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FACTORS AFFECTING INTERNATIONAL COMPETITIVENESS OF ICT SECTOR OF THE NATIONAL ECONOMY

ФАКТОРИ МІЖНАРОДНОЇ КОНКУРЕНТОСПРОМОЖНОСТІ ІТ-СЕКТОРУ НАЦІОНАЛЬНОЇ ЕКОНОМІКИ

Summary. *Introduction. The ICT sector is crucial to the national economy, significantly contributing to GDP, employment, and innovation. Understanding the factors that influence its international competitiveness is vital for sustainable growth and maintaining its role in the global economy. A holistic research approach is needed to identify synergies and trade-offs among key impacting factors, guiding the development of policies that enhance ICT competitiveness and foster a thriving digital economy and society.*

Purpose. Research aims to critically analyse and synthesise existing literature on the factors influencing the international competitiveness of the ICT sector.

Materials and methods. This study uses related literature review, analysis, synthesis and graphic methods to identify key factors influencing competitiveness in the ICT sector. This study relies on various scientific publications from both domestic and international scholars and key studies by international industry experts.

Results. The study considers five main groups of factors influencing the international competitiveness of the ICT sector of the national economy (namely, the political and regulatory environment, the involvement of the ICT sector in international cooperation, the ICT infrastructure, the human factor and R&D) with a generalised definition of the role and nature of the impact on the ICT sector. In particular, the political and regulatory environment is considered in the context of the main directions of state policy in the field of ICT, the characteristics of governance, the impact of political stability on the stability of the ICT regulatory regime and economic freedoms. In addition, the study outlines the impact of international cooperation on the competitiveness of the ICT sector, identifies the main forms of international cooperation in the field of ICT (considering their advantages and disadvantages). In addition, the study provides a generalisation of the impact of ICT infrastructure on the international competitiveness of the ICT sector of the national economy; groups of its components and their main functions are identified. The authors specify the main characteristics of a strong and developed ICT infrastructure and emphasise the expediency of considering it in terms of ICT demand, availability, accessibility, affordability, quality and security. Furthermore, the authors consider the importance of the cybersecurity system, both of the ICT infrastructure and the state as a whole; the main components and key principles of a comprehensive national cybersecurity strategy are identified. It is proposed to consider the human factor

in terms of the consumer base and the ICT sector's talent pool (with the author's definitions and the nature of the impact on competitiveness); a generalisation of approaches to the classification of ICT skills is provided. Finally, the study considers the importance of R&D in ensuring the competitiveness of the ICT sector, provides structural and competitive organisational approaches to R&D in the ICT sector, expands the understanding of the formats of R&D in the ICT sector, notes the importance of R&D centres in the ICT sector and provides the author's classification of R&D centres in the ICT sector.

Discussion. Future research should focus on understanding the impact of internal and external factors on the competitiveness of the ICT sector of the national economy. In particular, further research is promising in terms of comprehension of the human factor, the dynamics of global competition in ICT, the role, effectiveness and coherence of government policy in ICT, the relationship between R&D investment and international competitiveness, the impact of investment in ICT infrastructure, etc. Finally, graphical materials can help simplify the display of the interrelationships and impacts of various factors on the ICT sector.

Key words: *competitiveness, ICT sector, IT market, ICT infrastructure, human capital, political and regulatory environment, R&D, international cooperation, cybersecurity.*

Анотація. *Вступ. ІТ-сектор має вирішальне значення для національної економіки, роблячи значний внесок у ВВП, зайнятість та інновації. Розуміння факторів, що впливають на його міжнародну конкурентоспроможність, є важливим для сталого зростання та збереження його ролі у світовій економіці. Для визначення синергії та компромісів між ключовими факторами впливу необхідний цілісний дослідницький підхід, який допоможе розробити політику, спрямовану на підвищення конкурентоспроможності ІКТ та сприяння процвітанню цифрової економіки та суспільства.*

Метою дослідження є критичний аналіз та синтез існуючої літератури щодо факторів, які впливають на міжнародну конкурентоспроможність ІТ-сектору.

Матеріали і методи. В дослідженні використано огляд літератури, аналіз, синтез та графічні методи для визначення ключових факторів, що впливають на конкурентоспроможність ІТ-сектору. Дослідження спирається на різні наукові публікації як вітчизняних, так і зарубіжних вчених, а також на ключові дослідження міжнародних галузевих експертів.

Результати. В дослідженні розглянуто п'ять основних груп факторів впливу на міжнародну конкурентоспроможність ІТ-сектору національної економіки (а саме, політичне та регуляторне середовище, залученість ІТ-сектору до міжнародного співробітництва, ІКТ-інфраструктура, людський фактор та НДДКР) із узагальненим визначенням ролі та характеру впливу на ІТ-сектор. Зокрема, політичне та регуляторне середовище розглянуто в розрізі основних напрямів державної політики в сфері ІКТ, характерних рис урядування, впливу політичної стабільності на регуляторний режим ІКТ та економічні свободи. Крім того, в дослідженні зазначено вплив міжнародного співробітництва на конкурентоспроможність ІТ-сектору, визначено основні форми міжнародної співпраці в сфері ІКТ (з врахуванням їхніх переваг та недоліків). Додатково, в дослідженні наведено узагальнення впливу ІКТ-інфраструктури на міжнародну конкурентоспроможність ІТ-сектору національної економіки; визначено групи її компонентів та їхніх основних функцій. Визначено головні характеристики сильної та розвинутої ІКТ-інфраструктури та наголошено на доцільності розглядати її в розрізі попиту на ІКТ, наявності, безбар'єрності, фінансової доступності, якості та безпечності. До того ж, розглянуто важливість системи кібербезпеки, як ІКТ-інфраструктури, так і держави в цілому; визначено основні складові та ключові принципи комплексної національної стратегії з кібербезпеки. Запропоновано розглядати людський фактор з точки зору споживчої бази та кадрового резерву ІТ-сектору (з наведенням авторських дефініцій та характеру впливу на конкурентоспроможність); наведено узагальнення підходів до класифікації ІКТ-навичок. Нарешті, в статті розглянуто важливість НДДКР у забезпеченні конкурентоспроможності ІТ-сектору; наведено структурний та конкурентний організаційні підходи до НДДКР в сфері ІКТ; розширено уявлення про формати НДДКР в сфері ІКТ; зазначено важливість R&D-центрів в сфері ІКТ та наведено авторську класифікацію R&D-центрів в сфері ІКТ.

