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Model of research infrastucture development in framework of European integration

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Abstract: Based on the analysis of strategic and operational approaches to the development of European research infrastructures, organizational approaches to the sharing of scientific equipment, ecosystem approach and ecosystems of research infrastructures, a multi-level model of research infrastructure development was proposed. Structurally, the model applies the Quadruple Helix approach and defines three structural levels. The structural level of research and innovation ensures the implementation of research and innovation projects. The structural operational level ensures the implementation of the roadmap and projects for the development of research infrastructure using operational operation support. The structural strategic level defines: mission, goal, strategic orientation of smart specialization of research infrastructure, sustainable development strategies, strategic and financial approaches to support the formation and development of research infrastructure from national and European institutions. According to the proposed model, the development of research infrastructure is envisaged in five stages. The first stage involves the application of an organizational approach to the shared use of scientific equipment of a collective use center as a local research infrastructure owned and operated within a single scientific institution/university. The second stage involves the application of an organizational approach to the shared use of scientific equipment of a collective use center as a local research infrastructure within one scientific institution/university with the use of scientific equipment of European research groups. The third stage envisages the use of the organizational approach of joint use of scientific equipment within the framework of research infrastructure, which is owned and operated by the scientific alliance of national and European scientific organizations/ universities. The fourth stage involves the organization of research using the research infrastructure of a network of scientific and technological equipment and resources of national and European scientific organizations/universities. The fifth stage envisages the organization of research using research infrastructure within the framework of a European consortium, which has a reasonable specialization in accordance with pan-European interests and is open to the research community in accordance with the charter of the consortium, taking into account the national and European legal format. The model defines the phased development of research infrastructure in the context of the transition from the approach organizing research with using a collective use center to the application of the approach organizing research with using research infrastructure in the framework of the integration of research infrastructure into the European landscape of research infrastructures.

Keywords: organizational approach, sharing of scientific equipment, research infrastructure, ecosystem approach, ecosystem of research infrastructures, model.

1. Introduction

The European Union (EU) has gradually formed the European Research Area (ERA), in which EU countries pool the potential of their national research and innovation systems to support the development of the EU innovation ecosystem [1]. Research infrastructures are of strategic importance in the context of the development of the European Data Network, which requires high-quality infrastructure for the collection, management, processing, analysis and archiving of scientific data[2].

Research infrastructures provide resources and services to research communities to conduct research and foster innovation. They include scientific equipment, toolkits, scientific data collections and archives, computing systems, and communication networks [3]. Research infrastructures have received support from the European Commission for many years to shape and develop the European ecosystem of research infrastructures [4].

The key objectives of European Research Infrastructures [2] are: to reduce the fragmentation of the research and innovation ecosystem; to avoid duplication of research; to improve coordination of the development and use of research infrastructures; to develop and implement strategies for pan-European, national research infrastructures; to join forces at the international level to respond to infrastructures' global challenges; to promote the development of the innovation potential of research infrastructures; to use research infrastructures for scientific cooperation and partnership building at the international level.

The formation and development of European research infrastructures involves the application of strategic and operational approaches.

The European Commission defines and implements strategic approaches to support the formation and development of European research infrastructures: European Strategy Forum on Research Infrastructures (ESFRI) [5]; European Research Infrastructure Consortium (ERIC) [6]; Global Research Infrastructures Group (GSO) [7]; European Open Science Cloud (EOSC) [8]; European Forum (EIRO forum) [9]; Association of European-level Research Infrastructures (ERF-AISBL)[10]; Global Science Forum (GSF) [11].

To implement strategic approaches to support the formation and development of European research infrastructures, covering all scientific fields and providing researchers with access to the most modern research facilities at the regional, national and European levels to strengthen Europe's global leadership [12], the following are applied at the operational level: the life cycle approach to the formation and development of research infrastructures [13]; approaches to organizational change in academia [14]; the dedicated Horizon Europe partnership supporting the involvement of civil society and users of research and innovation [15]; the ESFRI roadmaps giving research infrastructures increased visibility [16]; the ESFRI projects and benchmarks [17]; transnational access to research infrastructures [18]; the FAIR Data principles, which focus on improving the ability to find and use scientific data, and support their reuse [19].

Research infrastructures are implemented using different organizational approaches. The type of research infrastructure determines the organizational approach for the formation and development of the research infrastructure.

According to the concept of European Research Infrastructure, the following are defined: distributed research infrastructure, which allows the research community to use certain geographically dispersed facilities, resources and services; single-center (with one location) research infrastructure, which allows the research community to use certain facilities, services and resources geographically localized in one place; virtual infrastructure, which operates as an electronic infrastructure, providing electronic services, networks, archives, databases and data banks [20].

