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COMPARATIVE ANALYSIS OF THE SCIENTIFIC POTENTIAL OF THE REPUBLIC OF KAZAKHSTAN AND FOREIGN COUNTRIES

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Abstract. In the context of global technological competition, the development of scientific potential has become a pivotal instrument for ensuring national sovereignty. This article presents a comprehensive comparative analysis of the research and development (R&D) system of the Republic of Kazakhstan in relation to leading foreign nations and states with comparable levels of socio-economic development. The primary objective of the study is to identify the structural constraints hindering the international competitiveness of domestic science and to define strategic pathways for overcoming these barriers.

The research methodology is based on an integrated comparative analysis of macroeconomic indicators (R&D intensity of GDP), bibliometric analysis (publication activity within the Web of Science database), and an examination of successful institutional development models. The study provides a detailed investigation into funding mechanisms, the reproduction of human capital, and the current state of material and technical infrastructure.

The key results of the study demonstrate that Kazakhstan's current scientific model is characterized by a high dependency on state subsidies and insufficient involvement of the private sector. The analysis justifies the necessity of shifting from a quantitative accumulation of publications toward qualitative leadership in high-impact journals (Q1–Q2). The research findings allow for the identification of major structural constraints and promising directions for strengthening the scientific potential of the Republic of Kazakhstan. The analysis highlights the imperative to diversify funding sources, enhance the role of the private sector, and transition from extensive workforce management toward the creation of a high-tech research ecosystem.

Keywords: science, cooperation, space, scientific potential, scientific research, scientific system, comparative analysis, innovation development

Introduction

In the context of the formation of a knowledge-based economy and the intensification of global scientific and technological competition, scientific potential has become one of the key factors of sustainable socio-economic development and international competitiveness of states. The development of science and innovation determines countries' capacity to create and implement advanced technologies, enhance labor productivity, and ensure national security. In this regard, a systematic analysis of the state and dynamics of scientific potential at both national and international levels acquires particular relevance.

The Republic of Kazakhstan, pursuing a strategy of economic modernization and integration into the global scientific community, places significant emphasis on the development of the research and innovation sector. At the same time, an objective assessment of the achieved results and the identification of prospects for further development require a comparison of national indicators with international experience. A comparative analysis of the scientific potential of Kazakhstan and other countries makes it possible to assess its level of competitiveness, identify structural imbalances and institutional constraints, and outline directions for adapting effective international practices. In this context, the study acquires both scientific and practical significance for the formulation of an evidence-based national science and technology policy.

The purpose of this article is to conduct a comprehensive comparative analysis of the scientific potential of the Republic of Kazakhstan and foreign countries based on key quantitative and qualitative indicators of research and development activities.

Within the framework of the study, it is envisaged to assess the level of competitiveness of Kazakhstan's national scientific system in the international context, identify its strengths and weaknesses, and analyze the institutional, human resource, and financial factors influencing the formation and development of scientific potential.

Materials and methods

The empirical base of the study consists of official statistical and scientometric data from the Bureau of National Statistics of the Republic of Kazakhstan, UNESCO Institute for Statistics (UIS), OECD, WIPO, and the Web of Science Core Collection. The analysis covers indicators of R&D financing, human resources in science, publication and citation activity, patent applications, and international scientific collaboration for the period 2019–2024 (depending on data availability).

The methodological design is based on an integrated comparative approach combining: macroeconomic assessment of R&D intensity (R&D expenditure as % of GDP), statistical analysis of human resources (total R&D staff, researchers, qualification structure), bibliometric evaluation of scientific performance using Web of Science indicators (documents, CNCI, highly cited papers, top-10% share, and international co-authorship), and innovation effectiveness assessment through patent activity data (WIPO). Cross-country comparisons were conducted for global leaders (USA, Germany, Japan, Singapore, China), rapidly developing innovation economies (Turkey), and regional competitors (Uzbekistan).

To identify stable development trends and reduce the influence of annual fluctuations, cumulative growth rates and the Compound Annual Growth Rate (CAGR) were applied to key indicators (e.g., researchers per million inhabitants). In addition, elements of institutional and systemic analysis were used to interpret structural constraints in Kazakhstan's R&D model (public/private funding balance, accreditation versus actual R&D activity, and ecosystem fragmentation) and to connect "inputs" (funding, personnel) with "outputs" (publications, impact, patents).

First, the study follows the logic of a "science system" model, where scientific potential is interpreted as the interaction of three interdependent pillars: human resources, infrastructure, and funding. This makes it possible to assess not only the current level of resources but also the institutional readiness of the national system to convert these resources into internationally competitive scientific results.

Second, bibliometric indicators were selected to separate extensive development (growth in publication volume) from intensive development (growth in citation impact and presence in highly ranked outputs). Therefore, special attention was paid to normalized metrics (CNCI) and elite segments of scientific output (highly cited papers and the share of publications in the global top-10%), which better reflect global competitiveness than raw publication counts.

