ЕКОНОМІКА ПРОМИСЛОВОСТІ
ECONOMY OF INDUSTRY

http://doi.org/10.15407/econindustry2025.04.013
УДК 338.262:338.45:004.8:621.38+621.39
JEL: L52, O25, L63, Q55

Vitaliy A. OMELYANENKO, Doctor of Economic Sciences, Senior Researcher, Professor
https://orcid.org/0000-0003-0713-1444
E-mail: omvitaliy@gmail.com

Institute of Industrial Economics of NAS of Ukraine
2 Maria Kapnist Street, Kyiv, 03057, Ukraine

SECTORAL ASPECT OF INDUSTRIAL POLICY IN INDUSTRY 4.0 AND 5.0 CONDITIONS (CASE OF INSTRUMENTATION ENGINEERING INDUSTRY)

The article is devoted to the consideration of the features and global trends of the development of the instrumentation engineering industry and the main ideas for industrial policy for its development in the context of the transition to Industry 4.0 and 5.0. The basic global models of the development and projects in instrumentation engineering industry are determined. Recommendations for industrial policy in the field of instrumentation engineering industry in Ukraine are formulated.

Keywords: *instrumentation engineering industry, Industry 4.0 and 5.0, projects, industrial policy.*

The complexity of the innovation & technological systems of Industry 4.0 and 5.0 lies in their multidimensionality, integration of physical and digital environments, interaction between artificial intelligence, Internet of Things, robotic complexes and cyber-physical systems. They form a new type of production, where data becomes the main resource. At the same time, the speed of their processing and transformation into management solutions determines the competitiveness of enterprises and entire sectors (Manyika et al., 2017). The transition to Industry 5.0 is complicated by additional dimensions — human orientation, sustainability and harmonization of technological solutions with social and environmental needs. This creates a challenge for traditional industries, which must simultaneously ensure modernization and remain sensitive to public expectations and global trends of sustainable development.

The relevance of industrial policy for adapting traditional technological sectors to the conditions of Industry 4.0 and 5.0 is particularly evident in the field of instrumentation engineering industry. This sector has always been a key link between fundamental science, production and practice implementation of innovations. The transformation of the world economy under the influence of digitalization, automation and global challenges requires coordinated decisions from the state and business to ensure technological renewal and increase the competitiveness of the industry. Instrumentation industry is a basic sector that determines the possibilities for modernization of other industries. Control, measurement, monitoring and

Цитування: Omelyanenko V. A. Sectoral aspect of industrial policy in Industry 4.0 and 5.0 conditions (case of instrumentation engineering industry). *Ekon. promisl.* 2025. № 4 (112). P. 13—30. http://doi.org/10.15407/econindustry.2025.04.013

automation of processes are impossible without modern high-precision instruments and integrated systems. In the context of the transition to Industry 4.0, it appears not only as a tool for improving production, but also as a driver for the development of new technological structures (Prokopenko et al., 2025). The problem is that most traditional production systems were formed in previous technological eras. They are often characterized by an outdated material and technical base, limited use of digital solutions and low level of integration with global innovation chains.

Literature review

The transformation of industrial policy in 4.0 and 5.0 context has increasingly emphasized sectoral approaches that integrate technological innovation, digital infrastructure and institutional modernization. Within this framework, the instrumentation engineering industry occupies a pivotal position — it provides the essential technological base for automation, analytics and smart manufacturing systems. Research of industrial policy evolution demonstrates that states are moving from traditional industrial protectionism toward fostering complex innovation ecosystems that link industry, academia and digital tools (Juhász et al., 2024; Hamilton-Hart & Yeung, 2021). The role of government thus extends to shaping data platforms, supporting industrial clustering and ensuring technological sovereignty, particularly in strategic high-tech sectors like instrumentation and control engineering (Hsu, 2024; Hu & Zheng, 2021).

The instrumentation engineering industry is undergoing rapid technological convergence driven by the integration of artificial intelligence, cyber-physical systems and IoT-based solutions, transforming it into a central enabler of the new industrial paradigm (Asif et al., 2023; Zhu et al., 2020). Industry research indicates growing investment in AI-enhanced instruments, remote diagnostics and predictive maintenance, signaling the transition to fully digitalized manufacturing environments (Kyle & McVoy, 2024; Singh, 2025). As a result, industrial policy must increasingly address the dual challenge of supporting technological innovation within the instrumentation industry while ensuring that its outcomes drive modernization across other industrial sectors (Prokopenko et al., 2025).

From a regional and institutional perspective, the evolution of smart specialization policies demonstrates the importance of adaptive governance and targeted industrial support mechanisms (Pidorycheva & Bash, 2024; Zaloznova & Chekina, 2025). In countries like Ukraine, policy emphasis is shifting toward fostering digital clusters and sectoral innovation platforms to accelerate Industry 4.0 adoption and prepare for the human-centered features of Industry 5.0 (Vyshnevskyi et al., 2024). The experience of East Asian economies further illustrates how state-led coordination can effectively integrate digital transformation within industrial structures. Thus, sustainable growth in instrumentation engineering depends on aligning industrial policy with technological foresight, human capital development and cross-sectoral collaboration, positioning the sector as both a driver and beneficiary of smart industrial transformation.

Instrumentation engineering industry in many countries faces a double challenge. On the one hand, there is a need to update existing production capacities and technologies. On the other hand, there is a need to create an environment for the development of smart solutions, artificial intelligence, cyber-physical systems and Industry 5.0 technologies, which are focused not only on efficiency, but also on people, sustainability and environmental friendliness (Vyshnevskyi et al, 2024). Without a clear and consistent industrial policy, these challenges remain unresolved, which threatens the loss of scientific and technical potential, lagging behind in the development of technological systems and a decrease in international competitiveness.

Based on the conducted review of research, it can be determined that there is a lack of consideration of sectoral aspects of industrial policy under the conditions of Industry 4.0 and 5.0, particularly in relation to the instrumentation engineering industry. While numerous studies explore technological trends, digital transformation and innovation ecosystems, relatively few researches address how industrial policy specifically targets (or adapts) to the needs of this sector. This gap suggests that current policy frameworks often remain too generalized, overlooking the distinct technological, organizational and institutional dynamics, that characterize instrumentation engineering as a strategic enabler of smart industrial development. Thus, the formation of a modern industrial policy in the field of instrumentation engineering industry is a necessary prerequisite not only for the preservation of the industry, but also for creating a economic, institutional and technological foundations for the integration of traditional technological sectors into a new industrial paradigm.

