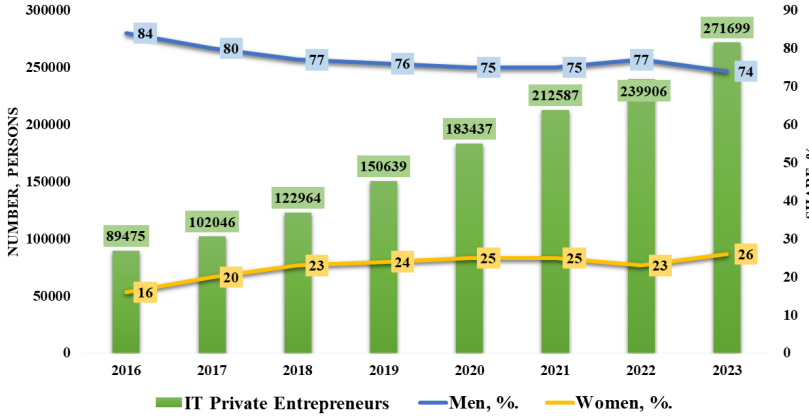

Figure 1. Ukraine's ICT Sector Talent Pool Dynamics in 2016-2023*

Source: compiled from [8–9]

** presented latest available data*

The distribution of registered IT individual entrepreneurs (IT FOPs) according to NACE codes in the first half of 2023 was as follows: 68.5% or 186.1 thousand active IT FOPs were registered under NACE 62.01 "Computer programming", 13.5% or 36.8 thousand active IT FOPs – NACE 62.02 "Consulting on informatization" and 12.3% or 33.4 thousand active IT FOPs – NACE 63.11 "Data processing, posting information on web sites and related activities". In terms of the geography of registration in 2023, most active IT individual entrepreneurs are concentrated in Kyiv (24.2% of all registered IT individual entrepreneurs) and Kyiv region (5.6%), Kharkiv region (12.7%), Lviv region (10.9%), and Dnipropetrovsk region (8.2%).

Another advantage of Ukrainian IT professionals in the context of international competitiveness is their predominantly fluent English, which is useful when searching for and communicating with foreign customers and contractors. According to the statistics [9], in 2016-2023, on average, IT professionals assessed their English proficiency as follows: 34% of IT professionals rated their level as Intermediate, 36% – have above-average language skills, and 12% – have advanced skills.

Also, Ukraine's ICT sector is the fastest among the key ICT exporters in Eastern Europe to recruit new specialists – about 39 thousand students of

technical specialties graduate from universities every year (compared to Poland – 17 thousand students, Romania – 8.2 thousand students, Czech Republic – 4.6 thousand students) [7, p. 49]. Higher education in the ICT sector in Ukraine is not mandatory, but it is crucial for students to gain knowledge about the industry and technologies, as well as for further self-education. Despite the active debate about the need for academic education to build a successful career in IT, on average 84% of working IT professionals in Ukraine have a complete higher technical or economic education.

Although IT education in Ukraine does not meet currently required standards, it still offers the necessary minimum for further development: (1) Ukraine's IT education offers basic knowledge and effective information absorption skills; (2) daily communication with friends and teachers in a common language is beneficial, as it provides a supportive environment for learning; (3) a student community is being formed during the student years, which later facilitates forming a supportive professional network; (4) courses cover popular IT professions like programmers, testers, and web designers, while universities' programmes cover other IT subject technologies like hosting, server administration, VDS servers, network organization, technical support, and engineering; (5) after university, students have more chances to become juniors than after courses, as it takes over three months to assimilate knowledge.

Additionally, most IT professionals take certain measures to improve their professional skills, in particular by taking online or offline courses or trainings, reading relevant professional literature, and participating in professional events of the IT community (conferences, meetings, trainings, etc.).

The study of the dynamics of median salaries of IT specialists in Ukraine during 2017–2023 shows a steady trend of gradual growth for IT specialists in most categories. This trend is a demonstration of the gradual technological improvement of Ukraine's ICT sector, as the development and implementation of advanced digital products and solutions require the involvement of highly qualified personnel, for whom IT companies compete and are willing to pay high salaries to ensure their success in the international IT market.

The main changes in the level of remuneration in the ICT sector of Ukraine during 2017-2023 include [10]:

1) salaries of software engineers in the Trainee (from USD 350 to 450 per month) and Junior (from USD 600 to 1000 per month) categories grew by an average of 9% annually;

2) salaries of software engineers of the "Middle" category grew by 8% annually (from 1700 to 2600 USD per month);

3) salaries of software engineers of the "Senior" (from 3300 to 4900 USD per month) and "Team Lead" (from 3600 to 5376 USD per month) categories grew by 7% annually;

4) salaries of software engineers of the "Architect" category grew by 5% annually (from 4750 to 6500 USD per month).

In the international context, domestic IT professionals have a number of strong advantages, including: firstly, Ukraine offers cost-effective software engineering services, providing high-quality work at a competitive price, making it an attractive option for businesses seeking to optimize development budgets without compromising quality (Table 5); secondly, Ukrainian software engineers excel in cultural compatibility, collaborating effectively with international teams and understanding Western business practices, ensuring smooth communication and successful project outcomes; thirdly, Ukrainian software engineers excel in English proficiency, facilitating effective communication with clients and team members globally, ensuring clear understanding of project requirements and high-quality execution; fourthly, Ukraine's advantageous time zone facilitates collaboration with European and US companies, enabling efficient communication and seamless teamwork across different regions.

Table 5

Software Engineers Annual Employment Cost Comparison in 2024

Country	Annual Salary	Employer Taxes		Total
	USD thousand	%	USD thousand	USD thousand
1	2	3	4	5
Europe				
Ukraine	48.18	24	11.56	59.74
Poland	49.83	26.15	13.03	62.86
Czech Republic	53.05	37.5	19.89	72.94
Hungary	49.00	21.5	10.54	59.54
Slovak Republic	51.99	35.20	18.30	70.29
Romania	49.16	16.25	7.99	57.14
Moldova	46.34	25.5	11.82	58.16
United Kingdom	67.18	20.8	13.97	81.16
Germany	61.62	22.42	13.82	75.44
France	62.19	51	31.72	93.92
The Netherlands	63.57	27.65	17.58	81.15
Sweden	61.45	33.45	20.56	82.01
Norway	67.40	18.10	12.19	79.60
Lithuania	51.73	5.39	2.79	54.51
Latvia	50.75	36.05	18.29	69.04
Estonia	52.43	34	17.83	70.26
America				
USA	103.30	24	24.79	128.09

(End of Table 5)

1	2	3	4	5
Canada	59.45	12.6	7.49	66.94
Asia				
Republic of Korea	60.26	18.80	11.33	71.59
China	57.06	39.21	22.38	79.44
Hong Kong	66.62	9.75	6.50	73.11
Taiwan	55.35	24.45	13.53	68.89
Japan	61.70	21.20	13.08	74.79
India	45.09	17.65	7.96	53.05

Source: compiled from [11]

** presented latest available data*

It is worth noting that hiring IT specialists from Eastern Europe is more cost-effective for companies from the US, UK, and Western Europe, as it reduces annual labor costs for IT developers by an average of 22%. According to the results of a comparative analysis [7, p. 49], Ukraine retains an absolute advantage in terms of wages among the key ICT exporters in Eastern Europe.