Third, methodological limitations include differences in national statistical accounting and the lack of unified international standards for measuring scientific infrastructure, as well as partial gaps in country-year coverage in some datasets. However, the use of harmonized international sources (UNESCO, WIPO, Web of Science) ensures the comparability and reliability of the key cross-country indicators used in the study.

Literature Review

Scholarly interest in assessing scientific potential and the mechanisms of its realization is interdisciplinary in nature. An analysis of recent publications makes it possible to identify three key directions that form the theoretical framework of this study.

1. Human and intellectual capital as the foundation of the scientific system.

In the international literature, human capital is regarded as a long-term factor of development. K. Diebolt and R. Hippe demonstrate that contemporary regional differences in innovation are largely predetermined by the historically accumulated levels of human capital [1]. This idea is further developed by A. Valero and J. Van Reenen, who substantiate the role of universities as central hubs for knowledge generation. Additionally, De Martino highlights that, in the digital era, universities continue to serve as cores of networked educational and research ecosystems, facilitating the transformation and dissemination of knowledge [2, 3].

In the context of Kazakhstan, the significance of this factor is confirmed by empirical evidence. A. Moldabekova and Z. Satpayeva, employing factor analysis of the Republic of Kazakhstan's development over the period 2011–2019, reveal that intellectual and human capital play a decisive role in the country's socio-economic progress [4]. At the same time, A. Kadyrova and co-authors emphasize the need not merely for quantitative growth, but for the training and stimulation of those qualified specialists who are specifically demanded by an innovation-driven economic model [5].

2. Infrastructure provision and spatial organization

Modern scientific infrastructure is viewed not only as a technical base but also as a complex institutional environment. While foreign scholars such as R. Fabre et al. emphasize the importance of digital monitoring of infrastructure through Current Research Information Systems (CRIS), domestic researchers focus on the regional dimension [6]. F. Miedema extends this vision by justifying the shift to the 'Open Science' concept [7]. He argues that infrastructure should not only support the technical cycle but also promote transparency, open data access, and the collaborative use of resources, which radically increases the inclusiveness of the scientific system.

N. Nurlanova and colleagues justify the necessity of transitioning to a cluster-based organization built on special economic zones and technology parks [8]. However, as noted in the study by F. Alzhanova et al., existing spatial asymmetries in the distribution of Kazakhstan's scientific potential create risks of scientific environment degradation in certain regions, which requires the adaptation of science and technology policy to territorial specifics [9].

3. Funding and the efficiency of potential realization

Resource provision acts as a catalyst for breakthrough results, as demonstrated in the works of A. Raghuvanshi et al. and G. Cimini et al. [10-11]. In the context of Kazakhstan, this issue acquires critical significance due to the structure of investments. E. Aryn and colleagues argue for the necessity of attracting private capital, noting the low efficiency of a model relying solely on government grants [12]. Expanding on this view, L. Soete et al. provides evidence from OECD nations that public R&D spending drives economic effects by enhancing total factor productivity [13]. He argues that optimal outcomes depend on the dynamic complementarity of public and private investment. His research suggests that public funding yields the highest productivity within ecosystems that effectively absorb and commercialize knowledge, requiring high-quality institutional frameworks rather than simple budgetary expansions.

By synthesizing findings from domestic and international research – notably Gokhberg et al.'s 'Doing Science' framework and Courtioux et al.'s insights on developing scientific systems – this study adopts a three-pillar model to assess Kazakhstan's scientific potential [14 -15]. This model focuses on three critical dimensions: human resources, scientific infrastructure, and funding.

This synthetic approach allows for the assessment not only of the current state of resources but also of the institutional readiness of Kazakhstan's scientific system to make a qualitative transition to the stage of post-industrial development.

Results and discussion

Despite the presence of a number of studies in the contemporary scientific literature dedicated to the general analysis of the scientific and technological potential of the Republic of Kazakhstan, its structural components, and comparative characteristics in the context of global trends, issues of in-depth systemic assessment remain insufficiently addressed. This article aims to fill this research gap by conducting a comprehensive analysis of the current state and development trajectories of domestic science.

The systematization of previous research results made it possible to differentiate the structure of scientific potential into key components that are functionally interdependent.

Human resources are of particular significance. In this context, it is reasonable to assert that in economically developed countries, the accumulation of human resources plays a crucial role. There is a direct correlation between the number of scientists engaged in research and development (R&D) activities and economic development in developed countries.

Ideally, this indicator should include not only the number of scientists and researchers but also the qualitative characteristics of the workforce: level of education and qualifications, possession of academic degrees, publication activity, experience in participating in research projects, as well as the development of structures enabling the reproduction of scientific personnel.