The Australian Strategic Framework identifies three types of research infrastructures: local research infrastructure, which owned and operated within a single institution; national research infrastructure, which supports collaborative research and is part of the national research capacity; and large-scale facilities (separately located or distributed) that serve large and diverse user communities and are part of the global research capacity [21].

There are a variety of options for the legal form of a research infrastructure: a single institution, for example, a university or a public research center; a consortium between two or more legal entities; an independent legal entity representing existing legal entities and managing in the interests of all partners; a merger of previously independent research centers; a merger of two or more existing legal entities; a European Research Infrastructure Consortium (ERIC); research infrastructure integrated into the structure of clusters or valleys [22].

The ESFRI life cycle methodology defines six main stages of research infrastructure development: concept development; concept design; preparation of design and technical documentation; implementation and establishment; operational research and service delivery; closure. Existing research infrastructure for renewal and development can submit a proposal to become, as ESFRI project and can be included in the ESFRI roadmap [13].

The management of research infrastructure has been influenced by a public funding system that combines funding from ministries, competitive programs, foundations, the private sector, and infrastructure building/modernization and development programs. The main programs focused on financial support for the development of research infrastructure complemented by sub-programs that support operating costs and human resource development. A "full package" approach can also be used, whereby the costs of: development, research infrastructure construction, building maintenance and modification, research and personnel are financed. The key principle of most publicly funded research infrastructures is the principle of open access in accordance with the regulations for the management of open access on a contractual basis for the implementation of joint projects [22].

Research infrastructures have a dominant development in the direction of digital research infrastructures, which have: digital networks for research that allow researchers to share data and collaborate; data management that allows researchers to find and access scientific data; research software that allows researchers to access scientific data; advanced research computing [23, 24]. Digital research infrastructures are leading the global movement towards open, interconnected, data-driven, computational research that incorporates elements of digital services, making research infrastructures more accessible for collaboration between scientists across disciplines and geographical boundaries, as physical location of research infrastructure becomes less relevant [25].

A key element of the potential of research infrastructure (RI) is the policy of physical, remote and virtual access [26]. Research infrastructures integrate into the network and form an ecosystem of research infrastructures to solve large-scale scientific goals and socio-economic problems [27].

The ecosystem approach is gaining particular importance for the development of research infrastructures, as it stimulates the development of communities and networks of stakeholders who interact and seek balance in open public-private and socio-economic ecosystems for the joint development of new systemic solutions to achieve sustainable development goals. Particular importance in the development of the ecosystem approach is the Quadruple Helix approach, which emphasizes cooperation between four key sectors: government, academia, industry, and society. That cooperation is associated with the expansion of the role of science in economic development and the growing role of civil society in the development of science, technology and public policy to address new socio-economic challenges [28].

2. Research of existing solutions of the problem

Modern advanced scientific research requires technically complex, expensive scientific equipment. Scientific organizations and universities faced with the need to choose and apply an effective organizational approach to the use of complex, expensive scientific equipment for conducting scientific research. Among the organizational approaches to the shared use of scientific equipment, the following have become widely used:

- Collective use center (Core Facilities and derivatives core research facilities or core shared resources), which are a division of an academic or educational organization that provides physical access to scientific equipment and provides educational, consulting and expert services to users [29];
- Facility sharing fund that allows researchers to access scientific equipment from, for example, eight universities [30,31];
- Portal of scientific equipment of universities and research organizations, which provides the ability to search for external scientific equipment and provides access, for example, to the scientific equipment of 40 research centers and institutions [32];

- Research operations office that provides access to shared scientific equipment using a database, for example, 3000 individual units of scientific equipment in Cambridge, Oxford, UCL, Imperial College, Southampton and King's College London [33];
- Scientific equipment sharing platform that promotes the efficient use of large-scale scientific equipment [34,35];
- Scientific equipment sharing program that supports cutting-edge research and the career development of researchers [36];
- Network of collaborative research resources representing a wide range of individuals, departments, and functional offices, with a multitude of stakeholders, each with different expectations and methods of defining successful engagement and outcomes [37];
- Research infrastructure that distributed by type, location and field [38];
- Research infrastructure consortium ERIC [39].
- Ecosystem of research infrastructure aimed at solving large-scale problems that cannot solved by a separate research infrastructure [27].