Therefore, the objective of this research is to conduct a descriptive analysis and comparison of the models of instrumentation engineering industry development in leading countries (the USA, the EU, Japan and China) within the framework of industrial policy under Industry 4.0 and 5.0, to identify approaches relevant for Ukraine.

Instrumentation engineering industry trends analytics

Instrumentation engineering industry is a sector of mechanical engineering that produces means of measurement, analysis, processing and presentation of information, control devices, automatic and automated control systems (Dobrovska, Ovsienko, 2018).

The key task of modern instrumentation engineering industry is to create high-tech sensors, controllers, actuators and integrated systems capable of operating as part of a single digital environment of the city. The basis of such systems is the concept of the Internet of Things (IoT), which involves the interconnection of a large number of devices capable of collecting, transmitting and processing data in real time.

Based on this role of instrument making, it is advisable to use the industrial ecosystem approach for its analysis. The use of this approach is important for the development of the instrument making industry, since this area is characterized by high technological complexity, the need to integrate various scientific, production and digital components. Instrument making cannot function effectively in isolation. The development of the industry depends on close interaction with mechanical engineering, electronics, materials science, software engineering and energy. It is the ecosystem approach that allows you to combine these areas into a single innovative space in which common standards are formed, knowledge is exchanged, joint technological solutions and production chains with high added value are created. Such interconnection ensures the flexibility of the industry accelerates the introduction of new technologies and helps to increase the global competitiveness of products. In addition, the industrial ecosystem model makes it possible to respond more effectively to the challenges of digital transformation, develop cooperation between science and business, and support a continuous cycle of innovation, and accordingly develop an effective industrial policy.

Instrumentation engineering industry is undergoing a profound transformation driven by the convergence of digital technologies, automation and global industrial trends. The integration of smart sensors, artificial intelligence and IoT solutions has shifted the discipline from traditional measurement and control functions to being a critical enabler of Industry 4.0 and 5.0. Understanding these trends is essential for both academia and industry as they reveal not only the current state of innovation but also the challenges and opportunities for future development. Table 1 provides a structured overview of the key trends in modern instrumentation engineering industry, their implications and illustrative examples.

Technological innovation is a key driver of the development of global instrumentation engineering industry in the era of Industry 4.0 and the gradual transition to Industry 5.0. Advances in chromatography, mass spectrometry, spectroscopy and nuclear magnetic resonance have not only increased the accuracy, sensitivity and efficiency of analytical instruments, but also created opportunities for their inclusion in complex cyber-physical systems. This allows the integration of instruments into production and research processes, where digital twins reproduce the behavior of objects and systems in a virtual environment, providing real-time prediction, optimization and control (Market Research Future, 2025).

The combination of classical analytical methods with digital technologies of Industry 4.0 (artificial intelligence, machine learning, Internet of Things) has revolutionized the operation of instruments, giving them the ability to autonomous data processing, intelligent monitoring and predictive maintenance. As a result, it is possible to minimize the risks of human error, increase productivity and facilitate the emergence of flexible production and research platforms. Industry 5.0 paradigm emphasizes the collaboration of humans and artificial intelligence, which allows for personalized analytical solutions, focusing on safety, sustainability and social responsibility.

In addition, the trend towards miniaturization and the creation of portable devices increases the mobility of analytics, making it available in the field from remote medical centers to environmental monitoring and food safety control. Combined with digital twins, such devices become elements of "smart" ecosystems, where physical measurements are immediately integrated into virtual models to support decision-making.

Thus, the development of instrumentation engineering industry in the context of Industry 4.0—5.0 goes beyond the traditional increase in accuracy and efficiency, forming a new logic, where analytical systems are an integral part of the cyber-physical space, ensuring sustainable, human-centric and technologically flexible development.

Modern instrumentation engineering industry is no longer limited to traditional measurement and control tasks but has evolved into a multidimensional field that integrates digital technologies, including artificial intelligence and sustainability principles.

The identified technological directions (table 1) show a strong shift toward interconnected, intelligent and adaptive systems capable of supporting complex industrial, medical and environmental applications. At the same time, new challenges emerge, such as cybersecurity risks, ethical considerations of AI and the need for interdisciplinary expertise. The ability to address these challenges while leveraging advanced technologies will define the next generation of instrumentation and its role in shaping Industry 4.0 and the green transition.

According to experts of Grand View Research (2025) the global analytical instrumentation market size was estimated at USD 55,00 billion in 2024 and is anticipated to reach USD 90,48 billion by 2033, growing at a CAGR of 5,79 % from 2025 to 2033 (fig. 1). Among the underlying reasons for the market expansion, experts consider increasing demands for precise quality assurance, continuous innovation in research and development, stricter regulatory standards and wider use in sectors such as pharmaceuticals, environmental monitoring, food safety and chemical industries.

According to Straits Research "the global instrumentation services market was valued at USD 33,46 billion in 2023. It is estimated to reach USD 57,05 billion by 2032, growing at a CAGR of 6,1 % during the forecast period (2024—2032). The world is witnessing rapid automation in every sector and the industrial sector is no exception. The adoption of automation in the industrial sector aids in enhancing efficiency, productivity and quality control. Thus, the surging adoption of industrial automation is anticipated to drive the global market. Moreover, in recent times, key market players in the instrumentation services industry are taking up several strategic initiatives to enhance their market share, thereby creating opportunities for market growth" (Straits Research, 2023).

Instrumentation services include the installation, calibration, maintenance and repair of a variety of devices used to measure, control and monitor industrial processes. These services ensure the accurate and reliable operation of sensors, meters, gauges and controllers, which contributes to the efficiency, safety and quality of production operations. Instrumentation specialists have knowledge in the fields of electronics, mechanics and measurement technology and are responsible for performing these tasks in various industrial sectors, including manufacturing, oil and gas, pharmaceuticals and utilities. Regular inspections, troubleshooting and fine-tuning help avoid equipment failures, optimize production processes and comply with regulatory requirements. As a result, these services are crucial for increasing productivity, reducing downtime and maintaining the stability of industrial ecosystems.