Перспективи. Майбутні дослідження мають бути зосереджені на розумінні впливу внутрішніх та зовнішніх факторів на конкурентоспроможність ІТ-сектору національної економіки. Зокрема, подальші дослідження є перспективними для розуміння людського фактору, динаміки глобальної конкуренції в ІКТ, ролі, ефективності та узгодженості державної політики у сфері ІКТ, взаємозв'язку між інвестиціями в НДДКР та міжнародною конкурентоспроможністю, впливу інвестицій в ІКТ-інфраструктуру, тощо. Нарешті, графічні матеріали можуть допомогти спростити відображення взаємозв'язку та впливу різних факторів на ІТ-сектор.

Ключові слова: *конкурентоспроможність, ІТ-сектор, ІТ-ринок, ІКТ-інфраструктура, людський капітал, політичне та регуляторне середовище, НДДКР, міжнародне співробітництво, кібербезпека.*

Introduction. The ICT sector's importance in the national economy is undeniable, with significant contributions to GDP, employment, and innovation. Understanding the factors that affect its international competitiveness is crucial for fostering sustainable growth and ensuring that ICT sector remains a driving force in the global economy. As such, scientific and industry research has increasingly concentrated on understanding the myriad factors that influence ICT sector and the broader formation of the digital economy and digital society. Much of the academic and industry research focuses on the study of individual factors affecting ICT sector competitiveness or on the study of factors influencing the formation of the digital economy. While the previous research has provided valuable insights, it has also led to a fragmented understanding of the complex

interplay between various factors and their cumulative impact on competitiveness and societal transformation.

Finally, we believe that a more holistic approach to research can help identify synergies and trade-offs between different factors, and become the information base for the development of comprehensive policies that promote both the competitiveness of the ICT sector and the development of a thriving digital economy and society.

Analysis of recent research and publications. Various aspects of digital development and the readiness of national economies to use ICTs to achieve sustainable development goals (in particular, in terms of impact factors) are covered in numerous annual reports and studies by international organisations [1–9]. The NRI by Portulans Institute compares national digital readiness performance across countries/economies to benefit from ICT adoption [1, p. 223]. The WDCR by IMD examines and assesses the extent to which countries adopt and explore digital technology, resulting in transformations in governance, business models, and society as a whole [2, p. 40]. The FTRI by UNCTAD measures potential and readiness of countries to produce and implement advanced technologies [3]. The DII by Tufts University aims to comprehend the global impact of digital advances and provide practical insights to stakeholders on how to improve digital competitiveness, nurture trust in the digital economy and promote responsible use of advanced technologies for achieving SDGs [4]. Additionally, pre-2023 edition of IDI by ITU was developed to assess the level of the information and communication technology sector development, while reviewed IDI methodology aims to evaluate the extent to which connectivity is universal and meaningful within nations [5–6]. The GCI by Huawei examines a wide range of indicators related to ICT infrastructure and digital transformation, offering a detailed overview of the global digital economy [7]. The CDRI by Cisco holistically measures countries' level of overall readiness to foster an inclusive digital economy [8]. EDDB by Tufts University examines how easy it is for digital businesses to enter, operate, thrive, and exit, evaluating market attractiveness in terms of supply conditions and market sophistication [9, p. 17].

On the other hand, the most similar in terms of the object and subject matter of the study were scientific publications [10–16]. In particular, in the empirical study [10, p. 2–5], the authors considered the nature of the impact of economic wealth, human capital, regulation, demographic, geographic and regional factors on ICT infrastructure. In addition, the empirical study [11] examined the impact of broadband infrastructure, diversity of R&D funding and performance, number of researchers, education, openness to international trade, and socioeconomic factors on ICT innovation (with the subsequent indication of the crucial impact of a high level of broadband infrastructure and effective triple helix cooperation).

In Bhutan case study [12], the authors emphasise the significant impact of human resources, government policies, infrastructure, foreign direct investment (FDI) and culture among the factors influencing the growth of the ICT sector. Despite the thorough and multidimensional results of the case study, we believe that it is methodologically appropriate to differentiate between the concepts of "ICT sector growth" and "ICT sector international competitiveness". Thus, "the growth of the ICT sector" refers to its expansion in terms of revenue, employment, and contribution to the overall national economy (literally, the size and scale of the ICT sector within a country). On the other hand, "ICT sector international competitiveness" refers to the ability of a country's ICT sector to compete successfully in the global market, reflecting how well it can hold its competitive position against global rivals, attract international clients, and maintain a strong presence in foreign markets (literally, positioning and strategic advantages in the global digital arena). At the same time, both concepts are interrelated: growth can provide the resources and scale necessary for an ICT sector to become more competitive, while competitiveness can lead to increased market share and revenue growth. Nevertheless, it is important to understand that growth does not always lead to competitiveness, namely, an ICT sector can grow rapidly due to favourable impacting factors, but it may not be able to compete effectively in the global ICT market.

In the studies [13–14], the authors considered the case of Ukraine's ICT sector in terms of the availability of a talent pool, brain drain, domestic demand for ICT, compliance with international standards, foreign investment, tax burden, transparency of the government, as well as the political and economic situation in the country. In addition, another study [15] conducted a comparative analysis of the competitive position of Ukraine's ICT sector in Eastern Europe in terms of Ukraine's share in the region's ICT exports, ICT infrastructure, IT talent, R&D activities, access to financial sources and the general state of the business environment. Finally, the study [16] proposes to assess ICT sector international competitiveness in terms of five dimensions: ICT infrastructure, human capital, innovation potential in ICT, favourable business and regulatory environment, and the degree of ICT sector involvement in international economic relations.