The lack of detailed information on educational levels, professional competencies, and other qualitative parameters of the workforce necessitates the introduction of certain methodological limitations. In this regard, the further study will focus on the analysis of quantitative determinants, namely the dynamics of the number of researchers and their distribution across qualification categories (academic degrees).

Table 1 - Number of Employees Engaged in R&D Activities in Kazakhstan

Year	2020	2021	2022	2023	2024
Total R&D Staff	22 665	21 617	22 456	25 473	27 146
of which:					
Researchers	18 228	17 092	18 014	21 534	23 152
of which:					
Doctors of Science	1 883	1 652	1 743	2 061	2 050
Profile Doctors	62	55	96	85	318
Doctors of Philosophy (PhD)	1 757	1 962	2 462	3 458	4 156
Candidates of Science	4 329	3 843	3 946	4 842	4 727

Source: Bureau of National Statistics of the Republic of Kazakhstan [16]

The results of the statistical analysis of the data presented in Table 1 allow us to highlight the key parameters of the transformation of the scientific personnel in the Republic of Kazakhstan. During the study, the following quantitative and structural indicators were verified, characterizing the dynamics of the development of scientific potential over the period 2020–2024.

Table 2 - Dynamics of Scientific Potential Development in the Period 2020–2024

Staff Category	2020	2024	Total Growth (%)
Total R&D Staff	22 665	27 146	+19.77%
Researchers	18 228	23 152	+27.01%
Doctors of Science	1 883	2 050	+8.87%
Profile Doctors	62	318	+412.90%
Doctors of Philosophy (PhD)	1 757	4 156	+136.54%
Candidates of Science	4 329	4 727	+9.20%

Source: the authors' calculations

According to the results systematized in Table 2, over the analyzed period (2020–2024), the total number of personnel engaged in R&D activities increased by 19.77%. Notably, the growth rate of the "Researchers" category (+27.01%) outpaces the overall dynamic. This indicates a qualitative transformation of the workforce structure: the share of personnel directly involved in research within the total R&D staff has increased, reflecting a concentration of resources on core scientific and production activities.

The most pronounced growth is observed in the segment of Doctors of Philosophy (PhD), whose number more than doubled (+136.54%). This trend confirms the successful integration of Kazakhstani science into the international educational space and highlights the focus on training a new generation of scientific personnel.

The extremely high growth of Profile Doctors (+412.9%) – from 62 to 318 individuals – despite the small absolute numbers, reflects the ongoing institutional formation of this category of researchers within the national qualification system.

Against the backdrop of rapid growth in the number of PhDs, traditional academic degrees (Doctors of Science and Candidates of Science) show moderate, conservative increases (+8.87% and +9.20%, respectively). This can be explained by the natural generational turnover in the scientific community and the gradual replacement of the Soviet attestation system with the Western PhD model.

Analysis of data from the Bureau of National Statistics of the Republic of Kazakhstan for 2020–2024 indicates a stable trend of strengthening the human resource potential of science. The observed dynamics suggest qualitative renewal of the scientific core and gradual transformation of the qualification structure towards international standards.

To assess the potential of Kazakhstan's human resources in science, it is advisable to conduct a comparative analysis with neighboring countries and regional competitors, such as Uzbekistan, Turkey, and China, to identify their development trends and determine effective practices that could be applied in the Kazakhstani context. In addition, including leading global scientific powers – the United States, Germany, Japan, and Singapore – will allow for the identification of the existing gap in scientific potential and provide benchmarks for strategic planning and further development.

Table 3 - Number of Researchers per Million Inhabitants

Country	2019	2020	2021	2022	2023
China	1483.86	1600.31	1685.98	1849.24	2107.27
Germany	5398.63	5390.05	5520.58	5801.62	5926.07

Japan	5376.12	5450.44	5589.77	5629.80	5608.63
Kazakhstan	619.65	668.83	609.97	661.69	693.06
Singapore	7509.61	7503.33	7956.40	8781.74	-
Turkey	1737.58	1964.66	2209.70	2478.68	2644.66
USA	4367.21	4567.79	4900.77	4937.49	-
Uzbekistan	422.11	426.49	523.88	543.84	542.07

Source: UNESCO official data [17]

Table 4 - Dynamics of Growth of Scientific Personnel for 2019–2023

Country	Total growth rate (%)	Compound Annual Growth Rate (CAGR) (%)
Turkey	+52.20%	+11.1%
China	+42.01%	+9.2%
Uzbekistan	+28.42%	+6.6%
Germany	+9.77%	+2.4%
Kazakhstan	+11.85%	+3.0%
Japan	+4.32%	+1.1%
USA	+13.06%*	+4.2%
Singapore	+16.94%*	+5.4%

Source: the authors' calculations
Note: Data for Singapore and the USA are through 2022

The assessment of the dynamics of scientific potential development in the countries presented in Table 3 was carried out based on the calculation of the compound growth rate over a five-year period (2019–2023). The use of this indicator allows for the identification of stable trends in the development of scientific personnel while minimizing the influence of random annual fluctuations in the statistics.

