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Organizational and technological mechanism of interaction of subjects and objects of digital ecosystems of industrial enterprises with third-party information and communication resources and services

Abstract. In the context of Industry 4.0 development, it is especially important for manufacturing companies to continue purposeful improvement of digital ecosystems and increase the efficiency of their subjects' interaction with various external information and communication systems to achieve competitiveness. The authors of the article identify the goals, objectives and principles that are fundamental for the coordinated work of the organizational and technological mechanism, and also identify a set of levers of influence of various subjects of the ecosystem on the object, allowing to achieve all set goals and approved target indicators. The practical steps for implementing the mechanism, as well as the external and internal environmental factors imposing certain limitations on its functioning, are described. Examples of similar mechanisms used in Kazakhstan are provided, confirming the feasibility and potential of implementing the organizational and technological mechanism for the strategic development of industrial companies. The significance of the research results is based on the example of the successful implementation and adaptation of the digital ecosystem in the activities of LLP «Bëmer-Armatura».
The study also included a scientometric analysis of publications based on data from the Web of Knowledge (Web of Science Core Collection) for the period 1992-2024. The analysis was conducted using the VOSviewer software to construct thematic frameworks based on the search query: «digital ecosystem» and «industry». The final selection within the search formula consisted of 1,859 publications, which were further analyzed using the specialized VOSviewer software. The resulting framework clusters were constructed according to the following criteria: Co-Authorship Analysis and Co-Occurrence Analysis.
Keywords: Industry 4.0; Cross-Cutting Technologies; Digital Platform; Digital Ecosystems; Information and Communication Resources; Organizational and Technological Mechanism; Digital Transformation; Industrial Enterprises
JEL Classification: O33; M15; L24; L23; O32; Q55; F63
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1. Introduction

In the context of the accelerated development of Industry 4.0 and innovative transformations in cross-cutting technologies, industrial enterprises are presented with promising opportunities for automation and robotics in manufacturing, the implementation of artificial intelligence solutions for equipment monitoring, demand forecasting, and supply chain optimization. With the emergence of the digital ecosystem stage - a digital space based on one or multiple digital platforms that integrates various services and numerous physical and legal entities, which is able to meet the diverse needs of ecosystem participants within a unified process - the importance of professional knowledge and technological expertise for their effective management is increasing. The key features of this stage include process and system virtualization, digitalization, and the enhancement of cybersecurity regulations.

Industrial organizations with a high level of digital development / digital maturity leverage various information and communication resources and services such as databases, information systems, networks, software, cloud storage, and other tools to enhance communication and facilitate real-time data exchange among participants in digital ecosystems. These resources contribute to the efficient management of production processes, supply chains, and other critical operations. Therefore, in modern economic conditions, the priority tasks are not only the creation of digital ecosystems within industrial enterprises, but also the aspects of effective formation of an organizational-technological mechanism of subjects and objects communication within industrial digital ecosystems - OTMsoc with external information and communication resources (ICR) and services.

The research questions outlined in this scientific article are as follows:

1. What key research trends can be identified through a scientometric analysis based on the search query ««digital ecosystem» and «industry»» using the WoS data set (RQ1)?
2. What are the features of the implementation and adaptation of organizational-technological mechanisms for communication of digital ecosystem subjects with external information and communication resources and services at the enterprises of Kazakhstan (RQ2)?

2. Brief Literature Review

In the context of Industry 4.0, industrial digitalization is a key development area, as confirmed by modern scientific research conducted by scholars such as Babkin A. V., Tashenova L. V., Mamrayeva D. G., Shkarupeta Y., Karimov D., Andreeva T., Batukova L., Lejfej Ch., and others. Their studies provide examples of how digital ecosystems, platforms, and digital technologies such as digital twins, IoT, and cyber-social systems are actively transforming traditional business processes, enhancing their efficiency and resilience, and also consider the issues of creation of enterprise development mechanisms in new technological conditions (Babkin et al., 2017; Babkin et al., 2019; Khan et al., 2024). Digital technologies have had a significant impact on various aspects of organizational activities: they have changed work organization methods, strengthened interactions within platform ecosystems, and contributed to the formation of modern digital business strategies (Ayaganova et al., 2019; Zirar et al., 2023; Westergren et al., 2024).

The success of companies in the digital era depends on the integration of key digital economy tools, such as digital ecosystems and platforms, which create conditions for all ecosystem participants to develop new products and services. The use of an integrated digital platform is the most effective solution for accelerating logistics flows within supply chains. The author presents a logistics flow management mechanism, along with models of the transport and logistics services ecosystem and the interaction of its participants (Kotova, 2023). The authors of the study «The Digital Platform - New Opportunities and Implementation Strategy» identify key steps and tools for the successful implementation of digital platforms in a dynamic business environment, as well as insights into the potential of the ecosystem approach for business development (Popova et al., 2024).

Industries in the digital economy require a mechanism that ensures the digitalization of business processes across all sectors. For example, researchers Loseva O. V. and Abdikeev N. M. developed a conceptual model for the functioning of an industrial enterprise within a unified digital

space, based on the principle of optimality and adaptability to the needs of industrial enterprises. Additionally, the study defines key managerial functions and describes digital services that facilitate interaction among business ecosystem participants, with a focus on the information-service support of management functions (Loseva & Abdikeev, 2024). The developed organizational model of a digital business ecosystem, which details the expanded roles and rules of cooperation, ensures the fair distribution of resources while considering both common and individual goals of participants, ultimately enhancing the ecosystem's sustainability (Kornyshova et al., 2023).

Digital platforms can both create new ecosystems and integrate into existing ones, where successful integration becomes critically important. The article introduces the concept of «platform grafting»- the process of embedding a new platform into an existing ecosystem, leading to the united co-evolutionary adaptation process. Dynamic capabilities play a key role in this process, including the adaptation of the platform, its business model, and governance mechanisms (Björkdahl et al., 2024).

