Level and scope of involvement of Ukrainian higher education and research institutions in e-infrastructures: survey results

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Abstract

The article investigates the level and scope of engagement of Ukrainian higher education and research institutions in e-infrastructures. The article considers the impact of digital transformation on higher education and research, highlighting the role of e-infrastructures within these institutions. The article provides an overview of the main types of e-infrastructures in Ukraine. The key characteristics of these e-infrastructures are described. The organization and results of the All-Ukrainian survey conducted among higher education and research institutions regarding their levels of engagement with e-infrastructures are presented. This survey was initiated and organized by the authors of this publication with the support of the Ministry of Education and Science of Ukraine. Based on the survey results, the possibility of developing of various national and institutional policies, both general and personalized ones, considering the different levels of engagement with e-infrastructures for educational and research purposes in different institutions is highlighted.

Keywords

digital transformation education, e-infrastructure, higher education, support for scientific research, Ukraine

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1. Introduction

Digital transformation in education and science refers to the transition to using modern digital technologies and tools in research to enhance performance, efficiency, and competitiveness. Digital transformation in science and e-infrastructure are interconnected and mutually influential. It involves the implementation of advanced digital technologies and tools in scientific practices to improve performance, efficiency, and competitiveness.

E-infrastructure, in turn, provides the necessary information and technological foundation for implementing digital transformation. It encompasses various electronic resources, networks, services, and tools that enable researchers to easily exchange data, collaborate, and access scientific literature and other resources. E-infrastructure also facilitates the storage, processing, and analysis of large volumes of scientific data, allowing scientists to conduct more complex research and make new discoveries. Thus, digital transformation in science and e-infrastructure collectively contribute to the development of the scientific ecosystem, fostering collaboration, innovation, and advanced research.

The development of digital services and infrastructure is an important factor for Ukraine's integration into the European Research Area and the European Union's Single Digital Market. Global challenges, such as the pandemic and Russian aggression, have highlighted the necessity of active utilization of digital services and e-infrastructures in universities and research institutions to meet educational and scientific needs. Higher education and scientific activities are interdependent sectors in Ukraine aimed at societal development. The outcomes of research conducted at scientific institutes or universities can serve as vital sources for updating and supplementing knowledge for students and educators. It is well-known that the application of current scientific findings in the educational process enhances the quality of education. The digital transformation of society and rapid technological advancements demand a continuous update of educational programs to align with labour market requirements, ensuring university graduates remain competitive individuals.

Meanwhile, universities must serve as catalysts for the advancement of science and the conduction of research. They should establish incentives for research and innovative ideas. Additionally, interaction between researchers and students, the opportunity to engage in research projects, and participation in scientific conferences contribute to the cultivation of a scientific culture among students.

In Ukraine, since 2019, a program of digital reforms has been underway, supported by EU4Digital. The website https://eufordigital.eu/uk states that the EU4Digital program encompasses a range of measures aimed at developing key areas of the digital economy and society in accordance with EU norms and practices. As part of this initiative, the EU facilitates the reduction of roaming tariffs, the expansion of access to high-speed broadband connection to stimulate the economy and enhance e-services, ensuring cybersecurity and harmonizing digital structures across different knowledge sectors, improving qualifications, and creating job opportunities in the digital industry. The EU4Digital initiative promotes access to pan-European online services for citizens, governmental institutions, and enterprises, in order to support sustainable digital transformation.

Ukraine has diverse types of e-infrastructures that serve different functions and tasks tailored to the needs of society. Special attention should be given to digital services and e-infrastructures

that support the development of the scientific and educational space and ensure its effective operation. The main types of e-infrastructures in Ukraine include [1, 2]:

- E-infrastructures designed for distributed computing, including the National Digital Infrastructure for Distributed Computing, Ukrainian National Grid (UNG).
- E-infrastructures intended for the accumulation, storage, systematization, analysis, and provision of access to scientific data and publications, such as the National Repository of Academic Texts (NRAT).
- E-infrastructures designed to facilitate communication and network connectivity, including connections with European and global e-infrastructures through the GÉANT network, the Ukrainian Research and Academic Network (URAN).
- Ukrainian Academic and Research Network of the Institute of Condensed Matter Physics of the National Academy of Sciences of Ukraine (UarNET).

Currently, the level of involvement of higher education institutions (HEIs) and research institutions (RIs) in Ukraine's e-infrastructures is gradually improving but still remains insufficient compared to European and US countries.

We agree with the viewpoint expressed by scientists [3] that for the scientific community, as well as for the formulation of a national scientific policy, it is necessary to have an overview of the existing research infrastructures. Information is needed regarding the available infrastructures, their governance, and the services they provide.

Thus, several research problems arise, which our research aims to address:

- insufficient information about the level and extent of involvement of higher education institutions and research institutions in e-infrastructures;
- the absence of strategic plans within HEIs/RIs for creating e-infrastructure clusters (distinct units of e-infrastructure that can be connected to existing nationwide e-infrastructures) is a reason why staff and students do not actively utilize domestic and international e-infrastructures for conducting research;
- insufficient information regarding the utilization of GEANT digital services within HEIs/RIs; whether HEIs/RIs require connectivity to high-speed GEANT channels and global cloud computing services such as Microsoft Azure, Amazon AWS, and others;
- insufficient information about the needs of staff and students within HEIs/RIs for additional awareness about modern digital services specifically developed for science and education.

2. Literature analysis and problem statement

Various aspects of applying digital services and systems for scientific purposes are presented in the research studies [4, 5]. Scientific publications [6, 7] focus on the implementation of open science principles. The issues related to the development of research infrastructures are described in the studies [8, 9, 10, 11, 12, 13, 14, 15, 3, 16, 17, 18, 19, 20], let's analyze a few of them in more detail.