The statistical analysis of UNESCO data for the period 2019–2023, presented in Table 4, allowed for the differentiation of the studied countries according to their strategies for developing scientific human potential. Based on the calculated cumulative growth indicators, the following key groups of nations were identified.

The Intensive Technological Breakthrough Group (Turkey, China, Singapore). Turkey and China emerge as leaders in the growth rate of human resources in science. The high dynamics in these countries reflect the implementation of long-term strategies aimed at expanding intellectual capital. The experience of Singapore merits particular attention; despite the absence of data for 2023, it demonstrated a significant growth rate of 16.94%. This reinforces Singapore's status as a global "attractor" of highly qualified personnel, where a high density of researchers is coupled with aggressive recruitment rates.

Group of mature scientific systems. Germany, the United States, and Japan demonstrate a high level of scientific development that is not directly dependent on the inflow of new personnel. Their competitiveness is based on the quality of scientific output and the well-coordinated interaction of all elements of the research system rather than on scale or mass participation. Network and structural analyses of scientific activity in the United States and Germany show that their superiority is determined not only by the volume of available resources, but also by the high complexity of scientific subsystems and the depth of specialization of human capital and technical capacity.

Kazakhstan, in terms of growth rates, belongs to the same cluster as leading Western economies. However, unlike developed countries, this growth in Kazakhstan is largely restorative and extensive in nature, which underscores the need to transition toward more qualitative indicators for assessing the effectiveness of human resources.

Uzbekistan, by contrast, demonstrates high rates of "catch-up development." Despite lower absolute indicators compared to Kazakhstan, the accelerated dynamics of this neighboring country create prerequisites for the emergence of a new competitive environment in the Central Asian region.

The conducted comparative analysis makes it possible to conclude that Kazakhstan's scientific potential is developing in line with global trends; however, it lags significantly behind the Asian "technological tigers" in terms of intensity. Bridging this gap requires a transformation of public policy from merely maintaining the number of researchers to creating conditions for their qualitative reproduction, drawing on the experience of Singapore and China.

Another equally important aspect is the development of scientific infrastructure, which includes a network of research institutes, sectoral and university laboratories, experimental centers, as well as specialized technoparks and innovation platforms. Scientific infrastructure provides the material, technical, and organizational foundation for conducting fundamental and applied research, enhances the quality of scientific outputs, and contributes to the formation of a sustainable research environment.

Conducting a representative analysis of the development of scientific infrastructure in the Republic of Kazakhstan is complicated by a shortage of verifiable statistical data, as well as by the fragmented nature of information on the quantitative composition and resource base of research organizations.

According to data from the Bureau of National Statistics, in 2024 there were 423 enterprises in Kazakhstan engaged in research and development (R&D) activities. Over a five-year period, this indicator exhibits fluctuations: in 2020 the number of enterprises amounted to 396, in 2021 to 438, in 2022 to 414, and in 2023 to 425. Thus, the number of organizations involved in R&D is characterized by an unstable trend. At the same time, official statistics do not disclose the criteria used to construct this indicator, which complicates its accurate interpretation.

A further assessment of the scientific sector can be drawn from the number of legal entities accredited for R&D. This accreditation is a primary requirement for securing public research funding. According to information published on the Digital Science Portal, the number of such organizations amounts to 808 [18]. This figure is more than twice the number of enterprises actually engaged in R&D according to official statistics.

The imbalance between the number of accredited organizations and the number of enterprises actively conducting R&D indicates the presence of structural features within the national scientific system. The large number of accredited legal entities may reflect a broad institutional framework of science, encompassing universities, research centers, laboratories, and other organizations that formally possess the right to conduct scientific activities. However, actual participation in R&D is limited to a smaller group of actors, which may point to insufficient research activity among some institutions or to constrained resources available for conducting research.

Moreover, the increase in the number of accredited organizations in the absence of a corresponding growth in active enterprises may indicate an excessive formalization of the accreditation process. This creates a situation in which many institutions obtain the status of a scientific organization without ensuring the systematic conduct of research, thereby reducing the efficiency of the allocation of scientific resources and complicating an objective assessment of the country's scientific potential.

In this context, the perspective of researchers regarding the role of research information systems and services, which are essential for scientific communities to conduct large-scale studies, merits particular attention. The analysis of research infrastructures in Kazakhstan is constrained by the current level of digital infrastructure development, the absence of centralized standards, and the limited availability of open data.

The assessment and direct comparison of scientific infrastructure across countries within a single quantitative model is not feasible, as there is no unified international definition or statistical accounting of the key elements of scientific infrastructure (research centers, laboratories, research facilities). Additional methodological limitations stem from differences in national science systems, levels of decentralization, departmental affiliations of research organizations, as well as from the heterogeneity and incompleteness of official statistical data published at the international level.