Therefore, **the purpose of our research** is to critically analyse and synthesise existing literature on the factors that influence the international competitiveness of the ICT sector in order to provide a comprehensive view of the key drivers of competitiveness in the ICT sector and their interplay, as well as identify gaps in the current research.

The research methods include: literature review through a comprehensive search of academic and professional publications, including journal articles, books, reports, and other relevant sources (to identify

existing research on the topic); analysis and synthesis (to develop a comprehensive view of the key factors that influence competitiveness in the ICT sector); graphic methods (to visualise the research results).

The materials that have formed the basis of this study are a number of scientific publications by domestic and foreign authors and key studies conducted by industry experts from international organisations.

Results. It should be noted that in most of the above-mentioned scientific and industry studies, the factors influencing international competitiveness have a rather dual nature of influence on the formation of competitive advantages and the ability of the ICT sector to compete in the global IT market, according to which all factors can be divided into two groups: favourable (provide competitive advantages for the ICT sectors of countries) and impeding (slow down or impede the ability of the country's ICT sector to compete in the global IT market).

We believe that government policy is a key factor in the legislation and regulation of the ICT sector, as it shapes the vision of ICT and its relationship to national development goals (Table 1). Governance encompasses the set of traditions and institutions responsible for wielding authority within a nation including processes for the selection, oversight, and replacement of governments, the capability of these governments to develop and execute effective policies, and the adherence of both citizens and the state to these institutional frameworks [17]. Legislation sets out: (1) how policy is implemented, providing a statutory basis for the necessary institutions, procedures and processes; and (2) the financial, staffing and reporting regimes under which regulatory institutions operate, and which define their functions and degree of autonomy. Moreover, ICT policy promotes competition for the supply of quality, diverse technology solutions at affordable prices (which is a powerful tool for consumer protection), limits anti-competitive behaviour, fosters a favourable investment climate in the ICT sector and optimises the use of scarce resources.

The main characteristics of good governance that contribute to the competitiveness of the ICT sector are voice and accountability (how much citizens can influence government decisions, and their freedoms of speech, association, and media), political stability and absence of violence/terrorism (the chances of political unrest and violence, including terrorism), government effectiveness (the quality and independence of public services and civil servants, policy making and implementation, and government reliability), regulatory quality (the government's ability to create and enforce policies that support private sector growth), rule of law (trust in societal rules, including enforcement of contracts, property rights, and effectiveness of police and courts, as well as crime rates) and control of corruption (the extent of public power misuse for private gain, covering both minor and major corruption, and state capture by elites and private interests) [17].

In addition, a stable political environment can support a stable regulatory environment that helps companies plan their operations and investments, while an unstable or unpredictable regulatory environment can create uncertainty and limit the growth of the ICT sector. It should be noted that a stable political environment is able to support strong intellectual property laws, which are important for the competitiveness of the ICT sector, as they can protect companies' R&D investments, encourage innovation and support the growth of the ICT sector. Additionally, a stable political environment will ensure that these policies (Table 1) remain in place over the long term, which can help the ICT sector grow. Finally, political stability can also affect a country's ability to access international IT markets, as it creates a positive image for the country, which can help open new markets and attract foreign investment.

We should admit, that considering economic freedoms is important when assessing the international competitiveness of a country's ICT sector because it directly impacts innovation, investment, market access, entrepreneurship, and human capital development — all of which are essential for a country to compete effectively in the rapidly evolving global IT market. In particular, the Index of Economic Freedoms methodology identifies four groups of economic freedoms: "Rule of Law", "Government Size", "Regulatory Efficiency" and "Open Markets" [18]. In the context of the international competitiveness of the country's ICT sector, we believe that the following freedoms are important "Regulatory Efficiency" (business freedom, labour freedom, monetary freedom) and "Open Markets" (trade freedom, investment freedom, financial freedom), as they influence business operations, market access, investment attractiveness, and overall competitiveness in the global IT market. Ultimately, a combination of supportive government policies, political stability, and economic freedoms is crucial for shaping the international competitiveness of a country's ICT sector, creating an environment that fosters innovation, investment, and growth of a country's global competitiveness.

Moreover, in today's interconnected world, the success of a country's ICT sector is increasingly intertwined with its ability to engage in international cooperation. While domestic policies and investments are crucial, international collaboration offers numerous benefits for enhancing ICT sector's competitiveness and ensuring long-term success. In our opinion, it is advisable to consider the involvement of the country's ICT sector in international cooperation from two perspectives: firstly, in terms of compliance with and implementation of international ICT standards and regulations; and secondly, in terms of various forms of international cooperation, production and trade. Thus, compliance with and implementation of international standards in ICT has a number of advan-

tages for ensuring the international competitiveness of a country's ICT sector, in particular: (1) it ensures compatibility and integration of products and services of the country's ICT sector with other systems in the global market; (2) IT companies are able to expand their influence on the potential customer base without facing technical barriers or compatibility issues; (3) international compliance facilitates cooperation with foreign companies and organisations, opening access to advanced technologies, experience and funding opportunities; (4) compliance with international standards signals to partners, customers and regulators the quality and reliability of the country's ICT sector's technological solutions, thereby building trust and

Table 1

Summary of key areas of state policy in information and communication technologies