In the work [11], it is determined that research infrastructures and their data repositories store data and make them available to researchers, but they rarely provide a computational environment for data analysis. Existing approaches to improving access to the data about the surrounding environment have been examined to facilitate faster data analysis in computational environments and thus promote seamless data integration and analysis. A roadmap and key action points are proposed for harmonizing technologies that form the basis for effective data integration and analysis.

The results of the research on the application of digital infrastructures are described in [15]. However, the conclusions drawn suggest that the digital infrastructure will become increasingly distributed until it becomes possible to dynamically allocate resources according to time, space, and energy. Numerous solutions support this shift, but it is expected that digital infrastructures can only sustainably evolve through: a) gaining broader awareness of digital resilience; b) ensuring accountability of each party for their resilience throughout the value creation chain; c) establishing cross-domain interactions [15].

A brief analysis of thematic services in the EOSC is described in the publication [8]. Recommendations are outlined for the integration of thematic services into the EOSC ecosystem regarding authentication and authorization (unified regional or thematic solutions based on EduGAIN), FAIR-compliant data and metadata preservation (both during cataloging and data storage, e.g., B2SHARE EUDAT), resource management services independent of cloud platforms (e.g., Infrastructure Manager), and workload management solutions. The experience of utilizing research e-infrastructures in Slovakia is described in the article [3]. Additionally, the experience of implementing the Research Infrastructure Map and its integration into the SK CRIS information system is presented.

The publication [21] schematically presents the main e-infrastructures and services that are intended to be included in the EOSC, as well as their interactions within the EU and the existing elements for building a National Hub in Ukraine. We consider this diagram to be a successful example of visualizing the interrelationships between research e-infrastructures and the services they provide for scientists.

The study [12] analyzes the Ukrainian research information infrastructure and identified databases that can be reused and integrated with the national Ukrainian Current Research Information System (URIS). The analysis reveals functional databases and registries that collect data on research activities and can serve as data sources for URIS. Specifically, the Unified State Electronic Database on Education is a potential data source for higher education institutions, the National Repository of Academic Texts provides metadata on scientific output, the internal database of the National Research Fund of Ukraine and the database on research projects maintained by UkrISTEI are also identified. It has been also found that the Ukrainian research infrastructure lacks a comprehensive and up-to-date registry of researchers. The challenges and solutions for further steps in developing a national CRIS are described [12].

The experience of creating and developing the European Open Science Cloud is analyzed in the article [22]. Additionally, a brief description of the Strategy for building the National Open Science Cloud in Ukraine is provided.

Digital transformation significantly impacts the improvement of digital technologies, giving rise to new types of digital services and e-infrastructures. Therefore, it is advisable to investigate the role of e-infrastructures in supporting scientific activities and determine the level and extent

of involvement of Ukrainian higher education institutions and research organizations in e-infrastructures.

3. The Aim and Tasks of the Study

The aim of the article is to determine the level and extent of involvement of Ukrainian higher education institutions and research organizations in e-infrastructures.

The research tasks:

- to analyze whether HEIs/RIs have a need for the use of e-infrastructures;
- to identify the e-infrastructures with which higher education institutions and research organizations collaborate;
- to analyze the users of e-infrastructures in higher education institutions and research organizations;
- to determine whether e-infrastructures in higher education institutions and research organizations are used for scientific and educational projects;
- to analyze the usage of GEANT digital services in higher education institutions and research organizations;
- to identify the needs of higher education institutions and research organizations for connecting to high-speed GEANT channels for collaboration and access to international research infrastructures (e.g., LHCONE, EUMETCAST, Copernicus);
- to identify the needs of higher education institutions and research organizations regarding connectivity to global cloud computing services such as Microsoft Azure, Amazon AWS, etc;
- to determine whether there is a need for information about modern digital services specifically developed for science and education.

4. Research results

4.1. The main types of e-infrastructures in Ukraine for supporting scientific activity

For Ukraine, an important task is the development of a research e-infrastructure ecosystem, interconnected with the implementation of open science principles. In the publication [23], it is noted that e-infrastructures provide opportunities for researchers, educators, and students to engage in open scientific processes at any stage of their research work. Furthermore, this publication outlines the top-priority issues that require addressing during the implementation of open science principles in Ukraine, namely:

- definition and justification of indicators for assessing the state of research infrastructure in higher education institutions and research institutions;
- development and approval of national procedures and indicators for ensuring the quality of research activity based on the principles and approaches of Open Science.

- development of the National Scientometric Database UkrScience;
- development of the digital platform "Ukrainian Open Science" for the national quality assurance system of research activity based on the principles and approaches of Open Science;
- improvement of the system of state funding for higher education institutions in accordance with the quality of their research activity through the introduction of criteria and indicators for ensuring the quality of research activity based on the principles and approaches of Open Science;
- promotion of the development and support of national research infrastructures that facilitate open access and their integration into European and global research e-infrastructure ecosystems.

Let us consider the main e-infrastructures in Ukraine that are appropriate for use to support scientific activity.