Notably, the list and structure of the most used programming languages among Ukrainian IT professionals expanded in 2010–2023 (Figure 2). At the end of 2010, the main programming languages used by IT professionals were C# – 22.8%, Java – 22.3%, PHP – 16.3%, C/C++ – 15%, and Python – 6.9%. However, due to the gradual development of the ICT sector and the expansion of the range of computer programming services in the subsequent years, in 2023, the most used programming languages included JavaScript (19.1%), Java (14%), Python (13.4%), C# (13.3%), and TypeScript (13.3%).

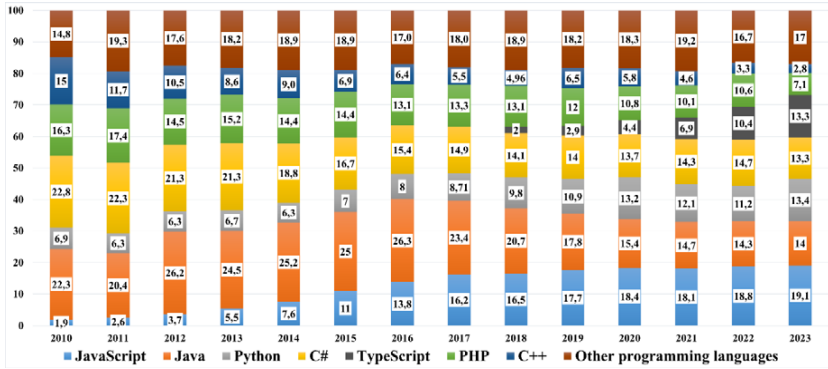

Figure 2. Popular programming languages in Ukraine's ICT sector, % of all software engineers*

Source: compiled from [12]

** presented latest available data*

It should be pointed out that most IT professionals specialize in Backend development (37%), Frontend and Full Stack development (21.2%), and Mobile development (8.7%) [10]. In addition to the programming languages they have already mastered, Ukrainian IT professionals continue to learn additional languages on their own, with professional teachers and specialized courses. In particular, the most popular languages in 2021–2023 are Go (17.5%), Python (16.7%), Rust (12.6%), JavaScript (10.8%), and TypeScript (10.2%).

To summarize, Ukrainian IT professionals have a strong competitive advantage in the global IT market, as they are competent in solving problems and completing tasks, proactive in anticipating potential problems and offering timely solutions, and possess strong communication skills and adaptability to change. Finally, Ukrainian IT professionals have in-depth knowledge of their field, focusing on new technologies and innovations.

Chapter 2. Regulatory Frameworks and Technological Advancements in Ukraine's ICT Sector R&D Landscape

The policy and regulatory environment plays a crucial role in shaping the growth and development of the ICT sector, as a supportive regulatory framework can promote a level playing field, encourage investment in infrastructure, and foster the adoption of new technologies, ultimately driving economic growth and societal development.

During 2018-2022, Ukraine's regulatory environment was characterized by various indicators that signify the level of corruption, quality of regulation, government effectiveness, political stability, and legal environment (Table 6). The IT sector in Ukraine has enormous potential to grow and make an important contribution to the country's economy, but over the past decade, a large number of IT companies have shown their decreased interest in developing business in Ukraine due to a number of systemic problems that hinder their activity.

The IT business in Ukraine faces challenges due to poor governance, high corruption levels, low regulatory quality, political instability, and a lack of rule of law and participation. The poor results on indices in Table 6 highlight the complex challenges facing Ukraine's ICT sector in navigating a regulatory environment characterized by corruption, inefficiencies, instability, legal uncertainties, and limited accountability. Addressing these issues will be crucial for fostering a conducive regulatory environment that supports the growth and competitiveness of the ICT sector in Ukraine.

Furthermore, Ukraine has rather weak and ineffective protection of property rights compared to other technologically advanced countries [15]. The protection of property rights to tangible assets is important for the international competitiveness of the IT sector, as it provides companies with innovative advantages, attractiveness to investors, and sustainable development

of the sector (Table 7). In addition, the registration process is important for the protection of intellectual property rights, which is a key element of IT companies' competitiveness, as if an IT company cannot register its innovations and technologies, other IT companies can use them for free, which can lead to reduced profits and investments in research and development. Finally, the availability of finance is an important factor for the development and growth of IT companies, as innovation and new product development in the IT sector requires significant investment, so the availability of finance is a key factor in ensuring the competitiveness of IT companies, as IT companies that have access to sufficient financial resources can develop and launch new products faster and more efficiently.

Table 6

Assessment of the Political Environment in Ukraine in 2018–2022*

Governance Indicator	2018	2019	2020	2021	2022	Absolute Change	Relative Change
Corruption Perception	32	30	33	32	33	1	3,1
Regulatory Quality	43,3	44,8	42,4	42,4	40,6	-2,76	-6,4
Government Effectiveness	37,1	38,6	37,6	35,2	33	-4,12	-11,1
Political Stability and Absence of Violence/Terrorism	5,7	9,0	12,3	12,7	5,7	0	0
Rule of Law	23,8	24,8	25,2	25,7	18,9	-4,94	-20,7
Voice and Accountability	43,7	46,9	51,7	49,3	45,9	2,2	5,04
Property Rights Index	4,3	4,4	4,5	4,5	4	-0,3	-6,98
Perception of Physical Property Protection	5,7	5,7	5,8	5,8	4,2	-1,5	-26,3
Protection of Intellectual Property Rights	4,4	4,6	4,6	4,4	4,4	0	0