It should be noted that the lack of integration of information resources and data processing algorithms significantly slows down the digital transformation of enterprises. Given the increasing costs of the digital economy and the scale of organizations involved in global value chains, research focused on developing an effective ontological mechanism for business ecosystem functioning is becoming particularly important. This will enable the creation of a unified conceptual space that facilitates the integration of digital technologies across various sectors of the economy (Medennikov, 2024).

The concept of AI-enabled smart manufacturing is increasingly being studied and implemented in the industrial sector, encompassing a wide range of tools for managing production processes, data exchange within corporate ecosystems, continuous operations monitoring, and the development of predictive problem-solving mechanisms. Many leading companies have successfully integrated AI into smart manufacturing. For example, Tesla employs a quality control system for immediate defects detection in vehicles, Bosch automates routine processes using robotic technologies, and Airbus utilizes AI to enhance the efficiency of production lines (Mikalef et al., 2023; Bustinza et al., 2024).

Artificial intelligence and smart manufacturing technologies continue to strengthen their position in the market economy and corporate governance. In 2023, more than a quarter of all private AI investments were directed toward the development of generative AI (Gen AI). Leading companies in this field include OpenAI, Anthropic, Hugging Face, and Inflection (Stanford University's Institute for Human-Centered AI, 2024). According to analysts, the global AI market, valued at USD 233.46 billion in 2024, is projected to reach USD 1.771 trillion by 2032 (Fortune Business Insights, 2024).

The future of digital transformation is shaped by technological progress and businesses' adaptation to emerging challenges. Modern technologies such as internet intelligence, machine learning, IoT, edge computing, 5G, and blockchain used in manufacturing processes are interdependent and drive the development and transformation of subsequent digital solutions. Cloud computing reduces capital expenditures on IT infrastructure by offering industrial enterprises a «pay-as-you-go» model, eliminating the need for costly on-premise servers (Yenugula et al., 2024). As the number of IoT devices increases, real-time data volumes grow, emphasizing the importance of edge computing, which processes data closer to the source of their generation, reducing reliance on centralized data centers. 5G networks enhance data transmission speed and reduce delays, fostering the further expansion of IoT and increasing the number of connected devices and applications (Tekle & Kumar, 2024). Blockchain technology provides decentralized and secure data management, preventing fraud, improving transparency and transaction security in supply chains (Liyanaarachchi et al., 2024).

In the highly competitive realms of retail and e-commerce, the volume of generated data is continually increasing, leading to challenges in data privacy, security, storage, and analysis. Big Data Analytics plays a pivotal role in addressing these issues by optimizing data management and enhancing the efficiency of industrial companies' supply chains. Authors analyze the impact of various big data practices on supply chain performance, enabling the selection of the most appropriate strategy based on prioritized supply chain performance metrics (Gopal et al., 2024).

The importance of enhancing the theoretical and methodological foundations of data protection in cyberspace is highlighted through the development of a brand protection system aimed at increasing brand recognition, strengthening reputation, and enhancing competitiveness. Criteria

for steganographic data protection methods in the virtual space were selected and evaluated, with integrated methods based on discrete wavelet and cosine transforms demonstrating the best results (Zghurska et al., 2023).

In 2024, modern trends in the digitalization of industrial enterprises include:

- creation and development of digital ecosystems as a key tool for cooperation and resource exchange in industry (Luchaninova et al., 2023; Kulzhambekova et al., 2023);
- expanding the use of digital platforms to manage the potential of strategic innovation-active industrial clusters (Babkin et al., 2021; Babkin et al., 2022);
- development of cybersocial industrial ecosystems to increase the adaptability and sustainability of production (Babkin et al., 2023);
- active use of digital twins, digital factories for modeling, forecasting, optimization of production processes (Kulzhambekova et al., 2023; Saporiti et al., 2023; Tashenova et al., 2023);
- implementation of Industry 5.0 technologies with an emphasis on human-centricity, including personalized digital solutions (Babkin et al., 2023; Yazdi, 2024);
- increasing the share of robotization and automation in industry (Duan et al., 2023; Kulzhambekova et al., 2023);
- promoting sustainable development through energy-efficient and environmentally friendly technologies (Babkin et al., 2024; Buyya et al., 2024).

The aforementioned directions confirm that digitalization serves as a central theme in the strategic management of industrial enterprises and necessitates a comprehensive approach, including the integration of technologies, knowledge management, and ecosystem development.

3. Methodology and Methods

In this study, general scientific research methods were employed, including a ***bibliographic analysis*** of scholarly works focused on the development mechanisms of digital ecosystems, and a ***systematic analysis*** to examine the functioning characteristics of digital ecosystems, ***the case study method*** to explore practical examples of organizational and technological mechanism implementation by industrial companies. Additionally, ***specialized*** methods were applied, including ***content analysis*** and ***scientometric analysis*** of publications, ***graphical frame construction*** using the VOSviewer program, and ***graphical interpretation*** to create schematic representations of the interaction mechanisms between subjects and objects of digital ecosystems with external information and communication resources.

Data collection for this study was conducted through an analysis of published works available in the Web of Science Core Collection scientometric database, utilizing the following search formula: All fields: «digital ecosystem» and «industry». The VOSviewer software (version 1.6.20) was employed to perform analyses based on the following criteria: «Co-occurrence Analysis (Keywords Co-occurrence Analysis)» and «Co-Authorship Analysis».

4. Results

4.1. Results of scientometric analysis (RQ1): general characteristics of search results ««digital ecosystem» and «industry»» in the Web of Knowledge database (Clarivate Analytics) and results of scientometric analysis in VOSviewer

As part of the study a scientometric analysis of scholarly publications was conducted using VOSviewer, based on data from the Web of Science (Clarivate Analytics), covering the topic of digital ecosystems from 1975 to the present. The search query «digital ecosystem» and «industry» yielded 1,859 publications, with 33% falling into the following Web of Science categories: «Management» - 298 (16.05%), «Business» - 239 (12.87%), and «Economics» - 74 (3.98%). This distribution underscores the significant scholarly interest in business organization within the digital economy and highlights the relevance of studying effective management strategies for digital ecosystems in the industrial sector.