1. **National grid infrastructure**. The Ukrainian National Grid is an important component in the development of scientific research and computational capabilities in Ukraine. It serves as the national digital infrastructure for distributed computing. Ukraine has joined the European Grid Infrastructure (EGI.eu). Affiliate participants have temporary membership status (from 12 to 24 months), equivalent to associated participants who do not yet have a national e-infrastructure development strategy and corresponding state financial support and want to assess the interest of scientific communities in such e-infrastructures. The EGI e-infrastructure is a global network of data processing centers and cloud providers funded by various countries. This e-infrastructure covers the entire Europe and other countries worldwide. EGI offers a wide range of services in the field of computing and data storage, as well as provides support to researchers, multinational projects, and research infrastructures. EGI services are provided through the unified EGI cloud and EGI data processing centers. These services are available to all participants in academic research and businesses through the EGI Marketplace. EGI closely collaborates with other e-infrastructures: EUDAT, GEANT, OpenAIRE, PRACE. Additionally, EGI acts as the coordinator of the European Open Science Cloud project (EOSC-hub) [24].
2. **The Ukrainian Academic and Research Network (URAN) is a national scientific and educational telecommunications network**. Its main purpose is to provide institutions, organizations, and individuals in the fields of education, science, and culture in Ukraine with information services based on internet technologies that meet their professional needs and contribute to their development. These services include fast access to information, exchange, dissemination, storage, and processing of information for scientific research, distance learning, the use of telecommunication methods, functioning of electronic libraries, virtual laboratories, conducting teleconferences, remote monitoring, and much more. The URAN network physically connects over 80 research and educational institutions, comprising 180 connection points. The URAN network also has its own fiberoptic networks covering 15 cities in Ukraine, with a total length of approximately 230 km (based on materials from the website http://uran.ua/~ukr/net-org.htm).

3. **The Pan-European Multi-Gigabit Research and Education Network GÉANT**. GÉANT is a network that connects over 8,000 scientific institutions and more than 40 million users. By utilizing GÉANT, collaborative scientific research can be conducted, cooperation for scientific activities can be facilitated, and educational programs can be implemented. According to the website http://uran.ua/projects/geant/first.htm, the URAN association provides the Ukrainian scientific and educational community with access to the GÉANT network and is the sole entity that has a contract with the network operator, GÉANT Ltd. (formerly known as DANTE Ltd.), following the principle of "one country, one scientific and educational network".
   At the same time, GÉANT acts as the coordinator of the EaPConnect project, actively contributing to the development and integration of six Eastern Partnership countries and their research and education communities into the European Research Area (ERA). GÉANT brings together specialized telecommunications operators created to meet the digital technology needs of the research and education communities in European countries into a single pan-European network for science and education [16].
   EaPConnect (2020-2025) is a part of the European initiative EU4Digital, which aims to expand network infrastructure and services for research and education to reduce the digital divide. The main objectives of this project include: 1) expanding network infrastructure and services for research and education; 2) fostering connections with other European infrastructures and initiatives; 3) enhancing the resilience of international connectivity and national research and education networks to sustain their national research and education ecosystems; 4) supporting the participation of researchers and educators from the Eastern Partnership in international collaborations, ensuring their presence in European initiatives and projects [25].
4. **The National Repository of Academic Texts (NRAT)** is a nationwide electronic database that collects, stores, and organizes academic texts [26]. The main purpose of NRAT is to support the development of educational, scientific, scientific-technical, and innovative activities by improving access to academic texts and promoting academic integrity. NRAT resources serve as auxiliary tools for examining academic texts for plagiarism. According to legislation, NRAT can integrate information with other databases, including open data resources from Ukraine and other countries, as well as databases of central executive authorities. The NRAT portal is updated daily with news, facilitating scientists' awareness of new trends in the scientific and educational fields and providing information about various scientific events such as conferences, seminars, round tables, online courses, etc.
5. **Ukrainian Research Information System (URIS)**. The URIS system has been designed as a central hub for aggregating data on the results of scientific and scientific-technical activities at Ukrainian research institutions and higher education institutions, as well as for the scientific personnel themselves. Currently, URIS performs the following functions: aggregation of data on the sphere of scientific and scientific-technical activities in Ukraine; automation of defined procedures and processes of entities in the field of science in Ukraine; information aggregation for scientists on a single platform; data integration, presentation, and provision of analytical tools for research; provision of data that is not available in accessible information sources; verification of data by verified system users.

The main planned outcome of URIS functioning is to ensure data openness regarding domestic science. Additionally, other anticipated results include the simplification of processes and procedures such as [27]: searching for information, data, equipment, services, and resources for conducting research; identifying performers for science-intensive projects; preparation of analytical information for managerial decision-making; filling out applications, forms, and reports for domestic scientists, research institutions, and higher education institutions; presenting the results of domestic research in the global scientific space.

In the publication [7], researchers emphasize that in the digital society, perceptions of work, education, culture, communication, and social life have significantly changed. The development of citizens' digital literacy is a key condition for the successful construction of a digital society. Therefore, it is important to conduct targeted training and professional development for experts in various fields of the economy, including scientists, to enhance their digital competence. After all, scientists and researchers are key participants in the process of digitizing science, ensuring its successful implementation.

Based on the analysis conducted and the scientific publications, several generalizations have been made. Therefore, e-infrastructures play an important role in supporting scientific research by providing various functions for the scientific community, including:

1. Data storage and archiving.
2. Support for open science.
3. Publication and access to scientific publications.
4. Access to specialized tools and software.
5. Collaboration and cooperation.
6. Access to international scientific networks.
7. Utilization of computational resources.
8. Ensuring cybersecurity.

Development prospects of e-infrastructures include:

- building national e-infrastructures requires joint efforts from the scientific community, government agencies, and other stakeholders to develop and support digital tools and resources that contribute to scientific progress and innovation;
- development of standards and protocols for e-infrastructures helps ensure compatibility, interaction, and information exchange among different scientific institutions, facilitating the creation of a unified scientific community;
- the development of e-infrastructures enhances opportunities for utilizing artificial intelligence, machine learning, and data analysis in scientific research, enabling more precise and high-productivity conclusions.
- the development of e-infrastructures demands attention to cybersecurity and the protection of scientific information, ensuring data confidentiality and integrity;
- research on the impact of e-infrastructures on the scientific community is necessary, including changes in the organization and communication of researchers through e-infrastructures and the dynamics of interaction among scientific disciplines and communities through e-infrastructures;

- the development of e-infrastructures requires the design and improvement of digital technologies and tools to support scientific activities;
- application of artificial intelligence, data analytics, and other modern methods in science;
- development and updating of recommendations regarding the peculiarities of using e-infrastructures in scientific research.