Source: compiled from [13–15]

** presented latest available data*

It is worth emphasizing that the weak regulatory environment for intellectual property has a number of drawbacks and potential problems in the context of ensuring the international competitiveness of Ukraine's IT sector:

1) the risk of infringement of intellectual property rights, which may lead to the theft of a company's idea, development or software;

2) the lack of effective legislation and mechanisms for the protection of intellectual property rights, which complicates the company's protection against violations

3) the possibility of losing a competitive advantage due to copying or use of the company's intellectual property by other companies;

4) difficulties in attracting investments and partners due to lack of confidence in the protection of intellectual property rights in the country;

5) potential threat to the company's reputation and brand due to infringement of intellectual property rights;

6) lack of incentives for innovation and development of new products due to low protection of intellectual property;

7) insufficient copyright protection for content, which leads to piracy and illegal distribution of materials;

8) risk of loss of confidential information and trade secrets due to insufficient protection of intellectual property rights;

9) reduction of competitiveness of companies due to the possibility of copying products and services without the permission of the owner of intellectual property rights.

Table 7

Assessment of Property Rights Regulation in Ukraine in 2018–2022*

Indicator	2018	2019	2020	2021	2022	Absolute Change	Relative Change
Perception of Physical Property Protection							
Property Rights Protection	3.8	3.9	3.9	3.9	3.9	0.1	1.6
Registering Process	9.4	9.4	9.5	9.5	4.9	-4.5	-48.1
Access to Financing	4.0	4.0	4.0	3.9	3.9	0.05	-1.2
Protection of Intellectual Property Rights							
Perception of IP Protection	3.8	4.0	3.9	3.9	3.9	0.2	4.8
Patent Protection	7.8	7.8	7.8	5.7	5.7	-2.0	-26.3
Copyright Protection	1.8	2	2	2	2	0.2	11.1
Trademark Protection	-	-	-	5.9	5.9	0	0

Source: compiled from [15]

** presented latest available data*

ICT regulation and policy play a crucial role in shaping the international competitiveness of the ICT sector, as the government can create a clear environment for businesses, encourage innovation, promote investment in new technologies, protect consumer rights, ensure data privacy, and foster trust in digital services, ultimately boosting the global reputation of Ukraine. Particularly, an empirical study of International Telecommunication union shows [16]: (1) the most impacting policy variables on investment in telecommunication sector are OECD membership (36.1%), WTO membership (35%), bureaucratic burden (17.1%), profit tax (13.8%), ICT Regulatory Tracker score (7.4%), which consists of Regulatory Authority (15.5%), Regulatory Regime (11.8%), Regulatory Mandate (11.3%) and Competition Framework (6.7%); (2) the most impacting policy variables on investment in

mobile sector are adoption of a National Broadband Plan, adoption of converged licences, spectrum sharing agreements, adoption of mobile number portability, openness to foreign telecom operators and existence of a competition authority (Table 8).

Table 8

Influence of Policy Variables on Mobile Sector Impact Areas between 2008 and 2019, %*

Policy Variable	Commentary	Impact Area				
		Mobile CAPEX	Coverage	Prices	Penetration	GDP per capita
Adoption of a National Broadband Plan	indicates that NBP has been adopted	209	190.6	66.8	114.2	102
Adoption of converged licences	indicates that a unified/ global licences or general authorization/ simple notification regime is in place rather than service specific licences	160.2	151.4	77.6	108.8	101.3
Allow spectrum sharing agreements	indicates if active infrastructure sharing agreements for mobile operators are permitted	214.4	197.4	65	115.1	102.2
Adoption of mobile number portability	indicates if number portability is required from mobile operators	163.4	154.4	76.6	109.2	101.3
Openness to foreign telecom operators	indicates if no restrictions are placed on foreign spectrum-based operators	209.9	190.3	66.9	114.1	102
Existence of a competition authority	indicates that a National Competition Authority exists	154.2	146.7	79.2	108.1	101.2
All six policies	combination of above-mentioned variables	347.2	303.3	47.6	126.5	103.6

Source: compiled from [16]

** presented latest available data*

According to the ITU [6], over the past 15 years, Ukraine has been effectively implementing modern internationally recognized regulatory practices in the ICT sector into its own legislative framework (Figure 3), which has transformed the national legislation from the G2 generation (44.8 out of 100 possible points) in 2007 to the G3 generation (78) in 2022.

Figure 3. ICT Regulatory Tracker Scores in Ukraine, 2007–2022*

Source: [6]

** presented latest available data*

Additionally, by participating in the WTO Information Technology Agreement, Ukraine stands to reap substantial benefits for its imports of ICT goods and the growth of its ICT sector. Firstly, the ITA's tariff elimination on ICT products significantly lowered import costs for Ukraine, making these products more affordable (thus, accessible) for businesses and consumers, thereby promoting increased technology adoption across various sectors. Secondly, the ITA's dismantling of trade barriers could expand Ukrainian businesses and consumers' access to high-quality ICT products, potentially boosting innovation, productivity, and competitiveness in the Ukrainian ICT sector. Finally, the adoption of the ITA partially streamlined Ukraine's digital

transformation by simplifying the acquisition of essential technology, promoting efficiency, connectivity, and innovation across various economic sectors.

During 2006-2021, R&D in Ukraine was in a transitional state, with major structural changes taking place in the context of a significant budget deficit. It should be noted that gross domestic expenditures on R&D as a percentage of GDP decreased from 0.91% in 2006 to 0.29% in 2021, and the number of researchers decreased from 68.8 thousand full-time employees in 2006 to 25.7 thousand in 2021, i.e. a 63% decline in the number of researchers in private and public institutions [17].

However, the dynamics of the brain drain was significantly changed by the R&D centres of technology TNCs, which started investing in Ukraine, hiring the best local specialists, and instead of relocating, offered to stay in their home country and enjoy all the benefits of working for an international company (higher salaries, a more progressive corporate culture, quality health insurance, paid courses and a gym, foreign business trips, etc.) Over time, R&D centres have evolved from an ordinary workplace into an ecosystem for innovative ideas, where talented professionals come together to solve big problems and receive significant investment support. In addition, the three largest R&D centres in Ukraine – Samsung, Ubisoft, and Snap Chat – generated about 83 mln. USD in ICT exports in 2022 and continue to operate despite the war, providing jobs and thus making regular tax injections into the economy [18].