The active implementation of automation in various industrial sectors is stimulating the global demand for services for the maintenance and calibration of measuring instruments. Such services are becoming key for the installation and support of automated systems, as companies strive to increase productivity, reduce personnel costs and improve production efficiency. With the increasing complexity of production processes and the increasing requirements for the accuracy of control instruments, the need for professional service of measuring instruments is becoming increasingly relevant. In addition, the development of industrial sectors (manufacturing, pharmaceuticals, oil and automotive industries) is accelerating the implementation of automation to optimize processes and maintain consistent product quality. This, in turn, stimulates the demand for specialized services for the installation, calibration and maintenance of complex automated equipment.

The market for instrumentation services is characterized by significant barriers due to high initial investments. The costs of modern equipment, technology and qualified personnel make the creation of a comprehensive infrastructure an expensive and difficult task. Such capital-intensive nature limits market access for startups and small businesses, reducing their ability to compete effectively and expand their activities.

In the context of state industrial policy, high initial costs become an important point of intervention: the state can stimulate the development of the sector through grants, preferential loans and modernization programs that support both new and existing market players. The need for constant technological renewal emphasizes the need for long-term state strategies to support innovation and reduce the risks associated with capital investments.

Market players actively use mergers, acquisitions and partnerships to strengthen their positions. For example, Allied Valve acquired Great Lakes Process Controls in 2022 to expand its presence and technological expertise in the Midwest. Similarly, Gemspring Capital Management acquired a controlling

Table 1. **Key technological directions in the instrumentation engineering industry**

Technological direction [1]	Description	Implications	Illustrative examples
Smart sensors and IoT integration	Development of interconnected sensors capable of wireless communication and real-time data sharing	Enables predictive analytics, process optimization and remote monitoring	Industrial IoT platforms, wireless temperature/pressure sensors, connected medical devices
Artificial intelligence and machine learning	Application of AI/ML for data analysis, pattern recognition and predictive maintenance	Enhances decision-making, reduces downtime, improves system efficiency	AI-based fault detection in manufacturing, ML-driven process control
Digital twins	Creation of virtual replicas of physical systems for real-time monitoring and simulation	Improves system design, testing, predictive maintenance and risk management	Digital twin of chemical plants, energy grids, or aerospace systems
Miniaturization and MEMS technology	Use of microelectromechanical systems for compact, precise instruments	Expands applications in healthcare, wearables and portable devices	MEMS accelerometers, gyroscopes, lab-on-a-chip sensors
Advanced materials in sensors	Use of nanomaterials, composites and flexible substrates for higher sensitivity and durability	Improves sensor accuracy, lowers energy consumption, enables wearable instrumentation	Graphene-based biosensors, flexible strain gauges
Cybersecurity in instrumentation	Protection of data integrity and control systems against cyber threats.	Ensures reliability and safety of critical infrastructure.	Secure industrial control systems, encryption for wireless instrumentation.
Sustainability	Designing instruments that support renewable energy, emissions monitoring and energy efficiency	Facilitates environmental monitoring and compliance with climate policies	Smart grids, emission detection sensors, energy-efficient industrial instruments
Edge computing in instrumentation	Processing data at the source of generation rather than in centralized systems	Reduces latency, increases efficiency, supports real-time applications	Edge-enabled vibration monitoring in turbines, local AI inference in IoT devices
Human-machine interfaces (HMI) and augmented reality	Advanced visualization and interaction tools for operators	Enhances training, decision-making and safety in complex environments	AR glasses for maintenance, digital dashboards in industrial plants
Integration of instrumentation with biotechnology	Development of medical and biological measurement systems	Expands diagnostic capabilities and personalized medicine	Wearable health monitors, biosensors for early disease detection

[1] The technological direction reflects the specific trajectory of the technological development of the industry and embodies the applied solutions, technologies and products that implement these changes in practice.
Source: compiled by author based on Maus (2025); General Instruments Consortium (2024); Wang & Zhang (2017); Zhu et al (2020); Singh (2025); Asif et al (2023); Kyle & McVoy (2024); Narayanan & Schuetz (2014); Lai & Zhao (2025).

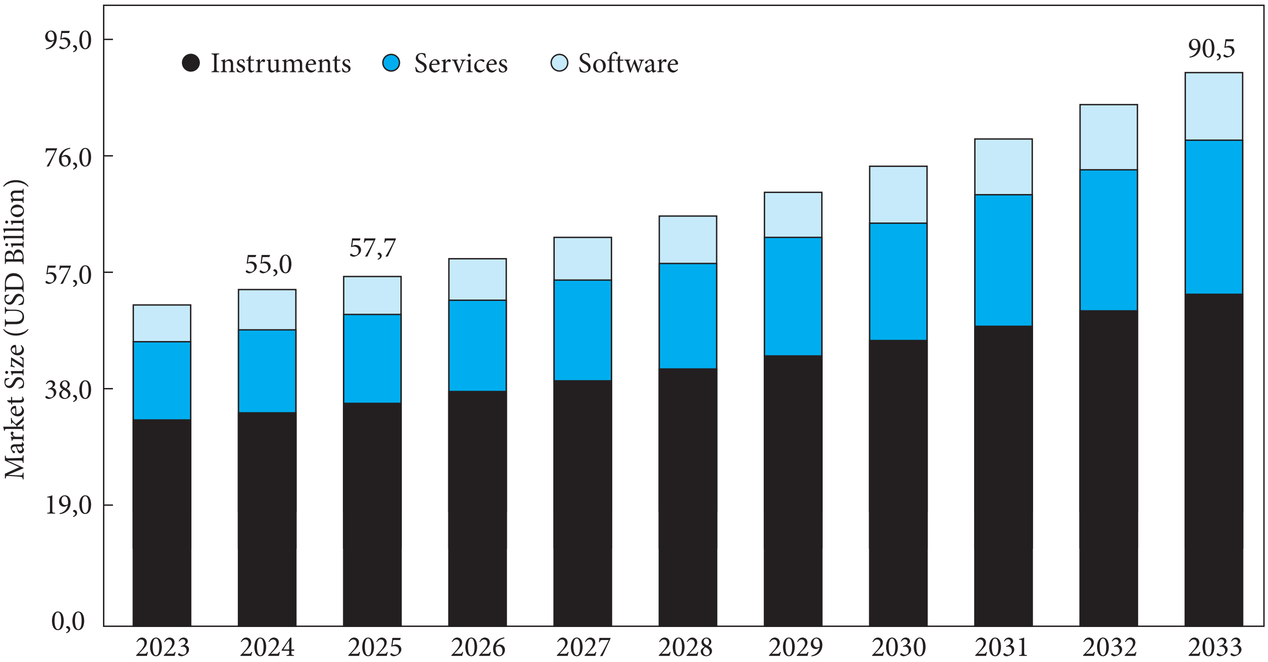

Fig. 1. Analytical instrumentation market, by product, 2023—2033
Source: Grand View Research, 2025.