4.2. Results of the survey "Level and Scope of Involvement of Ukrainian Higher Education and Research Institutions in e-Infrastructures"

The survey "Level and Scope of Involvement of Ukrainian Higher Education and Research Institutions in e-Infrastructures". The survey was conducted with the support of the Directorate of Science and Innovation of the Ministry of Education and Science of Ukraine. The questionnaire was distributed through reaching out to heads of higher education institutions and research institutions, requesting their participation in the survey through an official letter from the Ministry of Education and Science of Ukraine. Additionally, the survey was promoted via social media platforms such as Facebook and Instagram, and it was posted on the website of the Scholar Support Office.

The author of this article, G. Mozolevych, initiated the survey and the preparation of this publication as part of his professional responsibilities at the Ministry of Education and Science of Ukraine. The development of the questionnaire, sending official letters to higher education institutions and national universities, as well as communication with them, were conducted by A. Iatsyshyn, A. Sukhikh, T. Yatsyshyn. The preparation and execution of this survey took nearly six months, and the authors of the article dedicated a significant amount of their personal time and effort to its completion. The compilation of analytical materials based on the survey results and the summarization of the findings were carried out by G. Mozolevych, A. Iatsyshyn, A. Sukhikh. All these processes were conducted with the support of the Ministry of Education and Science of Ukraine, specifically through the Scholar Support Office, where the authors of the article are coordinators. Additionally, a professional sociologist-expert was involved in the processing and summarization of the survey materials. The analytical materials based on the survey results have been prepared in Ukrainian and will be presented on the website of the Ministry of Education and Science of Ukraine.

The empirical material was collected from November 1, 2022, to February 1, 2023, for Research Institutions (RIs), and from March 7, 2022, to April 1, 2023, for Higher Education Institutions (HEI), using the method of individual questionnaire surveys. The survey involved 87 HEIs out of 281* HEIs, including universities, academies, and institutes (*according to the State Statistics Service of Ukraine https://www.ukrstat.gov.ua/operativ/operativ2005/osv_rik/osv_u/vuz_u.html), and 34 RIs out of 200 RIs in Ukraine (*according to the Register of Educational Institutions "Higher Education Institutions" of the Unified State Electronic Database on Education (EDBO) as of May 2023), representing 31% of the total number of HEIs and 17% of RIs. The participating institutions represented the city of Kyiv and various regions of Ukraine shown in table 1. Furthermore, several relocated higher education institutions also participated in the survey and provided responses to the questions.

The study is not representative as the sample was not calculated using a proportional or quota sampling method. Therefore, the empirical data was obtained from respondents who

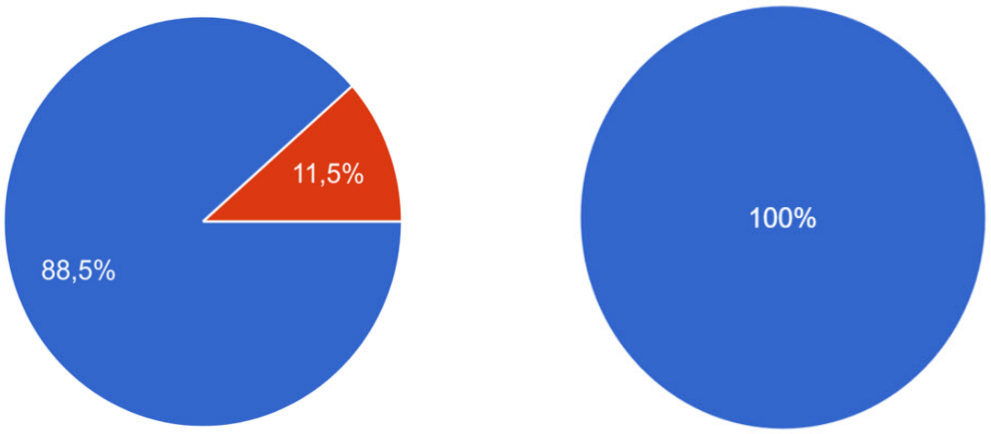
Table 1
Distribution of HEIs by regions of Ukraine.

№	Region	Number of universities from this region
1	Vinnytsia	2
2	Volyn	1
3	Dnipropetrovsk	6
4	Donetsk	2 (relocated)
5	Zhytomyr	1
6	Zakarpattia	1
7	Zaporizhzhia	4
8	Ivano-Frankivsk	1
9	Kyiv	1
10	City Kyiv	18
11	Kirovohrad	1
12	Luhansk	-
13	Lviv	8
14	Mykolayiv	1
15	Odesa	5
16	Poltava	4
17	Rivne	1
18	Sumy	2
19	Ternopil	2
20	Kharkiv	15
21	Kherson	2
22	Khmelnytsk	3
23	Cherkassy	2
24	Chernivtsi	3
25	Chernihiv	1

voluntarily consented to participate in the survey. Consequently, the results of this study cannot be extrapolated to the entire research population, but they provide a certain understanding of the needs for utilizing e-infrastructures in HEIs/ RIs for conducting scientific and educational projects, as well as the needs of HEIs/ RIs regarding connection to global cloud computing services such as Microsoft Azure, Amazon AWS, and others. According to the survey results, 88.5% of HEIs and 100% of RIs that participated in the study expressed a current need for utilizing e-infrastructures (figure 1).