Policy direction	Components	Commentary
Infrastructure	broadband connectivity	investing in fibre optic infrastructure, promoting wireless technologies; facilitating spectrum management; focusing on closing the digital divide by extending broadband connectivity to remote and rural areas; implementing policies that ensure open and non-discriminatory access to the Internet
	data centres and cloud computing	supporting the development of data centres and cloud computing services; promoting data storage, processing, and analytics; establishing clear regulations on data storage and processing; encouraging energy-efficient design and operation of data centres
	cybersecurity infrastructure	protecting critical digital assets, promoting secure data handling, building resilience against cyber threats; developing and implementing a comprehensive national cybersecurity strategy; conducting public awareness campaigns to educate citizens about cybersecurity risks and best practices; developing and testing incident response and recovery plans
	spectrum management and allocation	efficient allocation and management of radio spectrum resources, promoting competition and innovation in wireless technologies; prioritising spectrum allocation for the development and deployment of 5G and other next-generation wireless technologies; exploring new approaches to spectrum sharing and dynamic allocation to maximise efficient use of scarce spectrum resources
ICT skills development	education and training	fostering ICT skills in the workforce through education reforms, vocational training programs, and online learning initiatives; supporting STEM education, promoting digital literacy, and bridging the digital divide
	attracting and retaining talent	implementing policies to attract and retain skilled ICT professionals, (e.g. offering competitive salaries, providing visa pathways for international talent, and creating conducive working environments)
	research and development	supporting R&D in ICT (e.g. grants, tax incentives, and collaborations between universities, research institutions, and industry)
Legal and regulatory framework	competition and antitrust	ensuring a level playing field for ICT companies that prevent anti-competitive practices and promote fair competition
	data privacy and protection	establishing comprehensive data privacy laws and regulations that protect personal data, promote responsible data use, and foster trust in the digital environment
	cybersecurity regulations	requirements to adopt strong security measures, report data breaches, and ensure responsible data handling practice
Digital inclusion	digital literacy programs	bridging the digital divide and empowering citizens to participate in the digital economy
	accessible technology	ensuring that ICT technologies are accessible to all citizens through assistive technologies and inclusive design principles
	e-government services	developing and expanding e-government services to provide efficient, transparent, and accessible public services
Investment and innovation	tax incentives and grants	offering tax incentives, grants, and subsidies to encourage private sector investment in ICT infrastructure, R&D, and innovation
	venture capital and start-up support	fostering a vibrant start-up ecosystem through venture capital funding, incubators, accelerators, and mentorship programmes
	public-private partnerships	encouraging public-private partnerships to leverage private sector expertise and resources in developing ICT

Source: summarised based on [1–12]

fostering long-term business relationships; (5) compliance with international standards and regulations reduces legal risks.

In addition, international cooperation is important for the country's ICT sector to achieve global competitiveness, as it provides access to knowledge, resources and technologies, fosters innovation, enhances cybersecurity and creates a thriving global digital ecosystem. The main forms of international cooperation in ICT include:

1) bilateral and multilateral agreements (e.g. free trade agreements, partnership and cooperation agreements, memoranda of understanding);
2) joint ventures and strategic alliances (e.g. collaborative R&D projects, co-development agreements, shared infrastructure projects, technology partnerships);
3) international trade and export promotion (e.g. export credit agencies, trade missions, international trade fairs and expos, market access initiatives);
4) academic and research collaborations (e.g. international research consortia, exchange programmes, technology transfer, joint degrees and certifications, international research grants, collaborative publications);
5) public-private partnerships (e.g. innovation hubs and tech parks, digital literacy programmes, innovation clusters, publicly funded tech incubators);
6) international funding and investment (e.g. foreign direct investment, international grants and loans, venture capital and private equity, cross-border M&A);
7) cross-border data exchange and collaboration (e.g. cloud computing agreements, data sharing initiatives, cybersecurity alliances, collaborative data analytics projects, global data repositories, cross-border cybersecurity frameworks);
8) capacity building and training (e.g. technical assistance programs, workshops and seminars, online courses and e-learning platforms, international training programmes, international certification programs, training partnerships with global tech firms);
9) participation in global value chains (GLV) through outstaffing, outsourcing, offshoring, onshoring, nearshoring, rightshoring, etc.;
10) international forums and conferences, ICT summits etc.

Below are the main advantages and disadvantages of each form of international cooperation (Table 2).

The next factor affecting the international competitiveness of the ICT sector of the national economy is the focus of the ICT infrastructure on deploying and adapting advanced technologies such as artificial intelligence, the Internet of Things (IoT), Big Data and blockchain [15, p. 47]. An important factor in ICT is the full or partial automation of processes and the provision of services by government and non-government institutions through the Smart City infrastructure [19]. It is worth noting that a sufficiently developed and accessible ICT infrastructure can increase efficiency, foster innovation and entrepreneurship in the ICT sector, and improve interaction with customers and partners internationally and globally; in particular, the ICT infrastructure enables IT companies: (1) to collaborate more efficiently (regardless of their location), as well as have access to new technologies, tools and resources; (2) to provide customers with seamless and personalised products and services through multiple digital channels; (3) to reach customers and partners globally, leading to increased market share and revenue growth; (4) to collect, store and analyse large amounts of constantly growing data, which helps identify patterns, trends and opportunities and leads to fewer errors, streamlined processes, better customer service and increased competitiveness. Besides, the ICT infrastructure based on the principles of secure communication using 1–2 factor authentication allows to build infrastructure and digital data protection.

The following are the main components of the ICT infrastructure of the country's ICT sector that work together to support the storage, processing, protection and transmission of information in the ICT sector (Table 3).

A strong and developed ICT infrastructure in a competitive ICT sector typically exhibits the following characteristics, in particular it:

1) offers high-speed broadband connectivity, wide coverage, advanced fibre-optic networks, and 5G technology deployment for reliable, high-speed internet access in remote areas;
2) includes advanced data centres, high storage and processing capacity, redundancy for availability, reliability, and energy efficiency, reducing operational costs and environmental impact;
3) includes advanced threat detection, data protection protocols, and compliance with international cybersecurity standards;
4) demonstrates scalability, service variety, and seamless integration with various platforms and applications (e.g. cloud computing);
5) features innovative technologies, e.g. IoT integration, AI and machine learning, and blockchain implementation for secure data transactions;
6) consists of reliable, efficient, modern, high-quality service, and strong international connectivity for global communication and data exchange;
7) focuses on providing user-centric services, high-quality support, and customisable solutions to meet diverse business needs.