The scientific infrastructure of developed countries (the United States, Germany, Japan, and Singapore) is characterized by a high density of research organizations, stable integration of universities, national research centers, and specialized laboratories, as well as the presence of well-developed shared research platforms. A key distinguishing feature is the institutional diversification of scientific organizations and a high concentration of human resources in the research sector.

Turkey’s scientific infrastructure is currently undergoing a phase of active expansion and institutional consolidation, with the university sector playing a central role in scientific research. The development of research centers is accompanied by the gradual establishment of national coordination mechanisms in the field of science.

The scientific infrastructure of Central Asian countries (Kazakhstan and Uzbekistan) is characterized by the predominance of state research institutes and university-based research units. The region as a whole is marked by limited integration among scientific organizations and an insufficient presence of large interdisciplinary research centers.

Another strategic component is the system of financing research and development activities. The level and structure of public and private allocations determine not only the current operational sustainability of scientific organizations but also their capacity for long-term technological development.

Funding represents a further critical factor, as the development of science is directly dependent on the volume of both public and private financial resources. Public investment provides the basic infrastructure, supports fundamental research, ensures human capital development, and sustains the stable functioning of research organizations. At the same time, private funding stimulates innovation activity, the commercialization of research outcomes, and the adoption of new technologies. A balanced combination of public and private funding sources creates favorable conditions for scientific progress, enhances the competitiveness of research organizations, and contributes to the formation of a sustainable national scientific potential.

Table 5 - R&D Expenditures in Kazakhstan

Indicator/Year	**2020**	**2021**	**2022**	**2023**	**2024**
Domestic R&D Expenditures, million KZT	89 028,7	109 332,7	121 560,1	172 585,9	219 669,8

Share of Domestic R&D Expenditures in GDP (%)	0,13	0,13	0,12	0,14	0,16*

Source: official data of the Bureau of National Statistics

Over the five-year period under review, domestic R&D expenditures in monetary terms increased nearly 2.5 times (by 146.74%). The most pronounced surge was observed in 2023-2024, driven by the implementation of science and technology policies aimed at the priority development of research, carried out by the relevant governmental body.

Despite the substantial increase in funding in tenge, the share of R&D expenditures in GDP grew only marginally – from 0.13% to 0.16%. This indicates that the growth rate of Kazakhstan's overall economy, combined with inflationary processes, effectively "absorbs" the increased investment in science.

According to OECD standards, the threshold for effective innovation-driven development begins at 1.0% of GDP, while global leaders (Israel, South Korea) invest more than 4–5% [19].

The observed trend highlights the need to transition from predominantly public funding toward incentivizing private investment in R&D, which would help ensure qualitative technological sovereignty.

Table 6 - R&D Expenditures in Foreign Countries (% of GDP)

Country	**2019**	**2020**	**2021**	**2022**	**2023**
Israel	5,37	5,82	5,76	6,18	6,33
USA	3,14	3,42	3,47	3,49	3,45
Japan	3,22	3,26	3,28	3,41	3,45
Germany	3,11	3,09	3,08	3,07	3,15
China	2,24	2,41	2,43	2,56	2,65
Singapore	1,88	2,16	1,95	1,85	—
Turkey	1,32	1,37	1,40	1,32	1,42
Kazakhstan	0,12	0,13	0,13	0,12	0,14
Uzbekistan	0,10	0,13	0,12	0,14	0,11

Source: UNESCO official data [20]

A comparative analysis of the data in Table 6 reveals a significant disparity in the levels of science intensity among the countries under study. While developed countries (Israel, the United States, Japan) have reached a phase of high-intensity technological development, with R&D expenditures ranging from 3.4% to 6.3% of GDP, the Republic of Kazakhstan maintains a critically low level of investment in R&D (0.14%). This situation indicates that, despite the growth in absolute expenditures in national currency, the real relative share of science in Kazakhstan's economy does not even reach the OECD's minimum recommended threshold of 1%. This limits the country's capacity for a qualitative technological breakthrough and increases the risk of perpetuating a resource-oriented economic structure.

A logical continuation of the analysis of the resource base and human capital is the assessment of the performance (productive) potential, which reflects the ability of the national scientific system to transform accumulated resources into tangible intellectual and material outputs. While financial and human capital indicators represent the "input parameters" of the system, the performance potential determines its ultimate efficiency and socio-economic return.

In this study, the performance potential is structured along two key vectors: bibliometric productivity (theoretical recognition) and innovation-technological effectiveness (practical applicability). We will now consider the bibliometric productivity of Kazakhstan and the countries selected above.