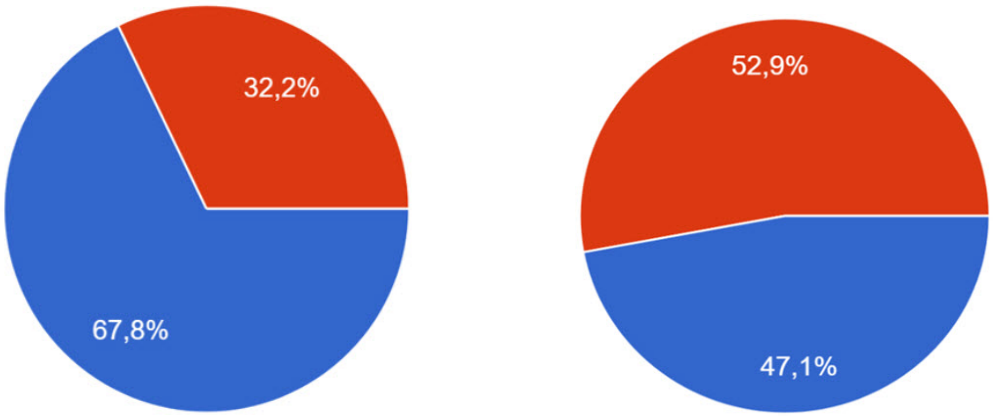
Currently, e-infrastructures are utilized by 67.8% of the surveyed HEIs and 47.1% of the RIs, respectively (figure 2).

The main users of e-infrastructures in HEIs are research staff (70.1%), academic staff (97.7%), graduate students (82.8%), and students (70%). In RIs, the main users of e-infrastructures are research staff (79.4%), academic staff (26.5%), graduate students, and students (52.9%). Regarding the pan-European multi-gigabit research and education network GÉANT, which connects over 8000 research institutions and serves more than 40 million users, it is known by 80.5% of HEIs and 44.1% of RIs among the surveyed participants (figure 3).



(a) (b)

Figure 1: Distribution of responses from representatives of HEIs (a) and RIs (b) to the question "Is there a need for utilizing e-infrastructures in your organization?".



(a) (b)

Figure 2: Distribution of responses from representatives of HEIs (a) and RIs (b) to the question "Do the facilities of your institution belong to the capacities of e-infrastructures?".

Regarding the EaPConnect project, which aims to connect research and education communities from the EU and Eastern partner countries, 55.2% of HEIs and 20.6% of RIs are aware of it, while 44.8% of HEIs and 79.4% of RIs are not familiar with the existence of this project (figure 4).

In response to the question "Are you aware of the membership in the European Grid Infrastructure (EGI) Council?", 62.1% of HEI representatives answered "yes," while 44.1% of REU representatives answered "yes." The diagrams are presented in figure 5.

Responses from HEI representatives to the question "Do you use the following digital services

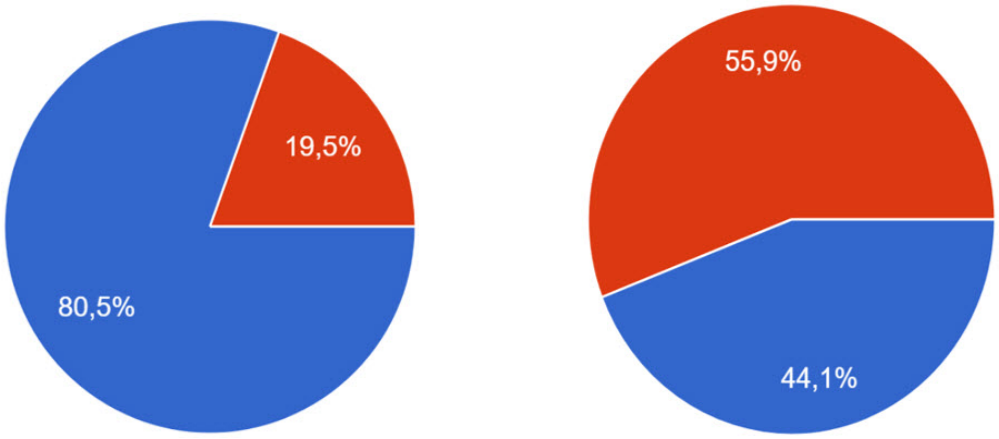


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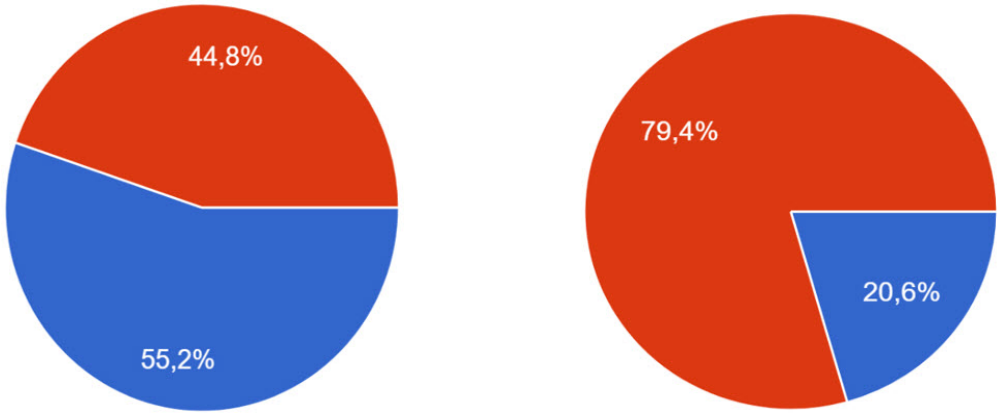
Figure 3: Distribution of responses from representatives of HEIs (a) and RIs (b) to the question "Are you familiar with the pan-European research and education network GÉANT?".