Hence, in our opinion, in the context of the international competitiveness of a country's ICT sector, it is advisable to consider the state of the ICT infrastructure in terms of demand for ICT, availability and accessibility of ICT infrastructure, affordability of ICT, quality of ICT infrastructure and security of ICT infrastructure because:

1) the demand for ICT products and services within a country signals a substantial market potential, providing a stable revenue base, which enables local companies to scale up and compete internationally;
2) the availability and accessibility of ICT infrastructure are essential for ensuring that users can access and utilise ICT resources when needed, including network uptime, data centre reliability, fault tolerance level and accessibility to services, etc.;
3) affordability (in terms of cost of acquiring and maintaining ICT resources, as well as cost of services for end users) plays a key role in enabling widespread access to ICT infrastructure;
4) the quality of ICT infrastructure directly impacts its performance, reliability, and usability;
5) security is critical for ICT infrastructure development, as it protects data, systems, and communications from unauthorised access, cyber threats, and potential breaches.

Moreover, Partner2Connect Action Framework identifies 4 focus areas aiming at connecting people, empowering communities, building digital ecosystems and incentivising investments within least developed countries (LDCs), landlocked developing countries (LLDCs) and small island developing states (SIDS) which involves considering the above-mentioned principles [20, p. 2]. In addition, the ITU experts emphasise that

Table 2

Generalised Pros and Cons of International Cooperation Forms in ICT

Cooperation Form	Advantages	Disadvantages
Bilateral & multilateral agreements	• facilitate regulatory alignment and harmonization • enhance market access and trade opportunities • promote cooperation on standards and best practices	• lengthy negotiation processes • potential for disagreements and conflicts • limited scope without broader multilateral participation
Joint ventures & strategic alliances	• pool resources and expertise • share risks and costs of R&D • access to new markets through partnerships	• complex management structures • potential for conflicts of interest • dependency on partners' performance and decisions
International trade & export promotion	• expand market reach for ICT products and services • boost economic growth and export revenues • foster competition and innovation	• trade barriers and protectionist policies • market entry challenges in foreign countries • dependency on global economic conditions
Academic & research collaborations	• foster knowledge sharing and transfer • accelerate innovation through joint research • enhance talent development and skills	• intellectual property protection challenges • coordination issues across institutions • funding and resource allocation complexities
Public-private partnerships	• involve combination of public sector resources and private sector innovation • drive infrastructure development and digital inclusion • improve policy-making through stakeholder collaboration	• balancing public and private interests • accountability and transparency challenges • long-term sustainability and funding issues
International funding & investment	• stimulate ICT sector growth and innovation • provide capital for start-ups and scale-ups • support digital development projects	• risk of capital flight in volatile markets • regulatory hurdles and compliance requirements • dependency on investor preferences and market condition
Cross-border data exchange & collaboration	• enable global data sharing for insights and analytics • facilitate international research and development • enhance collaboration on cybersecurity and data protection	• data privacy and security risks • compliance with diverse regulatory frameworks • data localisation and sovereignty concerns
Capacity building & training	• address skills gaps • enhance workforce productivity and competitiveness • support lifelong learning	• resource constraints for training programmes • need for adaptation to rapidly evolving technology trends • quality and relevance assurance of training initiatives
International forums, conferences, summits	• facilitate knowledge exchange and networking • showcase innovations and best practices • influence policy agendas and industry standards	• high costs for participation and sponsorship • limited impact without follow-up actions or collaborations

Source: authors' views summary

the cybersecurity of a country's ICT infrastructure is paramount for national security, economic stability, and the protection of citizens' privacy, as without adequate cybersecurity measures in place, a country's infrastructure and its citizens are vulnerable to a wide range of cyber threats that could have far-reaching consequences [20; 21]. In particular, cybersecurity of a country's ICT infrastructure involves multiple components, each addressing different aspects of protecting and securing the infrastructure (e.g. risk management, policy and governance, legal and regulatory framework, threat intelligence and information sharing, cyber defense capabilities, incident response and recovery, security awareness and training, R&D, critical infrastructure protection, encryption and data protection, supply chain security, etc.). We should admit that a nation's cybersecurity strategy is broader than just the ICT infrastructure itself, as it involves protecting the entire ICT ecosystem, including people, processes, and technology. The main components of the national cybersecurity strategy are [21]:

1) vision and goals (clear, overarching objectives for national cybersecurity, such as protection of critical infrastructure, safeguard of sensitive data, and fostering trust in cyberspace);
2) threat assessment (comprehensive understanding of the threats, such as cybercrime, espionage, state-sponsored attacks etc.);
3) risk management framework (for identification, assessment, and mitigation of cybersecurity risks across various sectors);
4) national cybersecurity policy (which is a set of guidelines, principles, and regulations that govern cybersecurity practices within the country);
5) identification of critical infrastructure (definition and classification of critical infrastructure sectors that are essential to national security, economic stability, and public safety);
6) development and enforcement of security standards and guidelines, as well as creation and test of comprehensive plans for responding to cyberattacks on critical infrastructure;