The most detailed results of the scientometric analysis are presented in the publication by Kulzhambekova B. Sh., Tashenova L. V., and Mamrayeva D. G., titled «Theoretical and practical approach to the essential characteristics and structure of digital ecosystems of industrial enterprises» (Kulzhambekova et al., 2023).

An analysis of the geographical distribution of publications revealed that the majority of research on this topic originates from five leading countries: the United States - 229 articles (12.33%),

China - 216 (11.69%), the United Kingdom - 187 (10.07%), Germany - 168 (9.05%), and Italy - 163 (8.78%). The highest number of publications occurred between 2019 and 2023, accounting for approximately 78% of all works, which indicates a rapid increase in academic interest in digital ecosystems and their impact on industry, driven by the development of new technologies, transformation of business strategies, and the implementation of innovations in this field.

In this study, the «Co-occurrence: Keywords» method was employed using the VOSviewer software to analyze data. This approach clusters keywords into thematic groups based on their frequency of co-occurrence (Figure 1). The analysis identified several clusters. For instance, the ***«Innovation»*** cluster (blue) encompasses research on innovation implementation strategies, competition analysis, and ecosystem interactions, highlighting the importance of business adaptation to dynamic market conditions.

The ***«Digital Transformation»*** cluster (purple) includes studies on Industry 4.0 implementation and the impact of platforms and ecosystems on business model transformation. The ***«Big Data»*** cluster (green) reflects the connection between key concepts in information technology (such as blockchain, IoT, cloud computing, digital twins, 5G, etc.) and industry, addressing issues of security, privacy, and ethics.

Another significant cluster, labeled ***«Ecosystem»*** (purple), examines the interaction of platform ecosystems with the educational system, media industry, and digital business, emphasizing their roles in learning, marketing, and value creation. The ***«Technology»*** cluster (brown) reflects the application of modern technologies in production processes, knowledge management, and the co-creation of innovative solutions.

It is noteworthy that international collaboration among scholars fosters the development of interdisciplinary research in the fields of digital technologies, management, and industrial economics. Such collaboration aids companies in adapting to digital transformation and effectively leveraging ecosystem advantages.

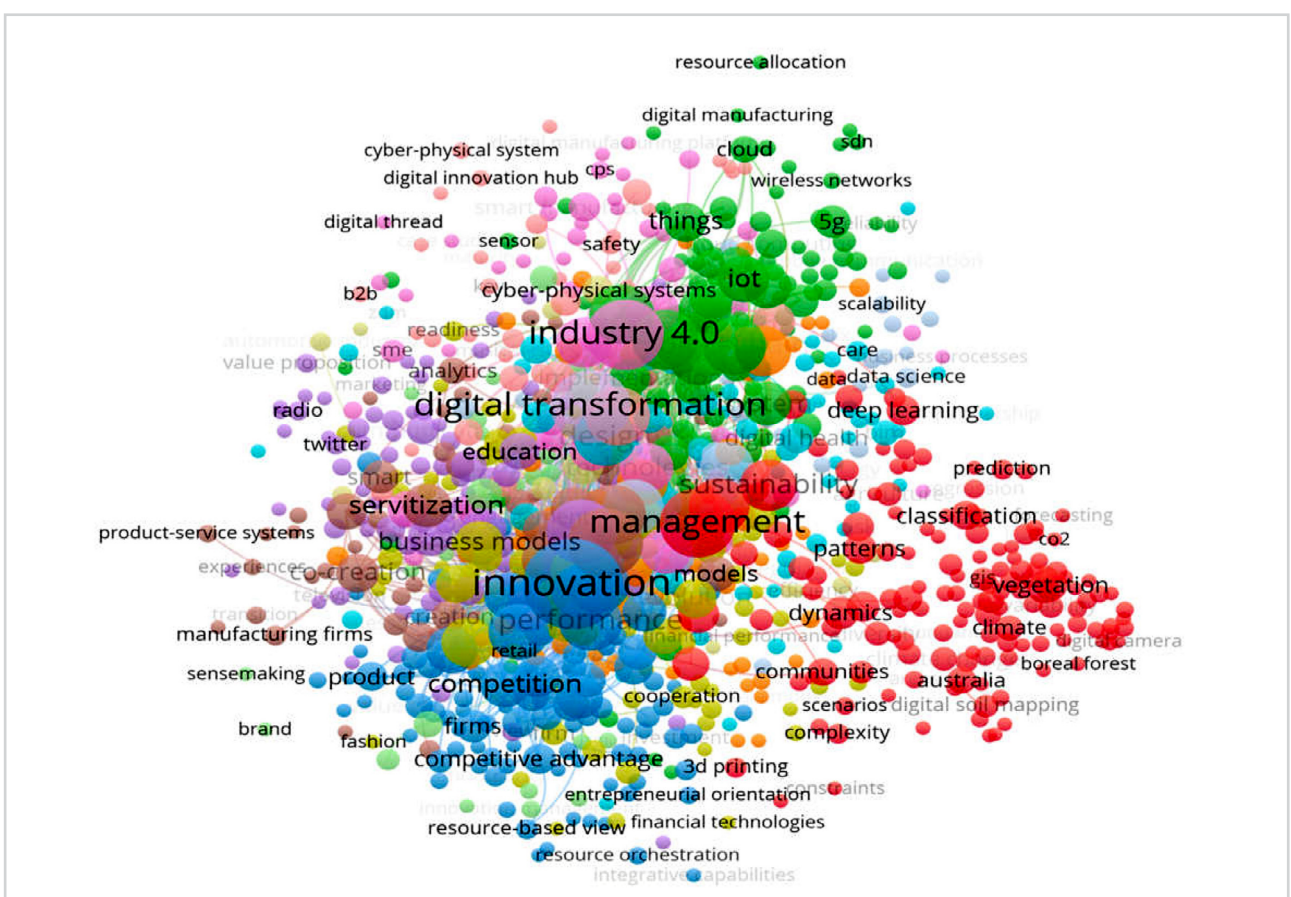

Figure 1:
Results of the scientometric analysis for the query ««digital ecosystem» and «industry»» based on the «Co-occurrence: Keywords» criterion
Source: Compiled by the authors

4.2. Implementation features of organizational-technological mechanisms by industrial enterprises: the experience of Kazakhstan (RQ2)

The presented OTMsoc is distinguished by a high degree of innovation, characterized by its adaptability, comprehensive approach, and scalability. A notable feature of this mechanism is its modular structure, which allows for the gradual implementation of solutions based on the enterprise's readiness and current needs. Its flexibility enables consideration of both internal enterprise characteristics and external environmental changes, including technological trends and market conditions. Furthermore, the mechanism integrates advanced digital tools such as digital twins, big data platforms, blockchain, and AI, providing not only process automation but also optimization through analytics and forecasting.