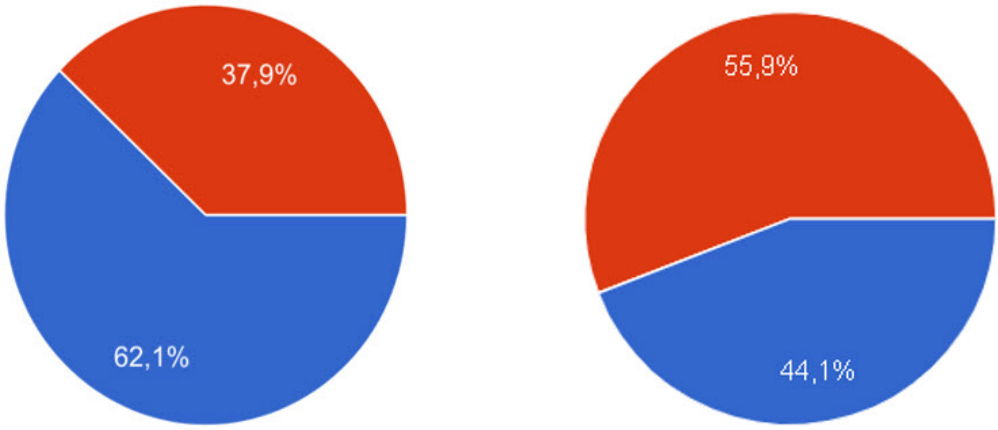


(a) (b)

Figure 4: Distribution of responses from representatives of HEIs (a) and RIs (b) to the question "Are you familiar with the EaPConnect project?".

from GEANT?" have yielded the following usage distribution: eduroam: 20.7%; eduMEET: 13.8%; eduGAIN: 10.3%; eduVPN: 5.7%; WebClass: 9.2%; Cloud Services: 13.8%; Additionally, 65.5% of respondents stated that they do not use any GEANT digital services.

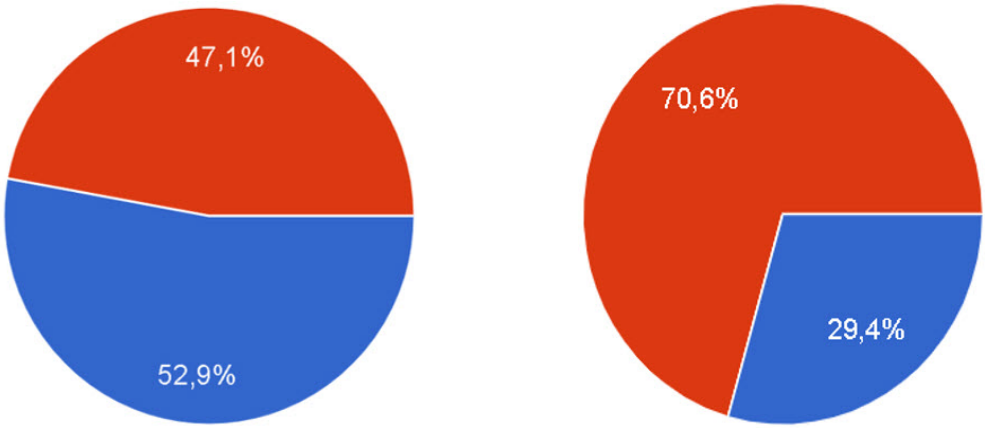
Responses from REU representatives to the same question have yielded the following usage distribution: eduroam: 0%; eduMEET: 2.9%; eduGAIN: 0%; eduVPN: 0%; WebClass: 8.8%; Cloud Services: 20.6%. Additionally, 76.5% of respondents stated that they do not use any GEANT digital services.



(a) (b)

Figure 5: Distribution of responses from HEIs (a) and RIs (b) representatives to the question "Are you aware of the membership in the European Grid Infrastructure (EGI) Council?".

In response to the question "Does your institution require connection to global cloud computing services such as Microsoft Azure, Amazon AWS, etc.?" the distribution of responses from HEI representatives is as follows: 52.9% answered "yes" and 47.1% answered "no". From RIs representatives, 29.4% answered "yes" and 70.6% answered "no". The distribution of responses is presented in figure 6.

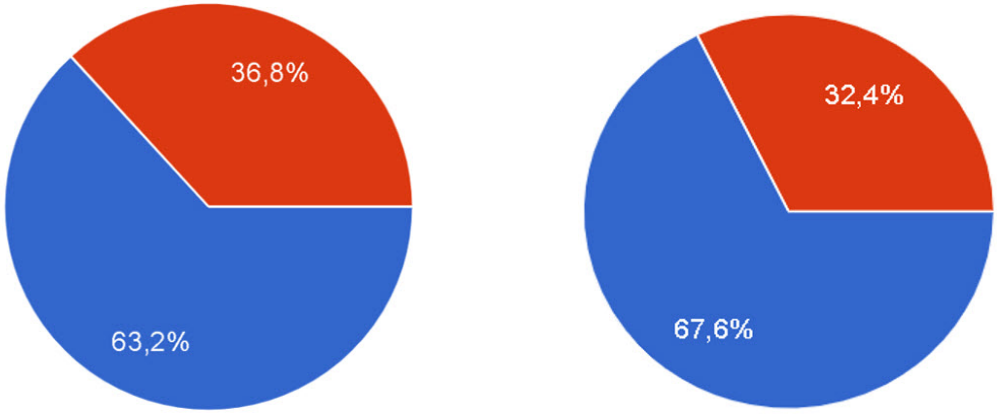


(a) (b)

Figure 6: Distribution of responses from representatives of HEIs (a) and RIs (b) to the question "Does your institution need to connect to global cloud computing services such as Microsoft Azure, Amazon AWS, etc.?".