The diversity of organizational approaches to sharing scientific equipment is a key characteristic of the European research system. However, the small size of the organizational structure sharing of scientific equipment has significant disadvantages: less visibility with accompanying difficulties in attracting funds, especially from governments and ministries; the need to charge for the use of scientific equipment; using only physical access to scientific equipment. In many cases, equipment purchase, operating costs, maintenance, modernization, and personnel servicing scientific equipment are the main limiting factors for the use of Core Facilities as organizational structures of small size. International cooperation and networking of scientific institutions/universities had considered an important condition for achieving and maintaining a high-quality level of scientific research within the framework of research infrastructure. Important criteria for the readiness of Core Facilities of scientific institution/university for development into research infrastructure are the ability: open access, joint research, use of digital tools that provide storage, archiving and analysis of data [40].

Core Facilities and Research Infrastructures provide an understanding of different organizational approaches to the use and access to scientific facilities. The Core Facilities approach involves providing physical access to scientific equipment and services to internal and external organizations with centralized management of a single research institution/university where the Core Facilities is located. The Research Infrastructure approach is a paradigm of collaborative academic governance with coordination of the effective use of scientific equipment and resources of the academic research environment. This paradigm recognizes the importance of collaboration, exchange and coordination within and between scientific institutions/universities, researchers; industry collaborates and ensures interaction with government, financial institutions and individuals, which shape the policy of developing research infrastructure ecosystems [41].

Given the growing need for effective formation and development of research infrastructures, the number of EU institutions, networks and projects supporting research infrastructures is increasing. However, there are few scientific publications on the operational management and development of research infrastructures. In this context, research on the change of organizational approach from the organization of research using the center of collective use (core facilities) to the application of the approach of organizing research using research infrastructure is important and relevant.

3. Research results

Based on the analysis of strategic and operational approaches to support the development of European research infrastructures, organizational approaches to the sharing of scientific equipment, ecosystem approach, ecosystems of research infrastructures, a multi-level model of research infrastructure development within the framework of integration into the European landscape of research infrastructures was proposed, Fig. 1.

Structurally, the model applies the Quadruple Helix approach and defines three structural levels that ensure the phased development of research infrastructure: the research and innovation level; the operational level; and the strategic level.