interest in JTI Electrical & Instrumentation, which enables the design and installation of complex electrical and mechanical systems, improving the efficiency of industrial processes (Straits Research, 2023). Such initiatives create additional opportunities for market growth, which can be supported by government industrial policy programs.

The global instrumentation services market can be structured by service type, technology, application and end-user industries.

By service type, calibration, diagnostics and repair, testing and commissioning, training and consulting services and maintenance are distinguished. The largest market share is occupied by the calibration services segment, which ensures the accuracy and reliability of equipment in manufacturing, healthcare, environmental monitoring etc. Calibration involves comparing the performance of an instrument with a known standard to identify and correct deviations, which is critical for quality, safety and regulatory compliance. Government policies can stimulate the development of this segment through grants and subsidies, supporting equipment modernization and increasing accuracy standards.

By technology, the market includes distributed control systems (DCS), SCADA systems, programmable logic controllers (PLC), MES and other solutions. PLCs are industrial computers that automate electromechanical processes, integrate with sensors and actuators, providing reliable real-time control. Government initiatives can support the training of PLC engineers and the implementation of modern automation systems in enterprises, increasing national industrial competitiveness.

By application, instrumentation services are used for control, monitoring, testing, safety and other tasks. They ensure the accuracy of production processes, help prevent equipment failures, optimize operations and reduce risks. In the context of industrial policy, the government can introduce standards and certification programs that stimulate enterprises to use modern monitoring systems and improve efficiency.

By end-user industries, the market covers oil and gas, chemicals, energy, pharmaceuticals, food industry, water supply, automotive and others. The role of services is particularly important in the food and beverage industry, where accurate measurements of temperature, pressure, pH, humidity and flow rate ensure quality, safety and regulatory compliance. Public policy can stimulate the implementation of such solutions by ensuring standards control and supporting innovative technologies in critical industries.

The global instrumentation services market plays a critical role in industrial automation, process control and quality assurance across diverse sectors. Understanding these segments is essential for designing effective national industrial policies that encourage innovation, ensure high standards of safety and quality and enhance industrial competitiveness. In the table 2 we have summarized the key segments, their roles and the opportunities for policy support.

Instrumentation services are indispensable for maintaining the accuracy, safety and efficiency of industrial processes. National industrial policies play a pivotal role in supporting the modernization of these services, facilitating workforce training and encouraging the adoption of advanced automation technologies. By strategically promoting investments in calibration, monitoring and process control, governments can enhance general industrial competitiveness, optimize operational efficiency and strengthen compliance with regulatory standards across key sectors.

Based on the analysis of the features of the development of industry technologies and current trends table 3 was formed.

Models of instrumentation engineering industry development through the prism of industrial policy and Industry 4.0—5.0

The development of instrumentation engineering industry is determined not only by technological innovations, but also by the specifics of national industrial policies. Each country forms its own model, which combines the strategic priorities of the state, the role of private business, scientific schools and international integration (Hsu, 2024; Lane, 2009).

In the context of Industry 4.0 and 5.0, instrument making acquires special importance, since it is it that provides sensor systems, automation, cyber-physical complexes and tools for human-technology interaction.

This allows us to distinguish several basic types of policies that determine the trajectory of the instrumentation engineering industry development:

1. American model (policy of technological leadership and market commercialization).

The USA implements an industrial policy focused on supporting high-tech sectors and global competitiveness in the era of Industry 4.0. Instrumentation is integrated into strategic areas — aviation, space technology, defense, biomedicine and IT, where innovation is considered as a basic tool for the transition to Industry 5.0, which emphasizes human-scale technologies and ethical use of AI. The main emphasis is on the market commercialization of innovations, which is supported by venture capital and partnerships of corporations (General Electric, Honeywell, Texas Instruments) with universities and public laboratories. American policy builds technological lea-

Table 2. **Instrumentation services market overview (policy perspective)**

Dimension	Segments / technologies	Role	Policy implications
Service type	Calibration, diagnostics & repair, testing & commissioning, training, consultancy, maintenance	Ensures accuracy, reliability and compliance of instruments across manufacturing, healthcare and environmental monitoring	Government grants, subsidies and modernization programs can promote adoption and standardization
Technology	Distributed control systems (DCS), SCADA, programmable logic controllers (PLC), manufacturing execution systems (MES)	PLCs and other systems automate electromechanical processes, monitor inputs/outputs, integrate with sensors and enable precise real-time control	Industrial policy can support training, certification and adoption of advanced automation to enhance national competitiveness
Application	Process control, monitoring & inspection, test & measurement, safety & security	Supports operational efficiency, early fault detection, safety and regulatory compliance	Policy measures can encourage certification programs, standards enforcement and adoption of modern monitoring systems
End-user industry	Oil & gas, chemicals, power generation, pharmaceuticals, food & beverages, water & wastewater, automotive	Food & beverage sector is highly dependent on precise measurements (temperature, pressure, pH, flow) to maintain quality, safety and regulatory compliance	Policies can incentivize the adoption of instrumentation, ensure food safety standards and promote innovation in critical sectors

Source: author's idea.

dership on a combination of cyber-physical systems, IoT and artificial intelligence.