Figure 7 shows the distribution of responses regarding the question "Do you require connec-

tion to high-speed GEANT channels for collaboration with higher education institutions and research universities in Europe/world and access to international research infrastructures (e.g., LHCONE, EUMETCAST, Copernicus)?" Representatives of surveyed HEIs indicated "yes" at 63.2% and "no" at 36.8%. Representatives of RIs indicated "yes" at 67.6% and "no" at 32.4%.



(a) (b)

Figure 7: Distribution of responses from representatives of HEIs (a) and RIs (b) to the question "Do you require connection to high-speed GEANT channels for collaboration with higher education institutions and research universities in Europe/world and access to international research infrastructures?".

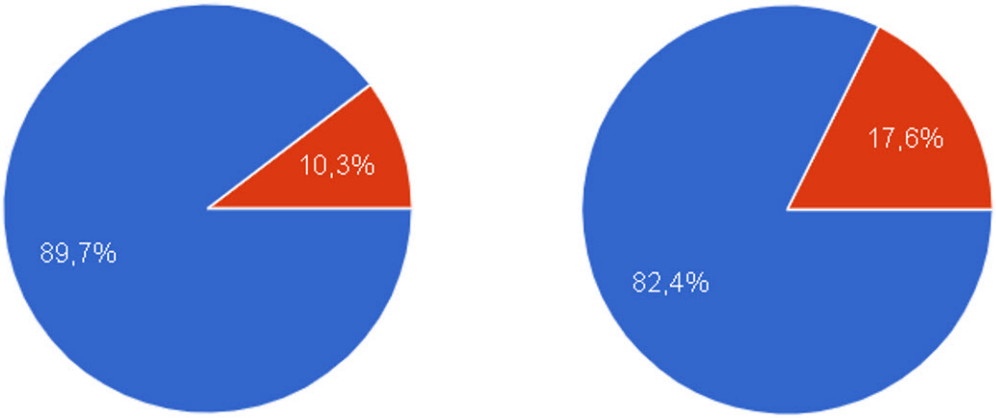
Regarding the question "Is there a need for providing additional information about modern digital services developed specifically for science and education?" 89.7% of representatives from HEIs responded "yes", while 10.3% responded "no". Among representatives from RIs, 82.4% responded "yes", and 17.6% responded "no". The diagrams illustrating the distribution of responses are presented in figure 8.

Analysis of the survey results contributed to the development of *general recommendations*. The general recommendations include:

1. To initiate the establishment of a working group to address the issues of involving Ukrainian HEIs/RIs in e-infrastructures, which will collaborate with the Ministry of Education and other relevant structures.
2. To conduct annual surveys to assess the level and scope of involvement of Ukrainian HEIs/RIs in e-infrastructures.
3. To organize and conduct scientific events (seminars, round table discussions) annually for educational and research institution administrators, researchers, academic staff, and doctoral students, focusing on various aspects of utilizing digital services and e-infrastructures for research activities.

Recommendations for HEIs and RIs:

- Foster the development of international cooperation and access to international research



(a) (b)

Figure 8: Distribution of responses from representatives of HEIs (a) and RIs (b) to the question "Is there a need for providing additional information about modern digital services developed specifically for science and education?".

infrastructures: Actively collaborate with international partners and establish access to international research infrastructures through high-speed GEANT channels.

- Promote the development of their own e-infrastructures: Invest in the development of in-house e-infrastructures to ensure the quality of education and research while reducing costs associated with external e-infrastructures.
- Enhance the qualification of teachers and researchers: Provide training and workshops on utilizing e-infrastructures for teachers and researchers, enabling them to effectively leverage e-infrastructures in the educational process and research activities.
- Raise awareness among students and graduate students regarding the application of e-infrastructures: Conduct informative campaigns to educate students and graduate students about the opportunities available for using e-infrastructures in learning and conducting research, as well as ensuring cybersecurity measures.

The above-prepared recommendations for higher education institutions are general in nature. However, each individual institution can develop its own action plan, roadmap, or recommendations for utilizing e-infrastructures to support the educational process and conduct research. It is important to emphasize that each institution has its own specific characteristics, and as the results of the conducted research confirm, certain institutions use e-infrastructures more actively and develop their own e-infrastructures. Simultaneously, there are institutions where e-infrastructures are used in a fragmented and incomplete manner. Therefore, for these institutions, it is a priority to develop and conduct a series of training seminars and workshops on various aspects of applying e-infrastructures for educational and research purposes. In other words, it is advisable for each institution to develop personalized recommendations for the application of e-infrastructures to support the educational process and research activities.

The authors are convinced that conducting surveys on the "Level and Scale of Engagement

of Ukrainian Higher Education Institutions and Research Establishments in e-Infrastructures" should be done annually. This practice stimulates and encourages the leadership of these institutions to analyze and compare the obtained results specific to their own institution. In turn, this contributes to the active development of various policies and educational initiatives for their own staff and students, addressing various aspects of utilizing e-infrastructures for educational purposes and conducting research.