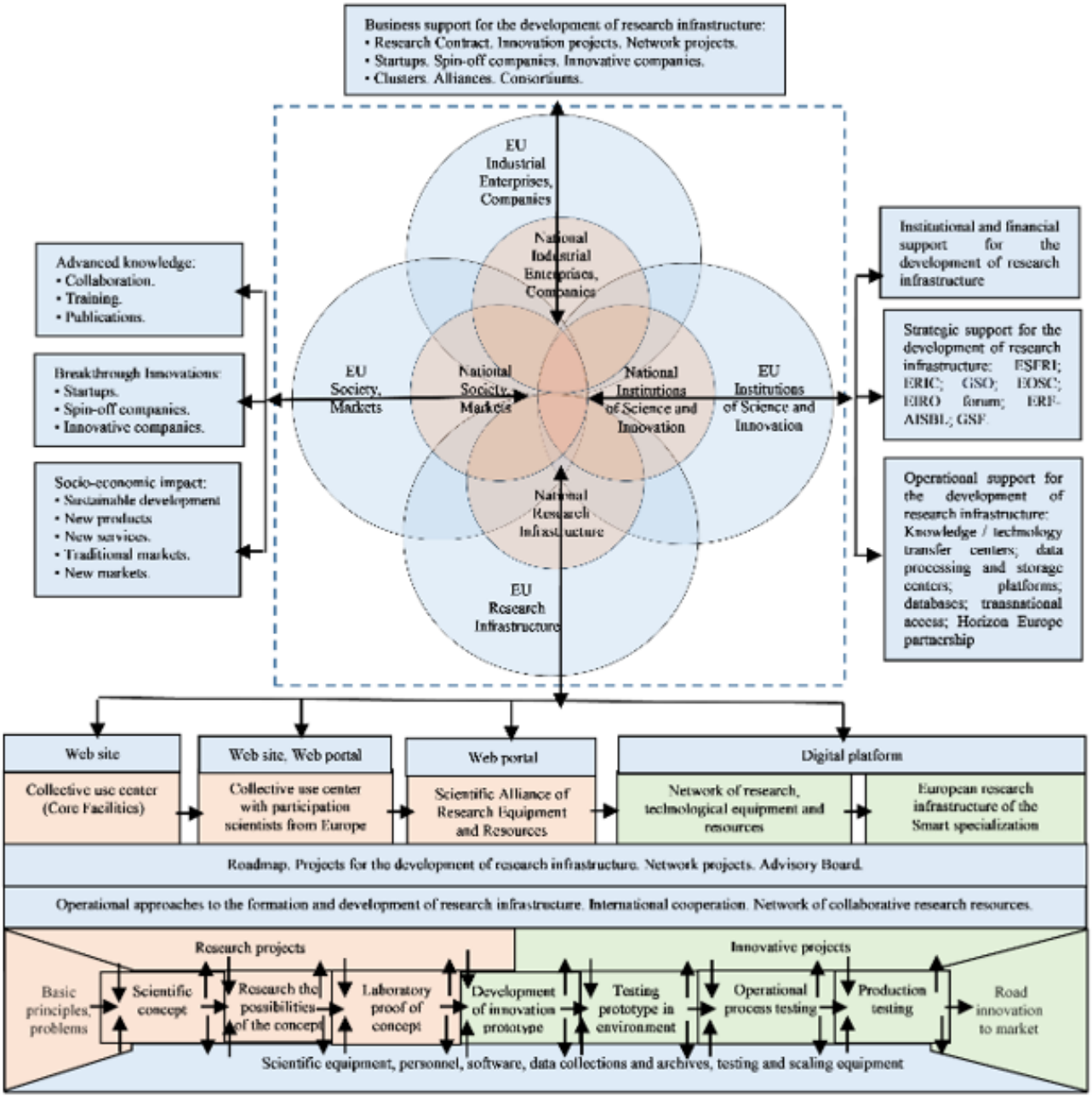

Fig. 1. Model of research infrastructure development in the framework of European integration.

The structural level of research and innovation ensures the implementation of research and innovation projects, including in the mode of network projects and include scientific equipment, equipment for testing, trials, scaling, scientific data, repositories and archives of scientific data, electronic infrastructure and software for the interconnection of research infrastructure components with computing systems and communication networks. At this level, the implementation of the research and innovation process had ensured in accordance with the consistent achievement of technological readiness levels (TRL1- TRL9) of innovations. Basic scientific principles for solving a scientific and socio-economic problem (TRL1). Formation of a scientific concept (TRL2). Research into the possibilities of a scientific concept (TRL3). Laboratory verification of the concept (TRL4). Development of prototype (TRL5). Testing of prototypes in an appropriate environment (TRL6).

Testing of prototypes in the working operational process (TRL7). Testing of the production of innovative products (TRL8). Production and introduction of innovative products to the market (TRL9).The key direction of the functioning of this structural level is the promotion of interdisciplinary research, cooperation with domestic and European research groups, including industry.

The structural operational level ensures the implementation of the roadmap and projects for the development of research infrastructure using operational approaches to the development of research infrastructure and operational support: knowledge and technology transfer centers; data processing and storage centers; platforms; databases; transnational access; Horizon Europe partnerships, etc. At this level, the acquisition of new scientific equipment and the constant updating of the scientific equipment portfolio will be ensured through the development of a network of shared research resources and the establishment of international cooperation between national and European scientific institutions/universities. Also, at this level, the acquisition of computing equipment, digital systems and scientific data management tools is ensured. Management activities at this structural level ensure a balanced application of organizational approaches to the development of research infrastructure and information and communication technologies, which ensure the functioning and development of the structural level of research and innovation.

The structural strategic level defines: mission, goal, strategic orientation of smart specialization of research infrastructure, sustainable development strategies, strategic and financial approaches to support the formation and development of research infrastructure from national and European institutions. This structural level ensures the involvement of stakeholders (scientists, industry, the public, government and financial institutions) for collaboration, joint management, decision-making and includes: a digital platform, a collaboration web portal, and network communication software. This structural level, it is intended to ensure the functioning of components of all structural levels to work together to create advanced knowledge and breakthrough innovations that solve socio-economic problems of sustainable development of society. Activities are coordinated by an advisory board of international experts, which provides recommendations on the mission, positioning strategies, roadmap, and research infrastructure development projects.

According to the proposed model, the development of research infrastructure is envisaged in five stages.