As of the first quarter of 2024, there are 90 R&D centers of foreign origin in Ukraine, with a predominant concentration in Kyiv (69 open offices), Lviv (15), Kharkiv (10), Odesa (10), and Dnipro (9) [3]. In terms of origin, most of the R&D centers in Ukraine were opened by tech companies from the US – 36 R&D offices (Cisco, Boeing, BigCommerce, Dell Technologies, Lyft, Netcracker, SAP Ukraine, Sitecore, etc.), the UK – 8 (Adstream, OnApp, etc.), Germany – 8 (Avenga, Bosch, Soft Xpansion, etc.).

It is worth noting that the format of R&D centres, in addition to diversifying labour practices in Ukraine, has a number of advantages and prospects for the further development of the ICT sector (Table 9).

Since 2013–2014, international cooperation and partnerships have had a profound impact on the output of scientific publications in Ukraine, which has contributed to increased scientific competitiveness as Ukraine has focused on building international partnerships and changing models of academic cooperation (Table 10). Previously, scientists from Russia were the most frequent partners of Ukrainian authors, but now scientists from Poland are preferred. Additionally, Poland is the largest recipient of Ukrainian foreign students with higher education, with almost 27,000, followed by Russia with 21,000 and Germany with 6,000 [19].

Table 9

Impact of R&D Centers in ICT: Benefits for Key Stakeholders

Stakeholder	Benefits
IT professionals	opportunity to gain experience in building and operating a company; know everything about the marketing and sales process of an IT product in foreign countries; ability to interact directly with C-level managers; climb the career ladder; possible invitation to the parent company's headquarters; learn from the experience and corporate culture; attend trainings together with American or European colleagues.
IT companies	market expansion; talent attraction and retention; intellectual property development; tax optimisation.
Market	economic growth; enhance of global competitiveness; Talent development; Export potential; Industry collaboration; Intellectual property creation; Diversification of the economy; unemployment rate reduction

Source: generalised by authors

Table 10

Ukraine's most popular partners in scientific cooperation in 2010–2020*

Partner Country	From Ukraine	To Ukraine	Balance	Number of Publications Co-Authored with a Partner Country
Russia	1771	964	-807	1298
UK	543	665	122	617
Germany	537	319	-218	972
USA	482	370	-112	914
Poland	486	355	-131	1504
France	279	208	-71	606
Czech Republic	125	70	-55	480
China	121	63	-58	619
Italy	71	63	-8	569

Source: compiled from [20]

** presented latest available data*

It should be emphasized that scientific and research activities in Ukraine in 2006-2021 were hampered by the constant outflow of scientists and inventors, as Ukraine has a bilateral deficit of academic mobility with most partner countries, especially Russia (Table 10). However, in our perception, it is reasonable to assume that in the long run, a full-scale Russian war in Ukraine will change Ukraine's academic mobility patterns.

The study of the areas of scientific research and development in ICT in Ukraine in 2001-2022 shows that the most popular subject areas of scientific

publications by domestic scientists include (Table 11): computer networks and communications (13965 publications, 21.3% of all publications in ICT), areas of computer science (12932 publications, 19.7% of all publications in ICT), various aspects of computer science (10045 publications, 15.3% of all publications in ICT) and information systems (6655 publications, 10.1% of all publications in ICT).

Table 11

Dynamics and Distribution of Scientific Publications in Computer Science in Ukraine in 2001–2022*

ICT Subject Category	Years					Relative Change, %			
	2001-2005 (P1)	2006-2010 (P2)	2011-2015 (P3)	2016-2020 (P4)	2021-2022 (P5)	P2	P3	P4	P5
Artificial Inteligence	142	178	501	1955	1194	25.4	181.5	290.2	-38.9
Computer Networks and Communications	1405	2026	2147	5525	2862	44.2	6	157.3	-48.2
Computer Science Applications	1285	1531	1893	5339	2884	19.1	23.6	182	-46
Hardware and Architecture	576	542	640	2163	690	-5.9	18.1	238	-68.1
Software	624	543	883	1586	434	-13	62.6	79.6	-72.6
Information Systems	437	503	847	3128	1740	15.1	68.4	269.3	-44.4
Signal Processing	85	283	500	2164	947	232.9	76.7	332.8	-56.2
Computer Science (miscellaneous)	507	648	1109	5052	2729	27.8	71.1	355.5	-46
Other	645	583	641	2299	1273	-9.6	9.9	258.7	-44.6

Source: compiled from [21]

** presented latest available data*

The popularity of these subject areas in Ukrainian science can be explained by several reasons. Firstly, IT is one of the fastest growing areas of technology, which requires constant research and development of new innovations. Secondly, IT is a necessary component in many areas of life, including business, science, medicine, education, and others, which creates a significant demand for research in these areas. Thirdly, Ukrainian scientists have a sufficiently high level of qualification and experience in these areas, which allows them to effectively conduct research and development. Finally, Ukraine has sufficiently qualified specialists in the field of telecommunications, which allows it to develop and produce high-quality equipment for export.

Having studied the dynamics of patents granted under the Budapest System in ICT in Ukraine (Table 12), we note that during 1996–2022, a total of 3372 patents were successfully granted in Ukraine. In particular, the largest

shares of granted patents belong to inventions in the following ICT segments: digital communications – 24.2% (816 granted patents), computer technologies – 22.3% (753 granted patents), telecommunications – 20.3% (685 granted patents), and audiovisual technologies – 13.1% (441 granted patents).

Table 12

Dynamics of Patent Activity in the ICT Sector of Ukraine, 1996–2022*

Field of ICT	1996-2000	2001-2005	2006-2010	2011-2015	2016-2020	2021-2022	Total	Share, %
Audio-visual technology	17	132	96	108	88	0	441	13.1
Telecommunications	26	180	248	189	41	1	685	20.3
Digital communication	5	88	204	455	60	4	816	24.2
Basic communication processes	7	72	93	110	42	0	324	9.6
Computer technology	8	220	169	202	145	9	753	22.3
IT methods for management	0	16	19	30	14	0	79	2.3
Semiconductors	2	86	94	65	27	0	274	8.1
Fields Total	**65**	**794**	**923**	**1159**	**417**	**14**	**3372**	**100**

Source: compiled from [22]

** presented latest available data*

The largest number of registered and granted patents was in 2001–2015 – 2876 granted patents, in particular: the largest number of patents in ICT was granted in 2011–2015 – 1159 patents or 34.4% of the total number of granted patents in ICT in 1996–2022, in 2006–2010 – 923 patents (27.4%) and in 2001–2005 – 794 patents (23.5%). However, starting from 2016, a downward trend in the number of granted patents can be observed: 431 patents were granted in 2016–2022, which is 62.8% less compared to the record volume of 2011–2015.