2. European model (integration policy, sustainable development and regulatory framework).

The EU is forming a model in which instrumentation engineering industry becomes the core of the transition to "green" Industry 4.0, based on digitalization and energy efficiency, as well as to Industry 5.0, which emphasizes the role of humans in technological processes and the balance between technology and sustainable development. Framework programs (Horizon Europe, Digital Europe) stimulate the creation of consortia of businesses, universities and government agencies. Devices are seen as a key tool for environmental monitoring, energy control and smart city management. The European model combines regulatory policy (standardization, data security, open innovation) with supranational coordination, ensuring an integrated trajectory in a global context.

3. Japanese model (policy of strategic coordination and technological nicheness).

Japan is building an industrial policy where device manufacturing is a critical foundation for Industry 4.0, with its automation, robotics and high-precision sensors and at the same time is focused on the challenges of Industry 5.0, which seeks a harmonious combination of technology and the human dimension. Manufacturers (Hitachi, Mitsubishi, Omron) are actively working on the development of MEMS, biomedical devices and intelligent control systems. Japanese policy is characterized by systematicity, where government programs coordinate the integration of corporations and universities. Its focus is niche leadership in high-precision instrumentation technologies, which is the foundation of the country's global competitive advantage.

4. Chinese model (policy of state dirigisme and large-scale investments).

China is actively forming its own model within the framework of the "Made in China 2025" and "Internet Plus" programs, focusing on a rapid transition to Industry 4.0 through automation, digitalization and mass production (Wang, Zhang, 2017).

Table 3. **Main dimensions of instrumentation engineering industry development**

Dimension	Key indicators	Current trends	Opportunities	Challenges
Production	Number of manufactured instruments, output in monetary terms	Moderate growth due to modernization of factories; increasing automation	Expansion in smart devices, medical instruments and IoT components	Aging infrastructure, dependency on imported components
Innovation and R&D	Patents, R&D spending, collaboration with universities	Increasing R&D investments; emergence of tech startups	Development of AI-enabled instruments, precision measurement, robotics	Limited funding, shortage of skilled researchers
Market and export	Export volume, market share, international partnerships	Rising exports to EU and Asia; integration into global value chains	Access to high-value international markets, certification of products	Competition from established foreign brands, regulatory barriers
Digital transformation	Adoption of Industry 4.0 technologies, IoT, digital twins	Growing implementation of smart factories and automation	Improved efficiency, predictive maintenance, reduced costs	High initial investment, cybersecurity threats
Human capital	Number of engineers, vocational training programs, STEM graduates	Workforce upskilling programs increasing	Stronger talent pool for high-tech development	Brain drain, mismatch of skills with industry needs
Financial and policy support	Subsidies, grants, tax incentives, cluster programs	Government incentives for modernization; public-private partnerships	Investment in modern equipment, technological renewal	Bureaucracy, uneven policy implementation
Sustainability and circularity	Energy efficiency, resource recycling, waste reduction	Slow but growing adoption of green manufacturing	Reduced environmental impact, cost savings, EU compliance	High costs, limited awareness of sustainable practices

Source: author`s idea.

Industrial policy has a pronounced dirigiste character: the state determines strategic priorities, directs investments and coordinates the development of instrumentation as an infrastructure for smart industry, telecommunications and medicine. In parallel, China is beginning to adapt the principles of Industry 5.0, in particular in the field of biomedical technologies and energy, gradually shifting the emphasis from copying to creating its own scientific developments. The main strategy is to scale up results and import substitution, which ensures rapid strengthening of technological sovereignty.

Ukraine is in the process of forming its own industrial policy, which has the potential to integrate into the European and global space of Industry 4.0—5.0. Traditional areas (aviation, defense and measuring instruments) create the foundation for the restoration of the industry and new opportunities are opening up in the areas of sensors, biomedicine and digital solutions.

The table 4 summarizes the features of global models and elements that can be used in Ukraine through pilot projects in instrumentation engineering industry.

Modern challenges stimulate an adaptation policy that combines participation in European programs, the development of startups and support for the defense-industrial complex. The creation of a hybrid model that will combine the European emphasis on standardization and the "green transi-

Table 4. **Features of global models of instrumentation engineering industry development, conclusions and pilot projects for Ukraine**

National model	Key elements of industrial policy	Conclusions for Ukraine	Pilot projects
American model (technological leadership and market commercialization)	• strong venture capital and start-up ecosystem; • rapid commercialization of R&D; • focus on disruptive technologies in AI, biotech, space, instrumentation; • university-industry collaboration;	• strengthen innovation financing (venture funds, accelerators); • promote technology transfer and spin-offs; • support entrepreneurship in high-tech industries;	• start-up accelerators for smart instrumentation; • AI-driven biotech pilot labs; • consortia for commercialization of Industry 4.0/5.0 solutions;
European model (integration, sustainability and regulatory frameworks)	• emphasis on sustainable development and green transition; • strong regulatory frameworks (environmental standards, data protection); • Industry 4.0 focus on digital platforms and smart specialization; • cross-border cooperation and integration of value chains;	• adapt EU regulatory frameworks for industrial modernization; • promote circular economy and eco-innovation; • implement smart specialization strategies regionally;	• green industrial parks; • smart specialization pilot projects in regions; • IoT-enabled energy efficiency pilots;
Japanese model (strategic coordination and technological niche orientation)	• strong state-business coordination; • human-centric society 5.0 vision; • focus on technological niches (robotics, precision engineering, healthcare tech); • integration of social and technological innovation;	• build coordination mechanisms between government, industry, academia; • develop niche sectors where Ukraine can lead (instrument engineering, agro-biotech); • promote human-centric innovation aligned with Society 5.0;	• pilot projects in precision medical instrumentation; • robotics-assisted manufacturing lines; • regional Society 5.0 living labs;
Chinese model (state dirigisme and large-scale investment)	• state-driven modernization programs • Large-scale investment in AI, 5G, robotics and smart manufacturing; • export-oriented strategy with global expansion; • national industrial zones - testing locations.	• create national programs for industrial digitalization; • establish large-scale industrial zones for Industry 4.0; • strengthen export-oriented high-tech production.	• national digital industrial parks; • smart manufacturing pilot zones; • export-oriented logistics and instrumentation hubs.