The first stage involves the application of an organizational approach to the shared use of scientific equipment of a collective use center as a local research infrastructure owned and operated within a single scientific institution/university. At this stage, it is planned to purchase new scientific equipment and configure it with the implementation of technical expertise, negotiation procedures with suppliers in accordance with procurement requirements, training of researchers and technical personnel. Provision of system access to scientific equipment for users is being established, automation of registration of applications, accounting, booking and reporting on the use of scientific equipment is being established. Subscriber service for regular users is being improved. At this stage, the strategic orientation of smart specialization, priorities, partners, roadmap and research infrastructure development plan are determined, which includes an analysis of potential users, costs, political and financial support, etc. Links with national scientific institutions, universities with which there has already been cooperation are strengthened. Cooperation with national industrial enterprises and SMEs is expanded. A website is used to inform and plan the provision of physical access to scientific equipment, services for employees of one's scientific organization/university and external national research groups and users

The second stage involves the application of an organizational approach to the shared use of scientific equipment of a collective use center as a local research infrastructure within one scientific institution/university with the use of scientific equipment of European research groups. This stage involves the acquisition of computing equipment, digital systems and scientific data management tools, training and improving the competencies and skills of staff/researchers in the application of open science practices, data sharing, use of databases and data management plans. At this stage, it is

planned to use of scientific equipments of the European research groups with testing of a remote access web portal according to uniform rules for the use of electronic and computing equipment, digital systems and tools for implementing joint research and innovation projects, ensuring the reproducibility of research results.

The third stage envisages the use of the organizational approach of joint use of scientific equipment within the framework of research infrastructure, which is owned and operated by the scientific alliance of national and European scientific organizations/ universities. At this stage, conditions are created for the joint use of scientific equipment and research resources of the scientific alliance with the creation of a coordination group/center. It is envisaged to expand the use of computing equipment, digital systems and scientific data management tools using open science practices (open access to knowledge, scientific articles, open exchange of scientific data). Electronic and computing equipment, digital systems and tools of the scientific alliance are synchronized using a web portal as an access point under uniform rules for cooperation between national and European research groups using physical and remote access. A policy of access to geographically located scientific equipment is determined, cooperation with European initiatives is established, including participation in ERIC competitions, regarding access to modern equipment for joint research. Strategic research and business planning are being conducted, and ways to attract funding from interested government agencies and commercial enterprises are being determined for the implementation of joint research and innovation projects.

The fourth stage involves the organization of research using the research infrastructure of a network of scientific and technological equipment and resources of national and European scientific organizations/universities. This stage involves the implementation of joint research and innovation projects, including network projects, that address socio-economic problems of sustainable development. At this stage the following are defined: procedures for using open science practices at the stages of the research process; procedures for using open innovation practices at the stages of the open innovation process; procedures for technology transfer, mobility of knowledge and/or researchers; issues of intellectual property rights; forms of contracts with industry; expansion of communications (seminars, conferences, brokerage events, briefings) and cooperation with a wide range of stakeholders, including incubators and accelerators supporting startups and spin companies created within the framework of research infrastructure activities.

At the fourth and fifth stages of the development of the research infrastructure, it is envisaged to use digital platform, as an access point according to uniform rules, which integrates networks of scientific and technological equipment, research and technological resources. The digital platform involves the use of coordinated software for the interconnection of research infrastructure components with computing systems and communication networks.

The fifth stage envisages the organization of research using research infrastructure within the framework of a European consortium, which has a reasonable specialization in accordance with pan-European interests and is open to the research community in accordance with the charter of the consortium, taking into account the national and European legal format. At this stage, procedures for the functioning of the research infrastructure are established in accordance with the European regulation and the roadmap for integration into the European ecosystem of research infrastructures. At this stage the following are defined: procedures for providing access (physical, remote, virtual) to scientific equipment; areas of cooperation with scientific communities, industry, government, society; competitions in European research and innovation programs for participation in projects aimed at expanding the scientific potential of the European research infrastructure consortium beyond the state of the art, which expands the national and European landscape of research infrastructures and provides added value in strengthening the European Research Area and strengthening the sustainable development of national and European innovation ecosystems.

4. Conclusions

Modern cutting-edge scientific research requires technically complex, expensive scientific equipment. Scientific institutions/universities faced with the need to choose and implement an effective organizational approach to the use of scientific equipment for conducting scientific research. The diversity of organizational approaches to the sharing of scientific equipment is key characteristic of the European research and innovation system. However, the application of the organizational approach of organizing research using the center of collective use (Core Facilities), which is a division of a scientific institution/university, has significant drawbacks. International cooperation and the association of scientific institutions/universities into scientific alliances, networks, consortia is considered an important condition for applying the approach of organizing research using research infrastructure for conducting advanced scientific research. A multi-level model of research infrastructure development in five stages is proposed. This model ensures effective coordination of the sharing of scientific equipment and resources with physical, remote and virtual access to them by a wide range of users from academia and industry for conducting interdisciplinary collaborative research that contributes to the creation of breakthrough innovations that solve socio-economic and environmental problems of sustainable development.

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