In addition, there are significant changes in the structure of the industry affiliation of granted patents before and after the COVID-19 pandemic and the outbreak of a full-scale war in Ukraine:

1) during 2001–2020, 3,293 patents were gradually granted in all 7 ICT areas, with a predominance of granted patents in digital communications – 807 (24.5), computer technologies – 736 (22.4%), and telecommunications – 658 (20%);

2) during 2021–2022, only 14 patents were granted in 3 traditional ICT areas for the IT sector of Ukraine, which is already 97% less compared to 2016–2020.

Thus, according to the aforementioned trends, we can state that inefficient regulation and protection of intellectual property in Ukraine affects the number of registered patents for ICT inventions, thus causing their substantial reduction. On the one hand, such reductions are related to the companies' inability to obtain protection of their intellectual property rights, and thus, they become less interested in innovative development and invest less in R&D, which, in turn, affects the international competitiveness of both IT companies and the IT sector of Ukraine as a whole. Besides, low gross R&D expenditures affect the reduction in the number of registered patents for ICT inventions, as due to a lack of funding, individual developers and IT companies are not able to produce advanced technologies and digital offerings, which leads to a technological lag of the Ukrainian IT sector compared to other countries where the financial component of innovation is more accessible and efficient. On the other hand, due to the inability of the domestic regulatory system to effectively protect intellectual property rights, IT companies will register patents for their inventions in the countries with more effective intellectual property protection and easily accessible financial resources, as this enables them to ensure greater protection of their innovations and access to a wider market. Furthermore, registering a patent in other countries can be an important part of a company's intellectual property protection strategy; thus, if an IT company has a patent for its technology in many countries, it may be less vulnerable to lawsuits and other attempts to infringe its rights.

Chapter 3. Strategies to improve the competitiveness of Ukraine's ICT sector

Ukraine's ICT sector has emerged as a symbol of prosperity in a country plagued by political unrest and regulatory difficulties. Despite these hurdles, the sector has shown amazing resilience and growth, demonstrating a strong export orientation that has drawn consumers from all over the world with the following increase in export revenues, thus contributing to economic growth.

In recent years, conflicts and wars have increasingly become significant factors affecting not only the geopolitical landscape but also the economic dynamics of nations. In the context of Ukraine, recent studies [7; 23] highlight the profound challenges faced by the domestic ICT sector as a result of ongoing conflict. These issues range from risks to ICT infrastructure to the forced relocation of companies and professionals, migration of talent, inadequate political and legal environment, cyber vulnerabilities, reputational damage, mobilization of specialists, labor market imbalances, and inability to compete with foreign counterparts in terms of remuneration.

One of the key challenges highlighted in these studies is the risk of failures in the ICT infrastructure, which can be classified into several categories [24–25]: (1) data centres, communication towers, and cables are vulnerable to

physical damage from direct attacks like bombings, missile strikes, or sabotage; (2) hostile entities can launch cyber-attacks to disrupt or disable critical ICT systems, such as DDoS attacks, malware infiltration, or hacking into network infrastructure; (3) communication interference, such as jamming or signal blocking, may disrupt various communication channels (wireless networks, satellite communication, etc.); (4) targeted attacks on power grids or infrastructure caused prolonged power outages, impacting ICT systems that rely on electricity; (5) wartime instability led to lax security measures and insider threats, increasing the risk of unauthorized access, data breaches, and sensitive information leaks; (6) military operations caused collateral damage to ICT infrastructure, leading to equipment loss, facilities disruption, and service disruption; (7) adversaries may use social engineering or disinformation campaigns to target ICT users, potentially compromising security practices or spreading misinformation.

The competitiveness of the ICT sector in times of war is closely linked to the availability, reliability, and security of ICT infrastructure that enables communication, data management, remote work, service delivery, innovation, and economic resilience. As of the end of 2023, the total impact of war on Ukraine's ICT sector is estimated to be more than 2 bln. USD in damage, 2.27 bln. USD in losses, and 4.67 bln. USD in needs (Table 13).

On one hand, in terms of monetary value of destroyed physical assets of ICT companies (valued at prewar prices), the most damaged ICT enterprises were fixed broadband operators – 950 mln. USD (45.4%), mobile operators – 899 mln. USD (43.0%), postal service providers 192 mln. USD (9.2%), and broadcasters – 51 mln. USD (2.5%). Moreover, the following regions experienced most damages of ICT infrastructure due to the war: Donetsk region (17%), Kharkiv region (17%), Zaporizhzhia region (13%), Kherson region (13%), and Kyiv region (11%).

On the other hand, in terms of revenue losses due to disruptions in postal and internet services (as well as additional expenditures for backup electrical generators to ensure uninterrupted internet service provision), postal operators faced the most significant losses – 65%, followed by mobile operators – 30%, fixed operators – 3.2%, and broadcasters – 1.6% [26, p. 149]. ICT companies (predominantly private ones) with the most operational losses are located in Kyiv region (30%), Donetsk region (16%), Kharkiv region (16%), and Zaporizhzhia region (10%).

Considering the specified challenges and losses, in order to rebuild and modernize Ukraine's ICT infrastructure, promote economic development, and improve the quality of life for citizens, the following areas should be taken into account: (1) repair or rebuilding of damaged or destroyed ICT hardware infrastructure, including data centres, telecommunications towers, fiber optic cables, and satellite systems; (2) expanding and strengthening network

connectivity to ensure widespread access to communication services, potentially through the installation of new cables, mobile network towers, and improved broadband infrastructure; (3) investing in cybersecurity measures, e. g. as firewalls, encryption, intrusion detection systems, and personnel security training; (4) introduce policies and regulations to attract investment, promote competition, and ensure responsible technology use; (5) seeking international aid, technical assistance, and knowledge sharing to supplement domestic ICT infrastructure reconstruction; (6) enhancing ICT infrastructure's resilience to potential conflicts or disasters by designing redundant systems, backup solutions, and disaster recovery plans.