Table 3

Key Components of the ICT Infrastructure Ecosystem

Infrastructure component	Infrastructure elements	Main functions and purpose
Hardware	servers, storage devices, routers, switches, firewalls, and other networking equipment	provision of the physical foundation for ICT systems, data storage, processing and transmission, as well as security appliances for protecting the infrastructure
Software	operating systems, databases, applications, and other software tools for managing and processing data	management and processing of data, control of hardware, data organisation and storage, as well as applications for communication, collaboration and data analysis.
Networks	personal area network (PAN), metropolitan area networks (MAN), local area networks (LAN), wide area networks (WAN), and other network infrastructure	communication and transfer of data between devices and systems
Communication systems	telephone wired networks, mobile networks, and computer wired and wireless networks, internet services, satellite networks	provision of the means for voice and data communication
Data centres	facilities for housing servers, storage devices, information security and networking equipment	housing and management of ICT infrastructure hardware components, as well as provision of an uninterrupted, secure and controlled environment for storing and processing data
Cloud infrastructure	infrastructure as a Service (IaaS) and Platform as a Service (PaaS)	offer of scalable and flexible computing resources, enabling organizations to access computing power, storage, and applications on demand
Security systems	firewalls, intrusion detection systems, encryption tools, and other	ICT infrastructure protection from unauthorized access, data breaches, critical cyber interventions and other cyber threats,
Backup and disaster recovery systems	systems for backing up data and applications, services and systems as well as plans for recovering from system failures or disasters	control and verification of data integrity and system stability
Monitoring and management tools	performance monitoring tools, fault management tools, capacity planning tools, automation, load control and orchestration tools, etc.	monitoring of the ICT infrastructure performance and health, as well as management and configuration of the components for optimal operation and security systems

Source: authors' summary

7) encouragement of collaboration and information sharing between government agencies, private companies, and critical infrastructure operators;
8) establishment of dedicated government agencies responsible for cybersecurity (e.g. national cybersecurity centre or a dedicated cybersecurity department within relevant ministries);
9) enacting cybersecurity laws and regulations to protect critical infrastructure, personal data, and sensitive information, as well as setting cybersecurity standards for various sectors;
10) development of mechanisms for enforcing cybersecurity compliance and addressing non-compliance;
11) cybersecurity workforce development including education and training programmes (investing to develop a skilled cybersecurity workforce), cybersecurity awareness campaigns (raising public awareness about cybersecurity threats and best practices), incentives for cybersecurity careers, as well as support of cybersecurity R&D to advance technologies and best practices;
12) investment in and deployment of advanced cybersecurity technologies (e.g. intrusion detection systems, firewalls, and endpoint security software), implementation of data encryption, data loss (theft, destruction) prevention, data backup and recovery systems (separately for services and digital data), AI, ML, blockchain etc.), as well as collection and analysis of threat intelligence to stay ahead of emerging threats and possible interventions;
13) international cooperation and collaboration, particularly in forms of a) participation in international cybersecurity forums and initiatives, experience exchange, b) provision of cybersecurity assistance to other countries, particularly developing nations, c) use of diplomacy to promote international cybersecurity cooperation and norms; d) development and implementation of state centres for monitoring and responding to cyber threats, e) development of standards and their improvement for organising cybersecurity of critical infrastructure facilities and other business entities, government agencies, etc., f) introduction of certified centres for training and certification of specialists in cyber defence of critical infrastructure at various levels.

Fig. 1. 9 Overarching Principles of a Strong National Cybersecurity Strategy
Source: authors' summary of [22]

Accordingly, there are 9 basic principles of a coherent national cybersecurity strategy that should be considered at all stages of the process of drafting and implementation of a national strategy document (figure 1).

The ICT sector is highly dependent on well-educated and high-quality human capital as a key component of economic success and competitiveness. Two key human factors significantly influence this competitiveness: the consumer/customer base and the talent pool. At this point, we propose to define "ICT sector's consumer base" as a collective group of individuals, businesses, and organisations that utilise information and communication technology products and services, while "ICT sector's talent pool" refers to the collective workforce with the necessary skills, knowledge, and expertise to develop, implement, manage, and support information and communication technologies.

The consumer base in the ICT sector is diverse, typically consisting of personal consumers (individuals who purchase ICT products, services, tech solutions and software applications etc. for personal use), business consumers (companies and enterprises that utilize ICT products and services to enhance their operations, productivity, and competitiveness), government and public sector (use ICT to improve public services, enhance communication with citizens, and increase operational efficiency), educational institutions (leverage ICT, e.g. e-learning platforms, educational software, and digital libraries, for teaching, learning, and administration), healthcare providers (use ICT for patient management, telemedicine, electronic health records, and other health-related services), and non-profit organizations (utilise ICT to support their missions, enhance communication, and manage operations effectively).

It should be emphasised that in the context of ICT sector competitiveness, the consumer base and its digital literacy play a significant role, as they: (1) form a significant market size that is attractive to IT companies seeking to scale their operations and generate significant profits by meeting the diverse needs and preferences of a wide demographic of users; (2) attract domestic and foreign investment, as investors see the potential for high returns in markets with strong consumer demand and digital adoption; (3) provide valuable feedback to IT companies on their products and services, stimulating continuous improvement and innovation, leading to the development of more advanced technologies and solutions; (4) provide effective testing of the relevance of new ideas, features and products on different customer segments, reducing the risk of failure when scaling up globally; (5) form a potentially skilled human resource pool that is able to develop high-quality products and services, increasing the overall competitiveness of the ICT sector, thereby strengthening the economy's position in international trade (as it can export ICT products and services, attract foreign partnerships and investments, and actively participate in global digital ecosystems).

At the same time, quality ICT talent pool is crucial for ICT sector international competitiveness, as it: (1) fosters innovation, allowing companies to develop cutting-edge technologies and maintain a competitive edge in the global market (as talented professionals bring new ideas, expertise, skills, etc.); (2) helps organisations leverage technology to improve efficiency, service delivery, customer experience etc. within various sectors, including healthcare, education, finance, and government; (3) attracts both domestic and foreign investments facilitating economic development and technological advancement; (4) offers high-quality services and products, attracts international clients leading to stronger competitive position in the global IT market; (5) supports entrepreneurship and the growth of startups, as skilled professionals are more likely to innovate, start new ventures, and contribute to a dynamic and entrepreneurial ecosystem; (6) facilitates collaboration across different sectors. ICT professionals can work with experts in other fields to develop integrated solutions, driving innovation and enhancing overall societal well-being.