Table 7 - Comparative Bibliometric Indicators of Countries According to Web of Science, 2020–2024

Country	Documents Web of Science	% of Cited Documents	Normalized Citation Impact (CNCI)	International Colla-borayions	Highly Cited Papers	% of Documents in Top-10
China	4 094 673	86,91	1,19	876 451	51 175	13,82
USA	4 019 285	70,03	1,27	1 411 886	36 644	12,48
Germany	1 006 978	76,44	1,30	553 992	11 319	13,05
Japan	682 977	76,17	0,92	221 288	4 830	7,83
Turkey	356 190	73,67	0,90	99 344	2 404	8,72
Singapore	137 721	83,06	1,79	97 959	3 087	20,36
Kazakhstan	23 132	72,35	1,00	13 854	166	7,63
Uzbekistan	10 659	67,98	1,05	6 482	112	10,39

Source: data from Web of Science [21]

The data presented in Table 7 allow for a multifactorial analysis, categorizing countries into “scientific giants” (China, the United States), countries with established research traditions (Germany, Japan, Turkey), and dynamically developing systems (Singapore, Kazakhstan, Uzbekistan).

During the mentioned period, a historic shift in the landscape of global science was observed: China officially established its quantitative superiority, surpassing the United States in the total number of indexed publications in the Web of Science database. However, descriptive analysis indicates that the extensive growth in China’s publication activity has not yet translated into equivalent dominance in qualitative metrics. The United States maintains a higher Normalized Citation Impact (CNCI = 1.27 compared to 1.19 for China), reflecting the continued leadership of American research institutions in shaping the global scientific agenda and the higher academic significance of their publications.

Nevertheless, the absolute leader is Singapore. Despite a relatively small publication volume (137,000), the country exhibits an exceptionally high CNCI (1.79) and the largest share of articles in the top 10% globally (20.36%). This reflects a “quality over quantity” strategy and a high concentration of resources in breakthrough research areas.

It is worth noting that Uzbekistan, despite having the smallest number of publications in the list, exhibits a CNCI of 1.05, which is higher than that of Japan (0.92) and Kazakhstan (1.00), indicating a strong demand for certain targeted research outputs.

Particular attention should be paid to the regression trend in the impact metrics of countries such as Japan and Turkey. Despite generating substantial volumes of knowledge, their CNCI values (0.92 and 0.90, respectively) remain below the global parity level (1.0). This stagnation points to the need for a systemic review of national science and technology strategies. There is a clear risk of being confined to a predominantly “domestic” scientific agenda, which necessitates intensified participation in high-ranking international projects and a reorientation of research evaluation systems from quantitative volume to the support of breakthrough, highly cited studies.

International collaboration is a key driver of citation impact. In Germany, over 50% of publications are produced in collaboration with foreign colleagues. Kazakhstan (59.9%) and Uzbekistan (60.8%) demonstrate a very high degree of openness and reliance on international networks, which is typical for developing scientific systems striving for integration into the global research community.

China, by contrast, shows the lowest relative level of international collaboration among the leading countries (approximately 21%), reflecting the strong self-sufficiency of its domestic research environment.

Considering the Central Asian region, a comparative analysis of Kazakhstan and Uzbekistan reveals distinct development models. Kazakhstan leads in absolute terms, producing twice as many publications and a greater number of highly cited papers (166 versus 112). Uzbekistan, however, outperforms Kazakhstan in quality metrics, with a higher CNCI and a substantially larger share of publications in the global top 10% (10.39% versus 7.63%).

In this context, it appears advisable for Kazakhstan to transform the mechanisms of state research incentives: shifting from promoting the sheer volume of publications in international abstracting databases (such as Web of Science) toward prioritizing citation impact and journal prestige (primarily Q1 and Q2 journals). Focusing research efforts on high-impact-factor journals, rather than low-ranking outlets, is considered a key condition for concentrating scientific potential and enhancing the global competitiveness of national science.

Statistical analysis of research performance also indicates a deficit of highly cited papers within Kazakhstan's overall publication output: out of approximately 23,000 publications, only 166 are top-tier articles. The relative share of such publications (0.7%) is significantly lower than in technology-leading countries, notably Singapore (2.2%), highlighting the largely extensive nature of the national research environment.

Kazakhstan exhibits a high proportion of international co-authorship (around 60%); however, attention should be given to the transition from "passive" collaboration to a "leading" role. For a qualitative breakthrough, it is necessary to move from being primarily a provider of empirical data to assuming leadership in research projects.

Thus, global science can be characterized by a two-tier structure: large scientific powers (China, the United States) generate the main body of knowledge, while countries with compact but highly efficient systems (Singapore, Germany) set the standards of quality and scientific influence.

For developing scientific systems, the key drivers of growth are strengthened international collaboration, publication in high-ranking journals, and a focus on research with high potential impact.

The next section presents a statistical analysis of patent activity, serving as a key indicator of technological effectiveness.