Source: compiled by author based on Hsu (2024); Hu & Zheng (2021); Hamilton-Hart & Yeung (2021); Juhász, Lane & Rodrik (2024); Wang & Zhang (2017); Zaloznova & Chekina (2025).

tion", American-Japanese orientation on commercialization and precision, as well as the Chinese scale in production is promising. This will allow Ukraine to join to some areas of the global Industry 4.0 technological chain and prepare for the requirements of Industry 5.0, which emphasizes humanistic and sustainable aspects of development.

Projects in instrumentation engineering industry

Modern instrumentation engineering industry is one of the key industries that determines the level of technological independence and innovative potential of the state. In the context of the transition to Industry 4.0, it is transforming into a multifunctional sphere that combines the production of high-tech sensors, measuring systems, automated complexes and intelligent devices for various sectors of the economy. This transformation requires not only technical innovations, but also effective organizational and economic solutions that can ensure the synergy of science, education, business and public administration.

Organizational and economic projects for the development of instrumentation engineering industry cover a wide range of initiatives: from the creation of experimental factories and pilot production sites to the formation of educational & scientific clusters, technology parks and smart city projects. Their peculiarity is that they are aimed not only at the introduction of the latest technologies, but also at the modernization of management models, formation of partnerships between the state and business, as well as integration into the international scientific and innovative space.

In table 5 main projects for instrumentation engineering industry development are presented.

The presented in table 5 projects in instrumentation engineering industry act as a driver of industrial development, combining experimental production models, educational & research clusters, innovation parks and smart cities initiatives. They create conditions for the effective implementation of innovations, strengthening international cooperation and ecological transformation of production. In future such projects that will determine the competitiveness of the instrumentation engineering industry and its ability to adapt to the challenges of the global economy.

Table 5. **Projects in instrumentation engineering industry**

Project type	Description	Key features	Expected outcomes
Experimental factories	Pilot plants for testing new production technologies in instrumentation	Flexible manufacturing systems, integration of Industry 4.0 solutions, real-time monitoring	Faster innovation transfer, reduced risks in scaling, practical validation of new technologies
Educational & research clusters	Networks uniting universities, research centers and industry	Joint laboratories, interdisciplinary programs, training platforms	Skilled workforce, innovation-driven curricula, stronger industry—academia cooperation
Innovation and technology parks	Specialized industrial and research zones focused on instrumentation development	Business incubators, start-up accelerators, R&D hubs	Concentration of expertise, regional development, commercialization of technologies
Smart City projects	Use of instrumentation for urban digital transformation	Sensor networks, IoT applications, data-driven management systems	New demand for instrumentation engineering industry products, improved quality of life, sustainable cities
Public-private partnerships	Cooperative projects between government, industry and academia	Shared funding, strategic programs, long-term infrastructure projects	Sustainable financing, modernization of industrial base, systemic innovation
International cooperation projects	Cross-border programs for knowledge exchange and co-development	Joint R&D, harmonization of standards, collaborative platforms	Access to global markets, increased competitiveness, shared expertise
Green transition projects	Organizational initiatives for eco-friendly and sustainable instrumentation	Low-carbon production, recycling-based technologies, eco-innovation labs	Compliance with green standards, reduced environmental footprint, ESG integration

Source: compiled by author.

Recommendations for industrial policy of Ukraine in the field of instrumentation engineering industry

For Ukraine, it is advisable to combine different models of instrumentation engineering industry development in order to overcome the existing structural and technological problems of the industry. Generally current state of the Ukrainian instrumentation engineering industry is characterized by fragmentation of production, technological obsolescence, low level of standardization, weak connection between science and industry and insufficient commercialization of innovations. In the conditions of war and post-war recovery, the industry needs a new industrial paradigm that will ensure technological independence and integration into the global chains of Industry 4.0.

In our opinion, the most appropriate model for Ukraine is a hybrid model of instrumentation engineering industry development, which combines elements of proven global approaches. These particular components are chosen because they are mutually reinforcing and capture the core levers of modern industrial policy that can compensate for the sector's current weaknesses. It is advisable to borrow elements of the standardization system, "green" transformation and orientation towards sustainable development from the European approach. The American-Japanese model is useful for Ukraine as possible measures for commercialization of research, stimulation of startups and development of partnerships "university-business-state". The use of these elements will allow to form the demand for instrument-making products and strengthen the educational and scientific component of the development of the industry through support for technology transfer. The Chinese model demonstrates the effectiveness of scaling technological solutions and state support for the creation of national production chains at the initial stages.

The hybrid model will allow Ukraine to use its scientific potential and high level of technical education, create a domestic market for high-tech components, attract investments in "green" and digital production, and reduce dependence on imports of critical technologies.

Based on this, it is advisable to highlight a number of recommendations that can ensure the effective functioning and development of the instrumentation engineering industry as the as an enabling sector for the transformation of national industrial capabilities towards Industry 4.0 and 5.0:

1) ***stimulating the development of the instrumentation engineering industry as a key driver of modern industrialization***.

This includes comprehensive support for research and development in the areas of sensor technologies, intelligent controllers, robotics, energy management systems and IoT solutions, without which the functioning of smart production is impossible.

It is important to create specialized clusters, technology parks and innovation hubs that will become a space for cooperation between universities, startups and industrial companies. Such an ecosystem will allow to quickly transform scientific ideas into ready-made technological products.

The development of instrumentation engineering industry requires interdisciplinary research cooperation. In the conditions of rapid technological progress, independent efforts of individual industries no longer give the expected result. Modern instruments are created at the intersection of materials science, microelectronics, information technology and biomedicine. Therefore, the key task is to form research consortia that will unite engineers, programmers, doctors and natural scientists to develop new generation sensors, microelectromechanical systems (MEMS) and biodevices. Such an approach will ensure the emergence of innovative products with high added value and open new market niches for Ukraine.

2) ***Development of innovative institutional mechanisms of industrial policy that would contribute to the integration of instrumentation engineering industry solutions into industrial ecosystems***.

In Ukraine the problem of developing innovative institutional mechanisms of industrial policy lies in the fragmentation of management decisions and weak coordination between state structures, scientific institutions and business. The existing innovation management system does not provide a holistic approach to the integration of instrument-making solutions into industrial ecosystems, which slows down the process of digital transformation and modernization of production. The lack of sustainable interaction platforms, transparent financing instruments for joint projects and incentives for enterprises implementing Industry 4.0 and 5.0 technologies creates an imbalance between scientific potential and practical results. Underdeveloped technology transfer mechanisms, low level of commercialization of scientific developments and limited access to financial resources restrain innovative activity in the instrument-making sector.