However, on the other hand, an underdeveloped ICT sector causes the emigration of highly skilled personnel from one country to another, leading to a shortage of skilled workforce and a decrease in the international competitiveness of the ICT sector. It should be noted that the main reasons behind the emigration of highly skilled IT professionals include seeking higher salaries and better conditions, lack of opportunities for professional fulfillment in the domestic market, differences in the technological development of the IT sectors of different countries, as well as certain political, economic and cultural factors. Additional aspects of the negative impact of human capital on the international competitiveness of a country's ICT sector include the ageing of human capital (as older workers may be less likely to adopt new technologies and business practices in the ICT sector), as well as professional burnout and staff turnover (as a result of a lack of work-life balance, insufficient support or unrealistic expectations, which lead to a loss of talent, motivation and experience, as well as lower morale and productivity, etc.).

Furthermore, distinguishing between ICT skills is essential for the effective development of human capital in the country's ICT sector, as it enables targeted training and development, efficient workforce planning, enhanced productivity and innovation, improved resource allocation, and ultimately contributes to the country's global competitiveness in the rapidly evolving field of information and communication technology. Below are the main methodological approaches to the classification of ICT skills required for engagement in the digital economy, proposed by international governmental organisations, foreign and domestic scholars, and non-governmental organisations (Table 4).

Table 4

Generalisation of Approaches to ICT Skills Classification

Author (–s)	Classification Criteria	Skills Group	Commentary	Skills
ITU [23, p. 5–7]	proficiency level	basic	enable to function at a minimum level in society (basic digital literacy)	hardware (e.g. using a keyboard etc.), software (e.g. managing privacy settings or files on laptops/mobile phones etc.), and basic online operations (e.g. write an email, etc.)
		intermediate	enable to use digital technologies in different ways, including the ability to critically evaluate technology or create content	desktop publishing, digital graphic design, digital marketing, etc.
		advanced	those needed by specialists in ICT professions	AI, big data, coding, cybersecurity, Internet of Things, mobile app development, etc.
Coursera [24, p. 69–71]	skill domain	business	soft skills for every context, along with those that are required for the management and operation of an organisation	accounting, business analysis, data analysis, management, research & design, etc.
		technology	creation, maintenance, and scaling of computer systems and software	cloud computing, computer architecture, computer networking, computer programming, DevOps, security engineering, web development, software engineering, etc.
		Data Science	capturing and utilising the data generated within a business for decision-making etc.	data management & visualisation, maths & statistics, machine learning, statistical programming
Desyatko A. M., Shestak Y. I., Zakharov R. G. [25, p. 32]	competence-based and personal abilities	professional competences	determined by the educational programme of the student or speciality	
		market competences	underscore the importance of a proactive attitude, commitment to continuous personal improvement	active life position, seriousness of motivation for the profession, aptitude for self-development, etc.
		corporate competences	essential for effectively contributing to and thriving in a corporate environment	systematic thinking, professionalism, ability to work in a team stress resistance, ability to comply with corporate standards, conscientious and responsible attitude to work, etc.
The European Commission's Joint Research Centre [26, p. 9–50]	type & proficiency level	information and data literacy	browsing, searching, evaluating, filtering & managing data, information and digital content	
		communication & collaboration	interacting, sharing, engaging citizenship & collaborating through digital technologies, 'netiquette', managing digital identity	
		digital content creation	developing, integrating & re-elaborating digital content, understanding copyright and licences, programming	
		safety	protecting devices, personal data & and privacy, health & well-being, the environment	
		problem solving	solving technical problems, identifying needs & technological responses, creatively using digital technology, identifying digital competence gaps	

Source: compiled from [23–26]

In summary, a strong consumer base drives demand, innovation, and brand reputation, while a skilled talent pool fosters innovation, productivity, and global collaboration.

R&D and innovation activities can influence the international competitiveness of the IT sector, giving companies a competitive edge in the global IT market by enabling them to develop new and improved IT products, IT services and processes that can increase efficiency, reduce costs and improve quality. Structural approaches to research and development (R&D) in ICT vary depending on the size, goals, and structure of the organisation, and can be identified as:

1) centralised R&D, i.e. a single R&D department responsible for all research activities across the organization (e.g. such companies as IBM, Intel);
2) decentralised R&D, i.e. R&D activities are spread across various business units or departments (e.g. such companies as Google, Amazon, Cisco);
3) hybrid R&D, i.e. combination of centralised and decentralised approaches, often with a core central R&D team and satellite teams within business units (e.g. such companies as Microsoft, Samsung, Apple).

Furthermore, based on applied corporate competitive strategies, forming approaches for R&D activities may be classified into R&D competition (R&D rivalry), R&D cartelisation (R&D cartel, R&D cooperation), research joint venture (RJV) competition (RJV rivalry), RJV cartelisation (RJV cartel, RJV cooperation) and full industry cartelisation (full industry cartel, full industry cooperation) [27, p. 1124].

Below are the main formats of R&D activities in ICT, each of which plays a crucial role in stimulating innovation and technological progress (Table 5).

R&D centres serve as crucial hubs for fundamental research, providing a space for scientists, engineers, and researchers to delve into the core principles of ICT, leading to ground-breaking discoveries that often form the foundation for new technological advancements. Moreover, global practice includes three main types of foreign R&D centres: foreign-funded R&D centres, global R&D centres, and foreign-funded open innovation platforms [29, p. 51]. Additionally, the study [29, p. 51] highlights general corporate R&D engagement strategies of international IT companies, in particular through acquisition of local IT companies, establishing new R&D facilities, forming partnerships with local universities or research institutions, investing in tech start-ups, and establishing innovation hubs or accelerators.

Classification in Table 6 highlights the varying ownership structures, research focuses, geographic scopes, collaboration models, sizes, technological domains, innovation types, research outputs, organisational structures, market orientations, etc. in global R&D practice in ICT.