5. Conclusions

In Ukraine, the development and support of national e-infrastructures for research and alignment with European and global scientific initiatives on Open Science and Open Innovation have actively commenced. The development of national e-infrastructures and the utilization of international e-infrastructures expand the possibilities to significantly enhance the level of scientific research and improve the quality of educational services. Additionally, e-infrastructures contribute to the development of the national scientific community through the exchange of experience and collaboration between HEIs and RIs. The main types of e-infrastructures in Ukraine are briefly described: the Ukrainian National Grid (UNG), the Ukrainian Research and Academic Network (URAN), GÉANT, and the National Repository of Academic Texts. Their key characteristics are outlined. Among the main advantages of utilizing e-infrastructures to support and conduct scientific research are: access to infrastructure and resources, support for various scientific disciplines, collaboration and cooperation, high productivity and efficiency, integration with international initiatives, ensuring security and confidentiality, and fostering the development of the national scientific and technological community.

The publication presents the results of a nationwide survey titled "Level and Scope of Involvement of Ukrainian Higher Education and Research Institutions in e-Infrastructures". This survey was initiated, organized, and conducted by the authors of this publication with the support of the Ministry of Education and Science of Ukraine. A total of 87 higher education institutions and 34 research institutions in Ukraine participated in the survey.

Based on the conducted research, several generalizations have been made:

- the uneven development of e-infrastructure in HEIs/RIs in Ukraine may impact the quality of education and scientific research (some institutions have more advanced e-infrastructure and better access to digital resources). This disparity can lead to inequalities in the quality of education and scientific research, which affects the competitiveness of graduates;
- improving access to e-infrastructure requires investments (the government, businesses, and HEIs/RIs need to collaborate to ensure the necessary infrastructure and technical resources that enable HEIs/RIs to maintain a high level of education and scientific research);
- formulating a state policy regarding digital transformation and digital development in education and science in Ukraine is not a one-time effort and requires continuous updating and improvement. It is important to consider the dynamic development of digital technologies, the needs of HEIs/RIs, and the experience of the best global practices;
- there is a need to increase the level of digital competence and competence in open science among researchers, academic staff and students.

As a result of the conducted research, the following findings have been identified:

1. 88.5% of the participating HEIs and 100% of the RIs have a current need for using e-infrastructures.
2. Among the surveyed HEIs, 67.8% have access to e-infrastructures, while 47.1% of the surveyed RIs have such access. Collaboration is established with the Ukrainian Research and Academic Network (URAN) in 50.6% of HEIs and 23.5% of RIs, with the National Repository of Academic Texts (NRAT) in 36.8% of HEIs and 41.2% of RIs, with the Ukrainian Academic and Research Network (UarNET) in 10.3% of HEIs and 11.8% of RIs, and with the Ukrainian National GRID in 3.4% of HEIs and 2.9% of RIs. Other responses were related to isolated cases or the absence of collaboration.
3. The main users of e-infrastructures in HEIs are research staff (70.1%), academic personnel (97.7%), PhD candidates (82.8%), and students (70%). In RIs, the primary users are research staff (79.4%), academic personnel (26.5%), PhD candidates, and students (52.9%).
4. It has been confirmed that HEIs/ RIs do not fully utilize the capabilities of e-infrastructures for conducting research and educational projects. The total number of ongoing and completed research and educational projects involving e-infrastructures in HEIs and RIs has been identified. The majority of respondents do not involve e-infrastructures in their project tasks (49.8% – HEIs, 45.1% – RIs), followed by 1 to 10 projects (53.8% – HEIs, 32.4% – RIs), and more than 10 projects (3.8% – HEIs, 13.8% – RIs).
5. It has been established that 80.5% of HEIs and 44.1% of RIs respondents are familiar with the GÉANT network. Among HEI representatives, the usage of GÉANT services is distributed as follows: eduroam 20.7%, eduMEET 13.8%, eduGAIN 10.3%, eduVPN 5.7%, WebClass 9.2%, Cloud Services 13.8%. Additionally, 65.5% responded that they do not use GÉANT digital services. Among RU representatives, the usage of GÉANT services is distributed as follows: eduroam 0%, eduMEET 2.9%, eduGAIN 0%, eduVPN 0%, WebClass 8.8%, Cloud Services 20.6%. Additionally, 76.5% responded that they do not use GÉANT digital services.
6. It has been established that there is a need for connection to high-speed GÉANT channels for collaboration with HEIs and RIs in Europe/world and access to international research infrastructures (e.g., LHCONE, EUMETCAST, Copernicus). Among HEI representatives, 63.2% responded “yes” and 36.8% responded “no”, while among RU representatives, 67.6% responded “yes” and 32.4% responded “no”.
7. It has been determined that there is a need for connection to global cloud computing services such as Microsoft Azure, Amazon AWS, etc. Among HEI representatives, 52.9% responded “yes” and 47.1% responded “no”, while among RIs representatives, 29.4% responded “yes” and 70.6% responded “no”.
8. It has been determined that the need for information about modern digital services specifically developed for science and education is identified among 89.7% of HEIs and 82.4% of RIs. Additionally, the need for various digital services and solutions is present in HEIs/RUs, including digital document management (6 HEIs/RIs), cloud data storage, cloud servers, joining the eduroam network (2 HEIs/RIs), GEANT services: eduGAIN, eduVPN, Cloud Services; WMWARE, Wcloud; Amazon AWS, and others.

The goal of the publication, as a result of the conducted research, has been achieved – the level and extent of involvement of Ukrainian HEIs and RIs in e-infrastructures have been determined and described. Based on the obtained survey results, it becomes possible to develop various state and institutional policies, both general and personalized ones, for different HEIs/RIs, taking into account their level of engagement in utilizing e-infrastructures for educational and research purposes. In future research endeavors, the plan is to depict and showcase the best practices of HEIs/RUs, highlighting their experiences that could be extended to other institutions. This aspect is vital in terms of promoting the domestic expertise in developing their own e-infrastructures and implementing open science policies.

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