This point is not only about creating conditions for public-private partnership, but also about launching pilot projects in the field of smart production, including smart specialization (Pidorycheva & Bash, 2024). It is important to form financial and tax incentives for enterprises that invest in the digitalization of production, as well as develop state programs for the modernization of industrial facilities through the implementation of intelligent control systems.

Another main barrier to the development of instrumentation engineering industry in Ukraine is connected with insufficient level of commercialization of scientific developments. Strong academic potential is not always transformed into ready-made products for the market. Therefore, it is necessary to develop partnerships between universities and enterprises, create joint laboratories and business incubators. An effective tool will be support for technology transfer programs that will allow turning scientific discoveries into practical solutions for industry, medicine and the defense sector.

3) ***Development of the human resource potential of instrumentation engineering industry and smart engineering***.

Instrumentation engineering requires a new generation of specialists capable of working with complex systems that combine mechanics, electronics and programming. Therefore, it is important to develop educational programs that will train engineers with competencies in the field of "smart" instrument engineering, artificial intelligence in control systems and sustainable engineering (Prokopenko et al, 2024). So it is necessary to strengthen the training of specialists in the fields of engineering, cyber-physical systems, artificial intelligence, big data analysis and cyber defense. This requires updating educational programs, expanding dual education and creating joint educational and scientific platforms with the participation of universities and businesses. Focusing training on practical tasks will ensure the training of personnel capable of working in high-tech industrial environments.

4) ***Adapting the regulatory framework to the challenges of Industry 4.0 and 5.0.***

In Ukraine the regulatory framework in the field of industrial standardization, certification and security of technical systems remains largely focused on traditional production and does not take into account the requirements of the digital, cyber-physical and intellectual industries. The lack of modern standards for device compatibility, uniform requirements for cyber security of industrial systems and regulation of data processing processes creates barriers to the implementation of Industry 4.0 technologies and slows down the integration of Ukraine into the European technological space. This problem is particularly relevant in connection with the increased vulnerability of critical infrastructure, which requires clearly defined security rules when using automation systems, sensor networks and artificial intelligence.

The state should initiate the update of regulatory policy through the development and implementation of modern standards for device compatibility, requirements for cyber security and data protection, as well as the creation of a national system of certification of equipment in the field of instrument-making, harmonized with European directives (CE, RoHS, ISO/IEC 27000, etc.). This will contribute to increasing the level of safety and reliability of products, building trust among consumers and partners, and reducing technological risks associated with the use of intelligent systems in industry.

In addition, it is necessary to create institutional mechanisms for coordination between the government, scientific institutions, technical universities, manufacturers and operators of critical infrastructure for the joint development of standards and procedures. An important component should be the training of specialists in cybersecurity of industrial systems, certification of laboratories and test sites, as well as Ukraine's participation in international initiatives to develop standards for "smart" devices and secure data exchange.

5) ***Stimulating international cooperation and integration into global innovation networks***.

An important direction for the development of the instrumentation engineering industry of Ukraine is the active stimulation of international cooperation and integration into global innovation networks. Current trends in the development of Industry 4.0 and 5.0 demonstrate that the competitiveness of industrial sectors is determined not only by internal resources, but also by the ability to participate in international scientific and technological alliances, joint research programs and partnership projects with transnational companies.

For Ukraine, which is at the stage of industrial restoration and structural modernization of the economy, participation in such initiatives has a dual meaning as a tool for accessing the latest technologies and as an opportunity to strengthen its own scientific and production potential.

It is important to ensure the systematic integration of Ukrainian institutions and enterprises into international programs (Horizon Europe, Digital Europe, Green Deal, LIFE Programme etc.). They provid access to funding and opportunities for research, innovation, digital transformation and environmentally sustainable production. In parallel, it is necessary to stimulate the creation of bilateral and multilateral partnerships with leading EU universities, research centers, industrial associations and companies that develop technologies of sensors, cyber-physical systems, robotics, mechatronics and smart materials.

Special attention needs to be paid to the formation of the export potential of Ukrainian instrumentation engineering industry, which is currently limited by a low level of international marketing, insufficient certification of products according to European standards and lack of foreign economic support. To overcome these barriers, it is advisable to create state programs for the promotion of high-tech products of Ukrainian enterprises on global markets, as well as provide support in passing certification procedures, patenting and participation in international exhibitions. At the same time, it is important to stimulate the internationalization of research, the development of joint laboratories and technology transfer centers with European partners, which will allow Ukrainian scientists and developers to participate in the formation of global technological standards. Such integration will not only provide access to financial resources, but will also increase the prestige of Ukrainian science, expand opportunities for the export of intellectual products, and contribute to creating conditions for Ukraine's long-term presence in global innovation value chains.

6) ***Promoting the digital transformation of industrial ecosystems***.

Modern instrumentation engineering industry is gradually becoming a digitally oriented industry in terms of demand and supply. The integration of

Table 6. **Recommendations for developing instrumentation engineering industry in Industry 4.0**

Dimension	Recommendations	Examples / Focus areas
Industrial ecosystems	Develop clusters uniting firms, universities, R&D institutes and service providers	Instrumentation engineering industry clusters in aerospace, energy, medical equipment
	Integrate into global value chains	Supplier networks for European and global OEMs
	Promote digitalization of ecosystems	Shared platforms, digital twins, simulation labs
	Apply mission-oriented approach	Medical devices, green energy, infrastructure recovery, defense tech
Policy experimentation	Launch pilot policies at regional or industrial park level	Sandbox regimes for new business models
	Provide flexible grants and vouchers	Small-scale experimental R&D support with low bureaucracy
	Create regulatory sandboxes	"Instrument-as-a-service" or servitization pilots
	Implement adaptive learning in policymaking	Evaluation mechanisms that capture lessons for scaling
	Foster cross-sectoral collaboration	Joint projects with biomedical, energy, or agri-tech sectors
Institutional conditions	Establish policy labs with universities and regional agencies	Regional innovation & experimentation hubs
	Engage business associations in strategy setting	Roadmaps for mission-oriented industrial development
	Leverage EU mechanisms and best practices	Horizon Europe, EIC, Digital Europe programs

Source: compiled by author.