The feasibility of adapting OTMsoc in the activities of industrial enterprises is justified by its capacity to significantly enhance the speed and accuracy of decision-making, improve interactions with partners and clients, and ensure competitiveness in global markets through the rapid implementation of innovations. In the current context of digital transformation, this mechanism serves not only as a tool for increasing efficiency but also as a strategic solution for the sustainable development of enterprises.

Similar organizational-technological mechanisms are actively being implemented in the operations of industrial enterprises in Kazakhstan, demonstrating their effectiveness amid digital transformation (Table 1). For example, mining and metallurgical companies such as «Kazakhmys» and «Qarmet» have already adopted digital ecosystems to automate production processes, manage supply chains, and integrate with external information and communication resources.

Table 1:
Information on the implementation of organizational and technological mechanisms by manufacturing companies in Kazakhstan

Name of the company	Type of mechanism implemented and technologies used	Effectiveness of the mechanism
JSC «Qarmet»	Business process management system SAP ERP; electronic waybill for goods (EWG); Dow Jones online platform; project «Designed emergency warning system, positioning of personnel and mobile equipment with a mobile radio communication function»; QPartners procurement platform	Unification of all divisions of the company in a single information space; integration of EWG with the portal of the State Revenue Committee, simplification of the process of registration of necessary documents; verification of counterparties for reliability; minimization of sanctions and corruption risks; improvement of industrial safety and full automation of mining equipment worth 1.5 million US dollars; video monitoring of mining operations, automatic notification of gas concentration, and self-diagnosis of equipment.
LLC «Kazakhmys Holding»	Unified management platform of Kazakhmys Holding; Mining Production Management System and Digital Monitoring & Management System	Effective integration of all information systems to coordinate the business processes of Kazakhmys Holding LLP.
JSC «NAC «Kazatomprom»	Digital platform «eKAP»; digital twin of the geotechnological field of the mining complex «Mining and Geological Information system» at the enterprise of LLP «RU-6»; corporate SAP - ERP enterprise resource management system; ecosystem «Digital personnel»	The «eKAP» platform provides effective automation, integration and management of business processes of all Kazatomprom enterprises, increasing the efficiency and transparency of interaction; the digital twin optimizes mining processes, improving forecasting and resource management using an information system; the corporate SAP-ERP system and the «Digital Personnel» ecosystem increase business efficiency and staff well-being by optimizing processes and increased resource availability.
JSC «AK Altynalmas»	Digital mine for managing a gold extraction plant, including the SAP ERP system, 3DEXPERIENCE, MES, IoT, the technology of the intelligent solution «IntelliSense», the personnel task management system using EDP, the Mine Advisor platform with a database on mining and geological developments	Automation of business processes based on the SAP S/4HANA solution; optimization of operating costs by 15%, working capital by 5%, reduction of the number of routine operations by 20-30%; optimization of the operation of the company's mill No.1; forecasting possible overloads within 20 minutes for timely response, prevention or mitigation of overload; exclusion technological downtime associated with measuring the level of balls at the mill, where previously an average of 100 minutes per month was lost.
JSC «Shubarkol komir»	«Smart Quarry» – is an automated management system for mining and transportation complex; Modular system integrated with GIS and ERP system	Full transparency and control of all performance indicators of mining transport equipment; increasing the productivity of the dump truck fleet by 11% and the excavator fleet by 40%.
JSC «NK «Kazmunaygaz»	«Digital twins» at the Atyrau Oil Refinery Plant (AORP) and the Pavlodar Petrochemical Plant (PPChP)	The maintenance and repair management system at the AORP and PPChP plants allows enterprises to stop for repairs not every year, but every three years; an increase in the volume of processing by an average of 300 thousand tons per year at each of the enterprises; increased reliability of equipment; reduction of repair costs and inventory; reduction of the risk of emergencies and accidents; optimization of processes in the oil and gas sector: 30% increase in oil production from each well without additional capital investments.

Source: Compiled by the authors based on the companies' websites

Organizational-technological mechanisms enable industrial enterprises to enhance productivity, reduce costs, and improve product quality control. Consequently, implementing such mechanisms becomes a strategically important step for increasing the competitiveness of Kazakhstan's industrial companies in the global market.

This study proposes the author's definition of «OTMSoc» - as a system of interconnected components within a digital ecosystem, based on a set of applied tools, management principles and methods, and organizational and technological levers to regulate interactions with external information and communication resources and services, fostering fruitful collaboration between the subjects and objects of the digital ecosystem of industrial enterprises.

The primary objective of the developed OTMSoc is to facilitate seamless communication among all ecosystem participants by providing open access to innovative information and communication resources and services. Key tasks of OTMSoc include establishing new efficient and secure communication methods among ecosystem entities through unified data exchange standards, rapid real-time processing of large data volumes, developing a modern information infrastructure, and evaluating the mechanism's operational effectiveness.

The fundamental principles on the basis of which OTMSoc operates include the ***principle of compatibility*** of embedded digital services and ***adaptability*** to changing business conditions, the ***principle of scalability*** through the introduction of end-to-end technologies and the entry of the ecosystem into new markets, the ***principle of cooperation*** between ecosystem participants, the ***principle of quality control*** of external services and ICR and their compliance with the needs of the industrial company.