Table 8 - Number of Patent Applications

№	**Country**	**2020**	**2021**	**2022**	**2023**	**2024**
1	**China**	1 439 894	1 537 489	1 584 354	1 642 643	1 796 730
2	**Germany**	139 660	137 598	130 839	133 111	133 780
3	**Japan**	422 684	412 545	406 113	414 599	420 990

4	**Kazakhstan**	918	—	815	833	975
5	**Singapore**	7 681	9 429	8 327	9 271	10 333
6	**Turkey**	9 375	9 967	10 408	10 108	11 588
7	**USA**	503 348	520 626	527 057	521 382	503 265
8	**Uzbekistan**	379	428	475	541	526

Source: official data from the World Intellectual Property Organization (WIPO) [22]

An analysis of the patent activity trends in Table 8 reveals several key conclusions regarding the period from 2020 to 2024.There is a clear and sustained shift of innovation activity toward the Asian region. China demonstrates unprecedented growth in patent applications (from 1.44 million to 1.8 million), confirming its transition from a technology-import model to a model of advanced, leapfrog innovation development.

In contrast, innovation cycles in developed economies appear stagnant. The indicators for the United States, Japan, and Germany show no significant positive dynamics. This may reflect both the saturation of traditional technology markets and changes in intellectual property strategies, such as a shift toward trade secrets or know-how regimes.

Turkey and Singapore show strong growth in patent applications (over 20%), reaffirming their status as key technological hubs that provide favorable ecosystems for high-tech business development.

The analysis of patent activity distribution over 2020–2024 indicates a definitive shift of the innovation “gravitational center” from the Atlantic region to Asia, where China’s quantitative indicators now exceed the combined totals of the United States and Japan by more than threefold.

The development dynamics of emerging scientific centers are explored in the work of P. Courtioux. Through extensive bibliometric analysis, the authors challenge the stereotype that non-Western research systems are lagging behind. Their study demonstrates that over recent decades, countries in the region have made a qualitative leap, becoming full participants in the global scientific arena. This progress is evident not only in the rising volume of publications but also in the strengthening of collaborative networks, improved journal quality, and higher citation rates. This example confirms that sustained investment in a national scientific system enables countries to compete effectively on a global scale.

In comparison with Uzbekistan, Kazakhstan maintains a quantitative lead in patent applications, with nearly 1.8 times more filings in 2024. However, its more modest growth rate compared to Uzbekistan suggests a need for further incentives to drive the commercialization of intellectual property.

Conclusion

Based on the comparative analysis of the scientific potential of the Republic of Kazakhstan and its foreign counterparts, it is evident that Kazakhstan's national research system currently faces limited international competitiveness. This is reflected in the relatively low R&D intensity of the economy, as well as modest publication and patenting activity.

A significant bottleneck hindering the development of this potential is the high dependency on state funding, coupled with limited private sector involvement in R&D. Consequently, there is a clear need to strengthen the role of the private sector. This should be achieved by incentivizing business investment – particularly from large enterprises in core industries – through tax preferences, targeted levies, and other forms of R&D support.

However, increasing financial resources alone, without a concurrent strengthening of human capital, cannot ensure sustainable scientific and technological progress. A key priority must therefore be to expand the research workforce, primarily by attracting young scientists. Adapting the successful models of Singapore and China – focused on creating an ecosystem for the continuous professional development of researchers – represents a strategic path forward. Such an approach allows for a shift from the extensive management of human capital toward the intensification of intellectual potential, ultimately enhancing the long-term competitiveness of the national scientific landscape.

The structure of Kazakhstan's scientific infrastructure largely aligns with the model of an emerging research system, characterized by state dominance and a fragmentation of research organizations. Compared to developed nations, the key priorities for future growth remain the consolidation of research infrastructure, the expansion of university-based science centers, and the establishment of shared-use national research platforms.

A critical objective is also to deepen the integration of Kazakhstani science into the global research landscape. To enhance global competitiveness, a strategic shift is required: moving from the quantitative accumulation of publications toward a prioritization of high-impact metrics (Q1–Q2) and the support of highly-cited research, following the example of global technological leaders. This transformation hinges on a fundamental change in international partnerships moving away from passive co-authorship and data provision toward taking leadership roles as project initiators and corresponding authors.