Table 13

ICT Infrastructure Damage, Loss and Needs by Regions of Ukraine (USD mln.)*

Region	Damage			Loss			Needs		
	Public	**Private**	**Total in Region**	**Public**	**Private**	**Total in Region**	**Public**	**Private**	**Total in Region**
Cherkasy	0.0	13.9	13.9	0.0	1.6	1.6	0.0	22.4	22.4
Chernihiv	2.4	107.8	110.2	2.1	105.1	107.2	7.76	203.8	211.56
Chernivtsi	0.0	3.2	3.2	0.0	2.1	2.1	0.00	6.4	6.4
Dnipropetrivsk	0.0	89.6	89.6	0.0	52.6	52.6	0.00	132.7	132.7
Donetsk	6.6	351.0	357.6	7.0	354.8	361.8	25.39	738.6	763.99
Ivano-Frankivsk	0.0	55.9	55.9	0.0	3.0	3.0	0.00	82.8	82.8
Kharkiv	7.5	319.1	326.6	7.8	346.6	354.4	27.94	737.1	765.04
Kherson	7.2	267.7	274,9	3.2	173.5	176.7	14.6	313.9	328.5
Khmelnytsk	0.0	0.3	0.3	0.0	1.2	1.2	0.0	2.2	2.2
Kirovohrad	0.0	12.0	12.0	0.0	1.4	1.4	0.0	18.9	18.9
Kyiv	3.3	223.5	226.8	26.9	646.0	672.9	55.2	1273.4	1328.6
Luhansk	17.3	141.6	158.9	7.8	124.0	131.8	35.1	224.3	259.4
Lviv	0.0	15.7	15.7	0.0	3.7	3.7	0.0	27.5	27.5
Mykolaiv	3.6	52.7	56.3	2.7	89.1	91.8	10.5	165.5	176
Odesa	0.0	29.7	29.7	0.0	15.8	15.8	0.0	40.1	40.1
Poltava	0.0	0.3	0.3	0.0	2.3	2.3	0.0	4.4	4.4
Rivne	0.0	15.0	15.0	0.0	2.7	2.7	0.0	23.4	23.4
Sumy	1.8	29.8	31.6	0.7	53.0	53.7	3.4	49.3	52.7
Ternopil	0.0	0.3	0.3	0.0	1.4	1.4	0.0	2.7	2.7
Vinnytsya	0.0	2.3	2.3	0.0	3.4	3.4	0.0	6.7	6.7
Volyn	0.0	0.3	0.3	0.0	1.9	1.9	0.0	3.5	3.5
Zakarpattya	0.0	34.3	34.3	0.0	3.1	3.1	0.0	51.9	51.9
Zaporizhzhia	10.8	266.2	277	4.9	225.9	230.8	21.8	335.7	357.5
Zhytomyr	0.0	0.7	0.7	0.0	1.8	1.8	0.0	3.3	3.3
Total	**60.6**	**2032.9**	**2093,5**	**63.1**	**2215.2**	**2278.3**	**201.8**	**4469.9**	**4671.7**

Source: compiled from [26, p. 151–152]

** presented latest available data*

As for 2024, the total recovery and reconstruction investment priorities are estimated at 399.5 mln. USD for restoration of Internet access in the de-occupied territories; increasing communication resilience for local communities in Ukraine; restoration of access to online education, medicine, culture, and social services in settlements without communication in de-occupied, front-line, and border territories; upgrades of the digital infrastructure resilience (e. g. uninterrupted operation of critical information systems of Centres for the Provision of Administrative Services); creation of a confidential communication system for emergency services – fulfilling the urgent needs of ICT companies and repairing the broadcasting infrastructure [26, p. 151].

As noted in the source [7, pp. 28–33], the full-scale invasion of the Russian Federation into the territory of Ukraine causes certain negative trends, namely: a drop in demand in the IT labour market; curtailment or cancellation of projects by domestic IT companies due to lack of funds; deterioration of the position of the ICT sector of Ukraine as a location for offshoring, outsourcing and outstaffing of software development; liquidation of business locations; termination of contracts by foreign customers with domestic IT companies due to the risk of project failure; conscription of IT professionals into the Armed Forces; ineffective tax legislation and currency regulation; etc.

Additionally, the forced re-location of IT companies within Ukraine or abroad has created economic imbalances in different regions. This shift can disrupt established networks and partnerships, leading to uncertainties and challenges in maintaining business operations. On the other hand, the full-scale war has expanded the geography of Ukrainian IT companies' representative offices abroad. In particular, according to the IT Ukraine Association, the most popular locations for IT companies' relocations were Poland (40.1% of surveyed IT companies), Germany (14.6%), the United States (9.5%), Portugal (9.5%), Bulgaria (8%), the Czech Republic (8%), Romania (8%), Moldova (5.1%), Spain (5.1%), and Canada (5.1%) [24, p. 41]. Furthermore, the migration of IT professionals and scientists further exacerbates the situation by weakening the innovation potential of the sector, as valuable talent leaves the country in search of more stable opportunities.

At the same time, according to the representatives of the domestic ICT sector, there is a significant shortage of qualified IT personnel required by IT companies in Ukraine, in particular due to the low ability of the Ukrainian formal education system to adapt educational programs to many processes and trends in the ICT sector (Table 14). This, in turn, leads to the fact that IT companies are forced to hire insufficiently educated graduates/students and train them on the job (given that formal education institutions hardly ever develop competencies in "professions of the future", such as artificial intelligence and the Internet of Things). Additionally, there is still no

systematic dialog between the state and business, which means that companies are forced to train IT specialists, and the demand for qualified IT personnel continues to exceed the market supply.

Table 14

Challenges in Information Technology Education across All Educational Levels

Education Level	General Challenges
Complete Secondary Education	poor quality of STEM education in rural areas; insufficient number of teachers using modern approaches and methods of teaching STEM disciplines; 80% of students' choice of profession is influenced by their parents' attitudes; limited access to updated technology, inadequate infrastructure, and insufficient funding for IT programmes; inadequate training and qualifications for IT teachers; lagging behind the OECD countries in the performance of the most successful students in science and mathematics, due to the low quality of STEM programs in schools; gender stereotypes about mathematics and technology education reduce the number of potential IT professionals among girls
Professional, Vocational, Professional Pre-Higher Education	low quality of pre-higher education; low prestige of vocational education; limited collaboration between educational institutions and industry partners; significant mismatch between the quality of pre-higher education and market needs
Higher Education	lack of financial autonomy of HEIs; uncompetitive salaries of teachers and IT practitioners; weak management in HEIs; lack of "specialties of the future" (AI, Internet of Things, big data, cybersecurity); misalignment between the IT curriculum and industry standards; the curriculum and process organization lack focus on skill acquisition due to a lack of practice; the absence of project centres and hubs established by HEIs in collaboration with companies;
Non-formal education, lifelong education, self-education	a complicated licensing system; unequal tax conditions with foreign platforms; restrictions on the recognition of education obtained in non-formal educational institutions; underutilized scaling potential of informal IT schools due to the predominantly commercial and expensive learning process; a limited number of educational IT programs, such as adult retraining, socialization of vulnerable groups, etc.; there is no relevant control over the quality of non-formal education (regulated only by market mechanisms)