The ***organizational methods*** within OTMSoc address the management of interactions between subjects and objects in digital ecosystems, and ***information-technological methods*** are employed to coordinate data exchange processes and transform the technological workflows of industrial companies.

Figure 2 illustrates the OTMSoc framework developed by the authors, where the digital platform serves as the central core of the digital ecosystem; the levers of influence of the subjects of the mechanism (industrial organizations, government agencies, suppliers, scientific institutions) on the management object (data on production processes) included in its structure are considered, as well as the final result of its operation.

The ***technological*** levers within OTMSoc encompass cloud platforms, Open API interfaces, IIoT gateways, process automation and robotics systems, digital twins of products and processes, cybersecurity systems for the digital ecosystem and others.

The ***organizational*** levers of the mechanism can be categorized into two distinct groups: internal and external:

a) ***internal*** levers include standards for engaging with external ICT resources, established by the enterprise's management; policies for risk management, incident response, and user access rights to the system; initiatives to enhance personnel qualifications in the application of digital technologies, including the development of a digital corporate culture; designation of responsible teams within the company to manage interactions with external ICT partners and integrate external services into the digital ecosystems;
b) ***external*** ones are related to the legislative norms of the mechanism's functioning, its compliance with approved industry standards; the fulfillment of the terms of the agreement on the level of service for ecosystem entities, which specify the required service quality parameters, the obligations of the parties when using external ICT services; the application of industry recommendations for the implementation of external services and ICR; quality assessment systems for services provided; the conclusion of partnership agreements with educational, scientific research organizations for the implementation of jointly developed innovative technological solutions.

The ***«Resource Provision»*** component of the OTMSoc mechanism focuses on supplying the necessary resources to achieve its established objectives and is divided into two primary areas: the ***development of information infrastructure*** and the ***assurance of cybersecurity*** within the enterprise's operations.

To advance the information infrastructure of an industrial enterprise, it is necessary to modernize network systems; create data processing centers (DPCs) for storing, processing and protecting enterprise data; upgrade hardware assets (servers, workstations, network equipment), allowing the implementation of IoT devices for monitoring production processes, digital factories and digital twins in production processes and etc.

To ensure cybersecurity within an industrial enterprise, it is essential to fulfil a comprehensive set of measures aimed at protecting data, equipment, and systems from cyberattacks, unauthorized access, and other threats by implementing modern encryption and protection systems against unauthorized access; user access control through multifactor authentication and user rights control; threat monitoring using SIEM-systems to analyze security events in real time.

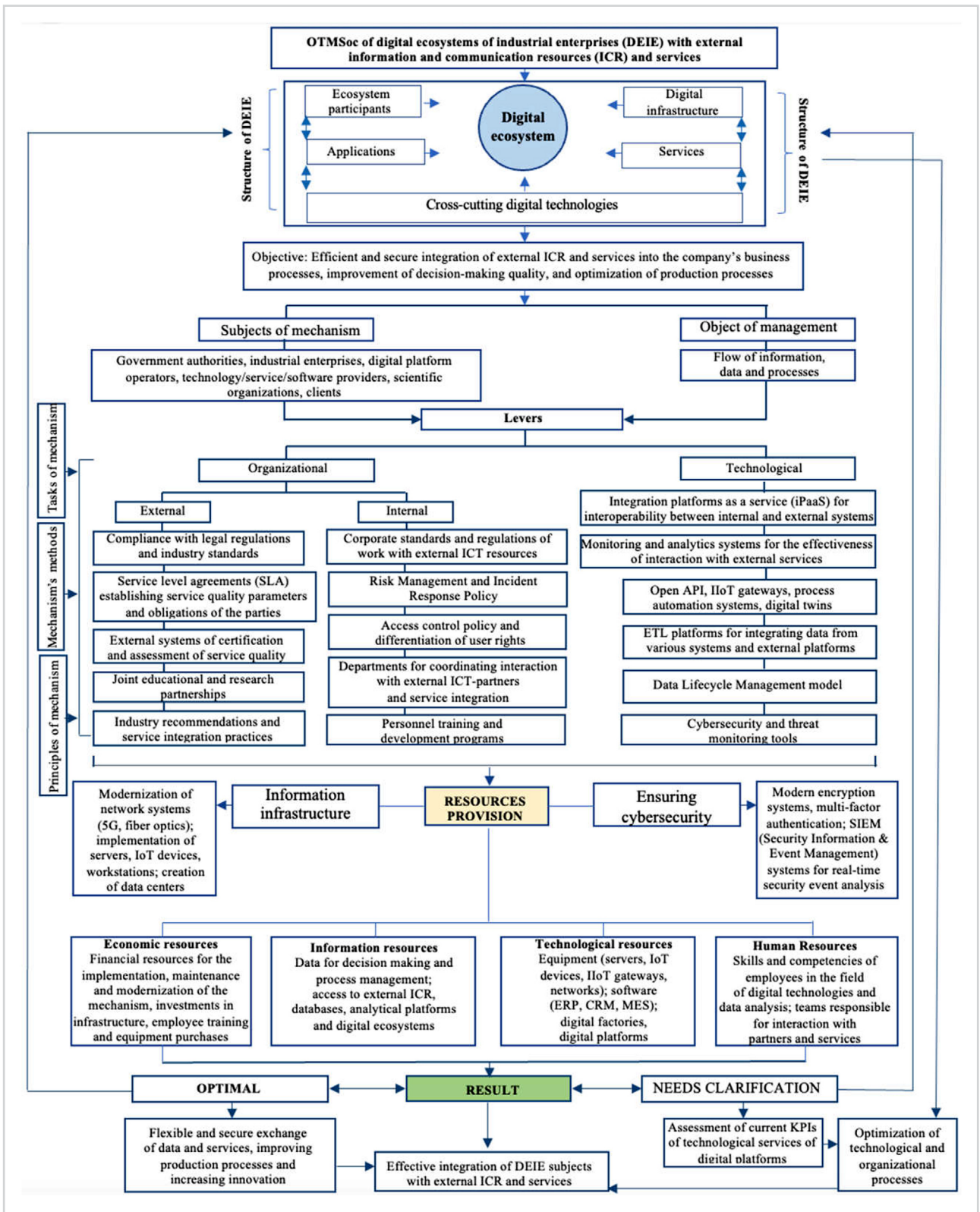

Figure 2:
OTMsoc with external ICT and services
Source: Compiled by the authors

The «Resource Provision» block is divided into four key resources: economic resources, informational resources, technological resources, and human resources, providing a comprehensive approach to the implementation of OTMsoc and including the key aspects necessary for its successful implementation.