In the face of accelerating global competition for scientific talent and technological leadership, these measures are of critical importance. Without a systemic transformation of the funding model, workforce reproduction, and organizational infrastructure, Kazakhstan risks remaining on the periphery of the global scientific and technological arena. Conversely, the consistent implementation of these reforms will establish the groundwork for a transition to a resilient and competitive national scientific system**.**

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ҚАЗАҚСТАН РЕСПУБЛИКАСЫ МЕН ШЕТ ЕЛДЕРДІҢ ҒЫЛЫМИ ӘЛЕУЕТІН САЛЫСТЫРМАЛЫ ТАЛДАУ

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Аңдатпа. Жаһандық технологиялық бәсекелестік жағдайында ғылыми әлеуетті дамыту ұлттық егемендікті қамтамасыз етудің шешуші құралына айналуда. Бұл мақалада Қазақстан Республикасының ғылыми-зерттеу және тәжірибелік-конструкторлық жұмыстар (ҒЗТКЖ) жүйесін жетекші шет елдермен және әлеуметтік-экономикалық даму деңгейі ұқсас мемлекеттермен кешенді салыстырмалы талдау ұсынылған. Зерттеудің негізгі мақсаты – отандық ғылымның халықаралық бәсекеге қабілеттілігінің артуына кедергі келтіретін құрылымдық шектеулерді анықтау және оларды еңсерудің стратегиялық жолдарын айқындау.

Зерттеу әдістемесі макроэкономикалық көрсеткіштерді кешенді салыстырмалы талдауға (ІЖӨ-нің ғылыми сыйымдылығы), библиометриялық талдауға (Web of Science дерекқорындағы жарияланымдық белсенділік) және дамудың сәтті институционалдық модельдерін зерделеуге негізделген. Жұмыста қаржыландыру тетіктері, кадр әлеуетін ұдайы жаңғырту және материалдық-техникалық инфрақұрылымның қазіргі жағдайы егжей-тегжейлі қарастырылады.

Зерттеудің негізгі нәтижелері Қазақстандағы ғылымның қазіргі моделі мемлекеттік субсидияларға жоғары тәуелділікпен және жеке сектордың жеткіліксіз қатысуымен сипатталатынын көрсетеді. Талдау барысында жарияланымдардың сандық жинақталуынан жоғары рейтингті журналдардағы (Q1–Q2) сапалы көшбасшылыққа көшу қажеттілігі негізделген. Зерттеу қорытындылары Қазақстан Республикасының ғылыми әлеуетін нығайтудың негізгі құрылымдық шектеулері мен перспективалы бағыттарын анықтауға мүмкіндік береді. Талдау қаржыландыру көздерін әртараптандыру, жеке сектордың рөлін күшейту және кадрларды экстенсивті басқарудан жоғары технологиялық зерттеу экожүйесін құруға көшу қажеттілігін көрсетеді. Бұл шараларды іске асыру ұлттық ғылымды жаһандық кеңістікке шеттегі қатысушы ретінде емес, жоғары технологиялық зерттеулердің бастамашысы ретінде біріктіруге мүмкіндік береді.

Тірек сөздер: ғылым, ынтымақтастық, кеңістік, ғылыми әлеует, ғылыми зерттеулер, ғылыми жүйе, салыстырмалы талдау, инновациялық даму

СРАВНИТЕЛЬНЫЙ АНАЛИЗ НАУЧНОГО ПОТЕНЦИАЛА РЕСПУБЛИКИ КАЗАХСТАН И ЗАРУБЕЖНЫХ СТРАН

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Аннотация. В условиях глобальной технологической конкуренции развитие научного потенциала становится ключевым инструментом обеспечения национального суверенитета. Данная статья представляет собой комплексный сравнительный анализ системы научно-исследовательских и опытно-конструкторских работ (НИОКР) Республики Казахстан в сопоставлении с ведущими зарубежными странами и государствами с сопоставимым уровнем социально-экономического развития. Основной целью исследования является выявление структурных ограничений, препятствующих росту международной конкурентоспособности отечественной науки, и определение стратегических путей их преодоления.

Методология исследования базируется на комплексном компаративном анализе макроэкономических показателей (наукоемкость ВВП), библиометрическом анализе (публикационная активность в базе данных Web of Science) и изучении успешных институциональных моделей развития. В работе детально рассматриваются механизмы финансирования, воспроизводства кадрового потенциала и текущее состояние материально-технической инфраструктуры.

Ключевые результаты исследования демонстрируют, что текущая модель науки в Казахстане характеризуется высокой зависимостью от государственных субсидий и недостаточной вовлеченностью частного сектора. В ходе анализа обоснована необходимость перехода от количественного накопления публикаций к качественному лидерству в высокорейтинговых журналах (Q1–Q2). Выводы исследования позволяют определить основные структурные ограничения и перспективные направления укрепления научного потенциала Республики Казахстан. Анализ подчеркивает необходимость диверсификации источников финансирования, усиления роли частного сектора и перехода от экстенсивного управления кадрами к созданию высокотехнологичной исследовательской экосистемы. Реализация данных мер позволит интегрировать национальную науку в глобальное пространство не в качестве периферийного участника, а в роли инициатора высокотехнологичных исследований.

Ключевые слова: наука, сотрудничество, пространство, научный потенциал, научные исследования, научная система, сравнительный анализ, инновационное развитие

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