Source: compiled and expanded from [27, p. 5]

In accordance with the challenges of IT education in Ukraine, as outlined in Table 14, the key areas for improving the efficiency and ability to form a competitive talent pool for the ICT sector in Ukraine include [27–28]:

1) improving the quality of teaching math and other STEM disciplines in general secondary education institutions;
2) development of a system of hub schools in villages;
3) implementation of an interactive online learning system;
4) conducting career guidance campaigns and raising the prestige of IT education;
5) training of IT switchers and raising the level of digital literacy of teachers;
6) creating positive incentives for business to promote public-private partnerships in vocational, technical and higher education;
7) reducing regulatory barriers to the participation of IT professionals in teaching at vocational, vocational-technical and professional higher education institutions, including foreigners;
8) improvement of mechanisms of public-private partnership, autonomy of higher education institutions, modernization of management processes of higher education institutions;
9) improving the functioning of dual education mechanisms, modernizing curricula, improving the quality of education and educational standards, supporting teacher training in cooperation with the ICT sector;
10) updating the system of state funding of higher education based on the principles of qualitative indicators of the performance of higher education institutions, co-financing of private higher education institutions, and portability of funding for educational services;
11) state incentives for the creation of curricula in the latest areas, including artificial intelligence, the Internet of Things, big data, and cybersecurity;
12) reducing regulatory barriers to the participation of IT professionals in teaching in higher education institutions, including foreigners;
13) simplified licensing of non-formal education institutions;
14) exemption of non-formal IT education providers from VAT;
15) Introduction of state funding for non-formal IT education programs and preferential loans for its acquisition, including for socially vulnerable groups.

To conclude, given the adverse effects of the war, it's crucial to reassess Ukraine's approach to developing human capital in the ICT sector. This review should focus on enhancing the sector's capacity to adjust, retain, and expand its pool of IT professionals, fostering innovation, and aligning with national goals for sustainable development and competitiveness (Table 15).

Research and development in Ukraine has long been plagued by a myriad of systemic challenges that have hindered its full potential and hampered its ability to contribute significantly to the country's economic and societal development. These challenges, ranging from issues in state policy to problems with funding instruments and human capital, have created barriers to innovation and progress in the R&D sector. Addressing these challenges is

crucial for Ukraine to unlock its scientific potential, foster innovation, and drive sustainable growth in the post-conflict era.

Table 15

Strategic Directions for Strengthening Ukraine's ICT Sector Human Capital

Strategic Direction	Supposed Measures
Talent pool increase and improvement	investing in education initiatives, forging alliances with relevant parties, backing entrepreneurial ventures, fostering innovation and digital proficiency, offering financial rewards, mentorship, and internships, setting up specialized training hubs, championing tech start-ups and small businesses, reinforcing assistance for tech clusters and innovation centres, revising laws for a conducive regulatory framework, and partnering with global organizations and educational bodies to cultivate IT expertise
Retainment and motivation of skilled IT experts in Ukraine	prioritize life safety, create job opportunities, offer attractive salaries, establish programs for career growth, advocate for flexible schedules and remote work options, and fortify the ICT community to facilitate knowledge sharing, collaboration on projects, career guidance, and mentorship
Involvement of foreign IT experts to Ukraine	focused promotional initiatives, streamlining immigration procedures, ensuring competitive remuneration, delivering supportive resources, upholding global labour standards, and fostering a diverse and equitable workplace that values various perspectives, backgrounds, and identities

Source: authors' proposals

One of the primary challenges facing R&D in Ukraine is the general problems of state policy in the R&D sphere. The lack of a coherent and consistent national strategy for science and technology has led to fragmented efforts and limited coordination among various stakeholders. Without a clear roadmap and vision for R&D, Ukraine struggles to prioritize investments, allocate resources effectively, and harness the full potential of its scientific community. Moreover, problems of governance and policymaking in R&D further exacerbate the challenges faced by the sector. Bureaucratic inefficiencies, lack of transparency, and corruption have hindered the effective implementation of R&D policies and programs.

The connection between science and the economy is another critical challenge that Ukraine must address. Despite the country's strong scientific base, there is a disconnect between research outcomes and their commercialization. Limited collaboration between academia and industry, insufficient technology transfer mechanisms, and a lack of entrepreneurial culture impede the translation of research into tangible products and services.

Additionally, problems with funding instruments pose a significant barrier to R&D in Ukraine. Insufficient public funding, overreliance on external sources of financing, and lack of diversified funding mechanisms constrain the sustainability and growth of the sector. The financial instruments should be of high quality and support a variety of missions, with numerous complementing funding options accessible: (1) basic funding for R&D and HE institutions should be established by evaluation findings and re-evaluated every 3–5 years to ensure it matches with each organisation's distinctive profiles; (2) competitive funding should be offered through various channels, including bottom-up, priority areas, and individual scholarships/awards through grants by funding agencies, focusing on excellence in research topics; (3) sate contracts for strategic (e.g. healthcare, security etc.) issues should be issued by competent state agencies, ensuring research groups' continued affiliation with their societies; (4) co-funding by business and its combination with equity financing, crowdfunding platforms and tax incentives; (5) international funding should be utilized primarily for the creation of joint research infrastructure among domestic and foreign R&D institutions.

Human capital and education also present challenges to R&D in Ukraine, as the brain drain of talented researchers, inadequate training programs, and limited opportunities for career advancement hinder the development of a skilled workforce in science and technology. The survey [29, p. 8] showed that 73% of respondents declared about their inability to be engaged in research activities as in pre-war times due to various reasons: constant interruptions with the Internet and communication, turning off the lights, lack of interest, apathy, safety issues, etc. Additionally, the surveys listed personal and research activity needs of domestic scientists, in particular: financial support, stable Internet access, research projects to be engaged in right now and in the near future, access to scientific literature, communication with the research teams and colleagues, mobility programs, access to information and data, licensed software required for scientific research, imployment in Ukraine and abroad (both, remote and on-site) etc. [29, p. 10; 30].