Achieving an ***optimal/rational result*** indicates the effective operation of the organizational and technological mechanism, as well as the efficient application of levers that facilitate the ecosystem's goals, which include optimizing production processes, reducing the development time for the latest innovative products and services, and capturing segments of the international market through the adoption of advanced technologies, external information resources and services.

When ***results require clarification*** or modification, it is advisable for management to analyze key performance indicators of technological services to assess the productivity parameters of connected ICT resources (for example, the percentage of software, digital equipment, the latest technologies put into operation; data flow speed, communication channel stability; financial savings resulting from the adoption of digital technologies and others). Subsequently, management should develop a ***comprehensive set of measures to enhance the performance*** of the organizational and technological mechanism, aiming to achieve optimal results in the future.

It should be noted that the influence of factors such as the external and internal environment of the OTMsoc imposes certain restrictions on the process of its functioning (Figure 3).

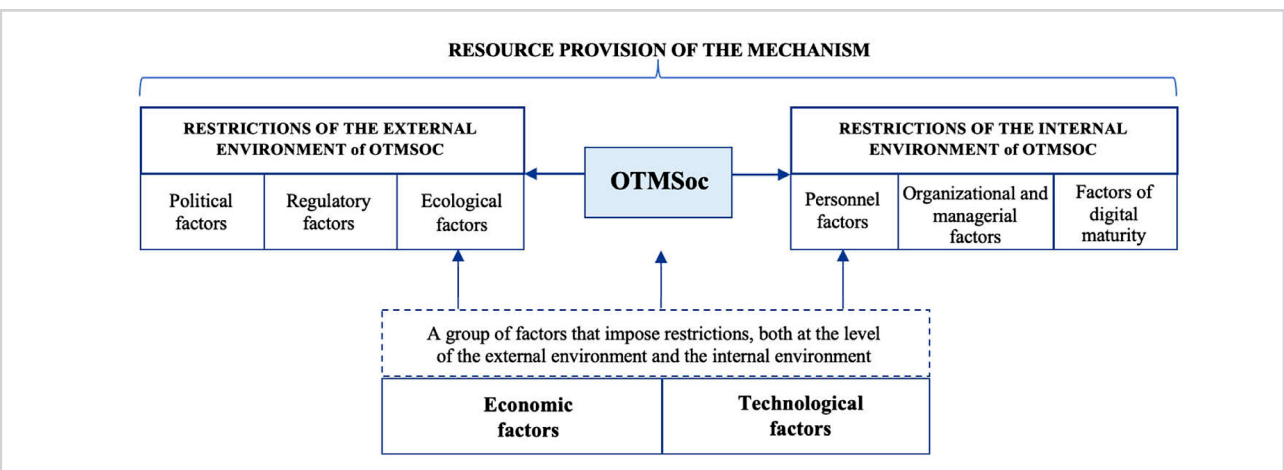

Figure 3:
Restrictions regarding the functioning of OTMsoc
Source: Compiled by the authors

The restrictions of the OTMSoc external environment include:

a) ***political factors:***
- unpredictable changes in the political environment can create uncertainty for long-term planning of companies' activities;
- international sanctions that restrict the use of certain technologies or interaction with foreign ICR;

b) ***regulatory factors:***
- legal restrictions/regulations on data protection, technology licensing or security standards may complicate interaction with external resources and services;
- taxation and trade barriers in the form of restrictions on the import of hardware and software can increase the costs of enterprises;

c) ***environmental factors:***
- energy restrictions when using energy-intensive equipment in regions with unstable energy supply;
- requirements for sustainable development, the introduction of technologies that meet environmental standards, can increase the costs and time of implementation of the mechanism.

The restrictions of the OTMSoc ***internal environment*** are represented by the following factors:

a) ***personnel factors:***
- lack of knowledge and skills in the field of digital technologies;
- resistance to change, fear of losing jobs or increasing workload;
- lack of incentive factors to involve staff in the digitalization process of the enterprise;

b) ***organizational and managerial factors:***
- the hierarchical complexity of the management structure makes it difficult to make decisions and implement changes;
- poor coordination between departments such as IT, production and marketing can slow down the integration of the mechanism.;
- the lack of responsible persons for the implementation and support of the mechanism reduces the effectiveness of its functioning;

c) ***factors of digital maturity of the enterprise:***
- weak integration of internal information systems (for example, ERP, CRM) can make it difficult to interact with external ICR;
- low level of process automation, in which a significant proportion of manual work or outdated production processes limit the possibilities of using digital ecosystems;
- lack of data, its fragmentation reduces the efficiency of the mechanism.

We will also consider in detail the factors that impose restrictions on the OTMSoc functioning process both in the internal and external environment:

a) ***economic factors:***
- financial constraints in the form of budget shortfalls for infrastructure modernization, staff training, maintenance of qualified specialists, introduction of new technologies, connection to ICR or payment for services from external suppliers;
- high operating costs for maintenance of equipment, software and infrastructure, and energy consumption during the introduction of energy-intensive technologies;
- economic instability, inflation, crises, currency fluctuations increase the cost of equipment and technologies;
- a long payback period for investments when implementing the mechanism;
- low level of economic return from implemented digital solutions due to imperfect integration or poor optimization of processes;
- limited financial capacity for long-term investments in digital transformation;

b) technological factors:
- insufficient level of digital infrastructure development, insufficient availability of high-speed Internet, servers or cloud technologies in the region may slow down the integration of external ICR;
- incompatibility of external platforms and tools with internal enterprise systems makes it difficult to integrate them;
- lack of automated processes in key areas such as production management, logistics and customer service;
- prompt hardware and software updates require significant financial and time resources;
- limitations in the scalability of technologies used in the ecosystem, with an increase in data volume or the involvement of new participants.