Finally, R&D in ICT relies on various factors such as financial investment, human capital, infrastructure, government policies, industry demand, collaboration,

Table 5

Formats of Research and Development in ICT

Format	General Objectives	General Activities	Possible Outputs
Basic Research	to gain a deeper understanding of fundamental principles without immediate commercial application	theoretical studies, experiments to validate theories, algorithm development	scientific papers, theoretical models, foundational knowledge (e.g. development of new cryptographic algorithms, etc.)
Applied Research	to solve specific, practical problems by applying existing knowledge	designing prototypes, testing technologies in controlled environments, feasibility studies	prototypes, patents, technical reports (e.g. new networking protocols creation, etc.)
Development	to bring new or improved products and services to the market	system design, integration, testing, and validation, pilot projects, market analysis	commercial products, software, hardware, systems (e.g. development of new smartphone models, software applications, IoT devices, etc.)
Collaborative Research	to leverage the strengths of multiple organizations or disciplines to address complex challenges	joint projects, consortiums, public-private partnerships, academic-industry collaborations	joint publications, shared patents, combined technological advancements (e.g. collaborative AI research between universities and tech companies)
Translational Research	to translate findings from basic research into practical applications	bridging the gap between lab and market, proof-of-concept studies, validation in real-world conditions	scalable prototypes, validated solutions, pilot implementations (e.g. applying cybersecurity research to industry-specific solutions, etc.)
Experimental Development	to experiment with new ideas and assess their feasibility	building and testing experimental models, simulations, exploratory coding	proof-of-concepts, experimental data, feasibility reports (e.g., testing new blockchain protocols, exploring new network architectures, etc.)

Source: formed and expanded on the basis of [28]

intellectual property protection, global competition, technological trends, regulatory environment, data access, market size and growth potential, corporate strategy, and international collaboration. Thus, sufficient funding, skilled professionals, advanced technological infrastructure, government incentives, industry demand, collaboration between universities and industry players, strong intellectual property protection, a conducive regulatory environment, etc. contribute to the effectiveness of R&D efforts in the ICT sector.

Discussion. The study is an attempt by the authors to systematically review and structure the existing research achievements on the factors influencing the formation of competitive advantages and supporting the international competitiveness of the ICT sector of the national economy. Thus, the study and review of scientific and industry literature helped us identify and summarise the impact of the main groups of factors on the competitiveness of the ICT sector, in particular the favourable political and regulatory environment in the country, political stability in the country, the involvement of the country's ICT sector in international trade and cooperation, the state of the country's ICT infrastructure (as the basis for the functioning of the ICT sector and the digital economy as a whole), the consumer base and the human resource pool of the ICT sector of the national economy (namely, in terms of their availability and digital skills), and R&D in the ICT sector.

From our perspective, in the future, it is advisable to continue research (both empirical and theoretical) on the degree and nature of the impact of internal and external factors on the functioning and competitiveness of the ICT sector of the national economy. In particular, we believe that further research will remain promising in terms of: (1) the human factor (in particular, in terms of digital literacy, ICT talent development, diversity and inclusion), which will allow for a better understanding of the relationship between digital literacy and the competitiveness of

Table 6

ICT Research and Development Centres Classification

Classification Criterion	Types of R&D Centres
by ownership and funding source	public/governmental, private, academic, non-profit
by research focus and specialisation	basic research centres, applied research centres, sector-specific centres, multidisciplinary centres
by geographic scope	local/national, international/global
by collaboration and partnership model	independent (without formal partnerships), collaborative/consortium (between multiple organisations, i.e., industry, academia, and government), joint ventures and strategic alliances
by size and scale	small/start-up centres, large/corporate centres
by technological domain	centres in software development & IT, telecommunications & networking, hardware & electronics, AI & ML
by innovation type	incremental innovation centres, disruptive innovation centres
by research output	theoretical research centres, experimental research centres, development and engineering centres
by organizational structure	centralised, decentralised, hybrid
by market orientation	consumer-focused, enterprise-focused
by lifecycle stage	early-stage (concept development & initial feasibility), growth-stage centres (scaling innovations, refining technologies, and bringing products to market), mature-stage centres (sustaining innovation and maintaining competitive advantages)
by application domain	healthcare, financial, education, environmental, etc.
by methodology	agile (employ agile methodologies for iterative and flexible R&D), traditional/waterfall (use structured, phase-based approaches)
by impact and reach	high-impact (for technological breakthroughs), low-impact (for incremental improvements)
by risk and innovation profile	high-risk (high-risk projects with the potential for high reward), low-risk (low-risk projects with more predictable outcomes)
by funding model	grant-funded, self-funded, crowdfunded
by intellectual property strategy	patent-driven (focus on generating patents), open-source (develop technologies with an open-source approach)
by human resource model	in-house (employ internal staff for R&D), outsourced (rely on external contractors or partners), hybrid
by technology adoption stage	emerging technology centres, mature technology centres

Source: authors' elaboration

the ICT sector, as well as the effectiveness of ICT talent development strategies (such as educational programmes and international cooperation, attracting and retaining qualified specialists in the global market); (2) the dynamics of global competition in ICT, using comparative analysis, assessing the impact of new technologies and determining the impact of globalisation and various forms of international cooperation in ICT; (3) the role, effectiveness and harmonisation of public ICT policies; (4) the relationship between investment in research and development and the international competitiveness of the ICT sector, focusing on how different sources and models of funding affect outcomes; (5) the impact of infrastructure investment, including cost-effectiveness, scalability and reliability, as well as the digital divide, resilience and security of ICT infrastructure; etc. Finally, we consider it advisable to accompany comprehensive studies of individual factors affecting the international competitiveness of the ICT sector with graphic materials (tables, graphs, flowcharts, diagrams, etc.) to visually simplify the relationship and impact of various factors on the ICT sector of the national economy.

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