Moreover, research infrastructure problems further impede the progress of R&D in Ukraine, as outdated facilities, lack of modern equipment, and inadequate research infrastructure limit the capacity for cutting-edge research and innovation. Hence, the national strategy for research infrastructure development should include a thorough evaluation of existing infrastructure, prioritization of investment areas, strategic long-term planning, sustainable funding mechanisms, collaboration and coordination among stakeholders, capacity enhancement, open access and data sharing, a supportive regulatory framework, monitoring and evaluation mechanisms, and international collaboration (as these factors may help identify deficiencies, strengths, and

areas for enhancement, optimize the impact of investments, and ensure the efficient development and operation of research infrastructure).

Lastly, problems of international cooperation and integration into the global and European research space present challenges for R&D in Ukraine. Limited collaboration with international partners, insufficient participation in European research programs, and barriers to accessing global knowledge networks hamper Ukraine's ability to leverage international expertise and resources. In formulating a comprehensive strategy for R&D internationalization, key components should be considered, encompassing the following measures: (1) engaging domestic scientists in collaborative research initiatives, projects, institutional development, and sectoral transformation; (2) implementing incentives to facilitate the return of prominent diaspora researchers to Ukraine for knowledge integration; (3) transitioning from a scenario of 'brain drain' to 'brain circulation' by utilizing diverse mechanisms aimed at retaining and attracting talent; (4) establishing virtual international partnerships to enable Ukrainian researchers to access global research infrastructure remotely; (5) advocating for the universal adoption of English as the primary working language in academic and research settings; (6) striving for the elimination of legal impediments that hinder international collaborations and partnerships within the research community.

In the wake of conflict and destruction, Ukraine stands at a critical juncture where it has the opportunity to not just rebuild, but to "build back better" by prioritizing investment in R&D and adopting a more strategic approach to science, technology, and innovation. The country's academic sector, long under-invested and overlooked, holds the key to unlocking a new era of societal transformation and economic prosperity.

One of the key pillars for Ukraine's recovery and reconstruction lies in harnessing the power of science, technology, and innovation to drive innovation-centric industrial strategies. By bridging the gap between academia and entrepreneurship, Ukraine can create a fertile ground for disruptive research to translate into tangible products and services that can fuel economic growth. This collaboration can lead to the creation of a vibrant ecosystem where ideas are nurtured, innovations are scaled, and businesses thrive.

Furthermore, Ukraine's strong scientific competence in fields such as computer science and mathematics positions it well to capitalize on the opportunities presented by the ICT service sector. By moving up the value chain and tapping into its existing technical and managerial expertise, Ukraine can position itself as a global player in the digital economy. This shift towards digitalization not only opens up new avenues for economic growth but also enhances the country's competitiveness on the global stage.

To fully realize the potential of science, technology, and innovation in driving Ukraine's recovery and reconstruction, a concerted effort is needed to

upgrade skills and foster collaboration through public-private partnerships. By connecting ICT services with traditional sectors like agriculture, aerospace, and heavy machinery, Ukraine can unlock synergies that drive productivity and competitiveness across industries.

Conclusions

Ukraine's ICT sector has shown significant growth and resilience in the face of challenging global economic conditions during the COVID-19 pandemic. The sector is characterized by the presence of major wireless and fixed broadband operators, fibre and capacity leasing companies, as well as state-owned enterprises involved in wholesale operations. The average cost of home broadband is relatively affordable compared to other European countries. As for mobile internet services, they have a different pricing structure and are competitively priced depending on data usage and additional features. The sector has witnessed notable market trends such as the expansion of 4G coverage, deployment of 4G networks in rural areas, increased internet usage, and growing demand for modern electronic services and IoT applications across various industries.

Ukrainian software engineers are highly skilled, cost-effective, and culturally compatible professionals with a strong educational background. Their fluency in English, combined with Ukraine's advantageous time zone, makes the country an attractive location for companies looking to expand their presence in Europe. The growing tech ecosystem, start-up scene, and supportive government policies further enhance Ukraine's appeal for businesses seeking high-quality software engineering services. The distribution of registered IT individual entrepreneurs and the evolution of programming languages reflect the dynamic growth and diversification of the ICT sector in Ukraine, positioning it as a competitive player in the global tech industry.

Ukraine's ICT sector faces significant challenges related to poor governance, high corruption levels, and inadequate regulatory quality, which hinder the growth and competitiveness of the industry. The decline in R&D expenditures and the number of researchers further exacerbates the situation, leading to a reduction in the number of registered patents for ICT inventions. Addressing issues such as inefficient regulation, lack of intellectual property protection, and limited funding for R&D will be crucial for enhancing the international competitiveness of Ukrainian IT companies and the sector as a whole. Improving the regulatory environment and fostering innovation through increased investment in research and development are essential steps to overcome these obstacles and drive the technological advancement of Ukraine's ICT sector.

The ongoing war in Ukraine has significantly impacted the ICT sector, leading to challenges such as infrastructure vulnerabilities, revenue losses, and

disruptions in services. To rebuild and modernize Ukraine's ICT infrastructure, promote economic development, and enhance the quality of life for citizens, it is crucial to focus on repairing the damaged infrastructure, expanding network connectivity, investing in cybersecurity measures, attracting investments through policies and regulations, seeking international aid, and enhancing infrastructure resilience.

Ukraine's ICT sector is facing a significant shortage of qualified IT personnel due to the inability of the formal education system to adapt to the rapidly evolving industry trends. To address this challenge and build a competitive talent pool, key areas for improvement include enhancing STEM education, implementing online learning systems, promoting public-private partnerships, updating curricula to reflect emerging technologies, reducing regulatory barriers for IT professionals in teaching, providing incentives for the creation of curricula in cutting-edge areas, etc.

Ukraine's R&D sector development priorities include implementing a comprehensive government strategy for STI, increasing budgetary support for R&D, reviewing cross-ministerial coordination mechanisms, creating a comprehensive research infrastructure map, developing fundraising efforts for post-war reconstruction, fostering links with the Ukrainian scientific and entrepreneurial diaspora, promoting business innovation and industry-academia co-creation, increasing Ukrainian scientists and entrepreneurs' involvement in European and international cooperation, and improving the research and innovation evaluation system.

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