The aforementioned constraints may also arise from the need for a balanced allocation of resources to support both the enterprise's current operations and the development of its digital ecosystem, which underscores the importance of a strategic approach to managing the mechanism, taking into account external challenges and internal capabilities. Therefore, for the mechanism to function successfully, enterprise management should conduct regular environmental monitoring to respond promptly to changes and minimize the impact of limiting factors.

The developed OTMSoc was proposed for adaptation into the operations of LLP «Böhmer Armatura», a leading company in Kazakhstan and abroad, specializing in the production of ball shut-off valves ranging from 15 to 1,400 mm in diameter, used in the oil and gas industries, as well as in heating and water supply systems, with a design capacity of 10,000 ball valves per year.

The Karaganda plant LLP «Böhmer Armatura» demonstrates a high level of technological readiness for the implementation and adaptation of digital ecosystems. According to the Harrington scale, this level corresponds to a range from 0.8 to 1.00, indicating the presence of necessary resources, modern equipment and software, a formed team of specialists, and experience for the successful realization of digital projects.

The implementation of the developed OTMsoc will allow LLP «Boehmer Armatura» to significantly increase the level of digitalization and connectivity between the company's departments by 20% through the integration of external ICR and services, and provide the company with short-term benefits in the form of a 15% reduction in operating costs through automation and optimization of processes that reduce time for routine tasks by 25%. The long-term benefits include the benefits associated with the growth of the company's innovation potential through the integration of innovative solutions such as digital twins, cloud platforms and IoT, which can modernize production processes and increase the economic efficiency of the enterprise, as well as improve investment attractiveness through transparency and reliability of business processes.

The main practical steps of adapting and implementing OTMsoc in the activities of industrial enterprises are presented in the form of a conceptual scheme in Figure 4.

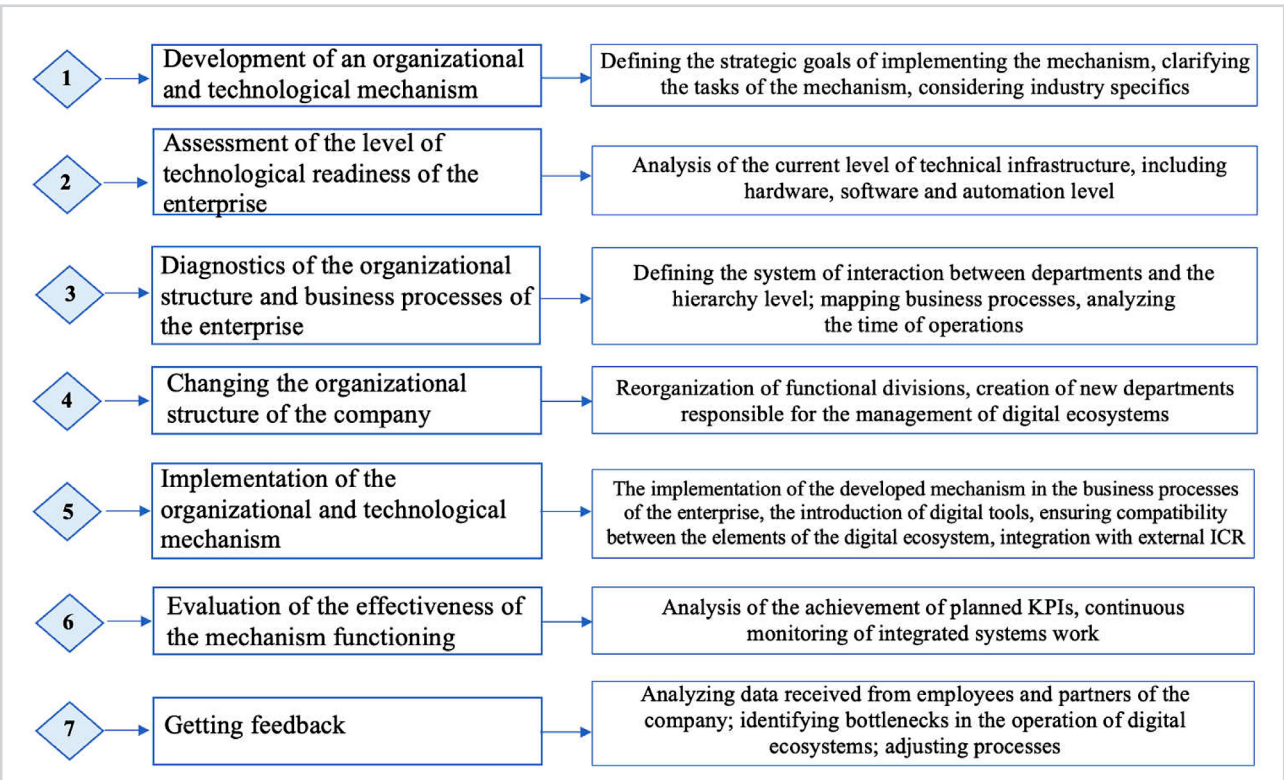

Figure 4:
Algorithm for adapting and implementing OTMSoc at the enterprise
Source: Compiled by the authors

The presented algorithm for adapting and implementing OTMSoc into enterprise operations is universal and can be adjusted to the specifics of any industrial enterprise, ensuring a smooth transition to a digital ecosystem and enhancing the efficiency of business processes.

It's important to note that modern digital ecosystems are in a constant state of evolution and with the emergence of new technologies, they gain access to innovative tools and methods that strengthen existing interaction models and increase their effectiveness (Figure 5).

New digital tools and methods include: artificial intelligence tools, virtual and augmented reality systems, hybrid cloud technologies, as well as a method of adaptive interaction based on artificial intelligence, a method of «smart contracts» based on blockchain, a method of managing interactions based on digital twins, a method of dynamic ecosystem tuning.

The introduction of these digital tools and methods will increase the speed and accuracy of decision-making, increase the efficiency of interaction between ecosystem participants, increase transparency of operations and improve process control, optimize resource use and reduce costs.

Thus, the effective integration of external ICR and services into the digital ecosystem, ensured by the well-coordinated work of the organizational and technological mechanism that creates the necessary connectivity, is important for the formation of competitive advantages of an industrial enterprise in regional, domestic and foreign markets.

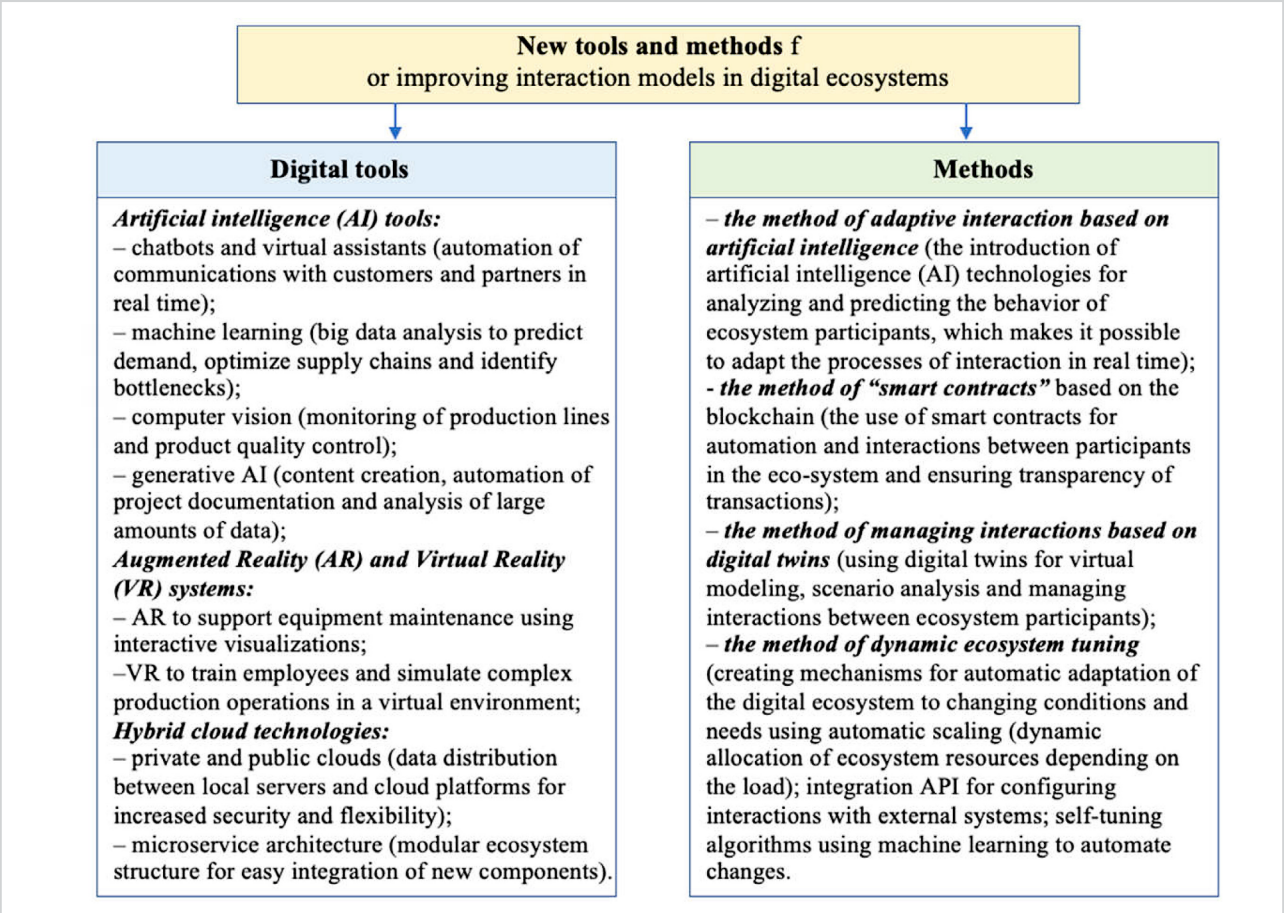

Figure 5:
New tools and methods used in digital ecosystems
Source: Compiled by the authors

5. Discussions

In-depth analysis of the current digital transformation processes within industrial enterprises highlights the importance of considering all participants involved in digital ecosystems, their perceptions of digital technologies, and their crucial roles in the transformation process. This indicates that the successful implementation of technologies such as IIoT, Big Data, AI, robotics, and automation of production processes requires not only technological adaptation but also active employee engagement and alignment of new technologies with organizational goals.

Therefore, successful digital transformation of enterprises requires not only the implementation of technologies but also a shift in corporate culture that fosters data-driven practices and a reevaluation of technological approaches. Organizations should clearly define their data usage objectives and adhere to ethical standards to effectively utilize technologies and protect confidentiality.

6. Conclusion

The organizational and technological mechanism developed by the authors, based on the active implementation and adaptation of the latest information and communication resources (ICR) and services, primarily enables industrial enterprises to improve production process indicators, enhance end-user satisfaction with products and services, and achieve strategic development goals of industrial enterprise.

As a result of the research conducted by the authors, the author's concept of the organizational and technological mechanism of communication of subjects and objects of digital ecosystems of industrial enterprises - OTMsoc with external information and communication resources and services was proposed, its conceptual structure was presented, examples of practical implementation of the organizational and technological mechanism in the activities of industrial enterprises of the Republic of Kazakhstan were considered.

A scientometric analysis of publications provided insights into current and prospective scientific directions in the field of digital ecosystems and digital transformation within the context of Industry 4.0, and identified leading countries and research organizations addressing these issues.

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