Internet of Things, artificial intelligence, digital twins and edge-computing technologies into instruments allows you to create systems that not only measure, but also analyze and predict parameters. This makes it possible to reduce the number of emergency situations, increase the efficiency of production processes and ensure flexible management in real time. As part of industrial policy, it is important to support the digitalization of instrument manufacturing, as this will contribute to the modernization of industry and integration into global value chains.

With the spread of smart systems, the problem of their security arises. Devices connected to critical infrastructure become a potential target for cyberattacks. Therefore, it is necessary to develop and implement modern cybersecurity standards that will ensure data protection and uninterrupted operation of systems. This is especially important for the defense and energy industries, where device failures can have catastrophic consequences.

7) ***Orientation towards sustainable development.***

Modern instrumentation engineering industry should be oriented towards the principles of sustainable development. It is not only about the energy efficiency of the instruments themselves, but also about creating equipment for monitoring the state of the environment, controlling emissions and supporting renewable energy.

Ukrainian enterprises can become important suppliers of environmental solutions, especially given the European integration course and participation in the “green transition”. This will allow combining industrial development with environmental responsibility.

Recommendations for developing instrumentation engineering industry can be organized into three interconnected blocks: industrial ecosystems, policy experimentation, institutional conditions. This structure reflects the multidimensional role of instrument engineering in Industry 4.0, where technological innovation, data-driven processes and integrated production networks require both sectoral coordination and adaptive governance. The three blocks also correspond to a project-based approach, distinguishing between technological projects (focused on product, process and digital innovations) and institutional projects (focused on governance, regulation and ecosystem development).

Industrial ecosystems component addresses the technological and organizational networks that drive production and innovation. In the context of Industry 4.0 this includes smart manufacturing clusters, digital platforms, cyber-physical systems and integration into global value chains. These ecosystem-level projects enhance competitiveness, enable cross-sectoral synergies and provide the infrastructure for advanced technological experimentation.

Policy experimentation emphasizes flexible, adaptive and project-oriented policymaking to support emerging industrial ecosystems. Such tools as pilot programs, regulatory sandboxes, adaptive learning mechanisms and cross-sectoral collaborations allow testing of innovative approaches with reduced risk, accelerating the scaling of successful technological and organizational innovations.

Institutional conditions component focuses on the governance and structural framework necessary to sustain both ecosystems and experimentation projects. Here policy labs, engagement of business associations and alignment with EU programs can be used. These tools create the institutional backbone for project implementation, long-term coordination and resource allocation, ensuring that both technological and institutional initiatives achieve systemic impact.

By structuring recommendations in three blocks the approach simultaneously addresses technical, regulatory and institutional dimensions, providing a comprehensive, project-driven strategy to strengthen Ukraine’s instrumentation engineering industry in the era of Industry 4.0 (table 6).

Based on given recommendations, we can note that modern industrial policy in the field of instrumentation engineering industry should be based on four key principles: innovation, institutional mechanisms, human resource potential and international integration. Its implementation will ensure not only technological renewal of the economy and increased productivity, but also contribute to the sustainable development, the formation of a new infrastructure of a smart society and strengthening competitiveness on a global scale.

Conclusions

Analysis of the development of the instrumentation engineering industry at the global level shows that the sector is undergoing a profound transformation driven by the convergence of digital technologies, automation and global industrial trends. Modern instrumentation engineering industry is no longer limited to traditional measurement and control functions. It has become an integrated component of cyber-physical systems that support Industry 4.0 and the gradual transition to Industry 5.0. The integration of "smart" sensors, artificial intelligence, digital twins and Internet of Things solutions has fundamentally changed the logic of instrument operation, providing real-time data collection, autonomous analysis, predictive maintenance and optimization of production and research processes. Technological innovations in analytical instruments, including advances in chromatography, spectroscopy, mass spectrometry and nuclear magnetic resonance, have increased the accuracy, sensitivity and efficiency of equipment, while allowing its integration into complex industrial systems. Miniaturization and portable devices combined with digital twins expand the capabilities of analytics, ensuring the use of equipment in the medical field, environmental monitoring and field conditions. This contributes to the formation of smart, interconnected ecosystems, where physical measurements are directly integrated into virtual models to support the decision-making process.

The development of the instrumentation engineering industry in the context of Industry 4.0—5.0 forms a new logic for the functioning of the sector, where analytical systems become an integral part of the cyber-physical space, contributing to sustainable, technologically flexible and human-centered development.

From the point of view of industrial policy, it is important that the modern development of instrumentation engineering industry combines technological, organizational and institutional aspects. They form a holistic ecosystem capable of ensuring the competitiveness of the industry and its adaptation to the challenges of the global economy. This allows not only to restore traditional areas (aviation, defense, measuring instruments), but also opens up new opportunities in the field of sensor technologies, biomedicine and digital solutions, laying the foundation for the sustainable and high-tech development of the instrumentation engineering industry of Ukraine.

The development of the instrumentation engineering industry is determined not only by technological innovations, but also by the specifics of national industrial policy. An analysis of global development models (American, European, Japanese and Chinese) shows that each country forms a unique approach that combines the strategic priorities of the state, the role of private business, scientific schools and international integration. In the context of Industry 4.0 and 5.0, instrumentation engineering industry is of particular importance, as it provides sensor systems, automation, cyber-physical complexes and tools for human interaction with technology.

The experience of leading countries demonstrates different strategies. The USA emphasizes technological leadership and commercialization of innovations. The EU pays attention to integration, standardization and "green" transition. Japan prioritizes strategic coordination and niche development of high-precision technologies. China pays attention to state dirigisme and large-scale investments.

For Ukraine, the formation of a hybrid model that will combine European approaches to standardization and "green" transformation, American-Japanese orientation to commercialization and Chinese approach to large-scale production is promising. This strategy will allow integrating Ukrainian instrumentation engineering industry into global chains of Industry 4.0 and preparing it for the requirements of Industry 5.0, which emphasizes the sustainable aspect of development.

Projects presented in the instrumentation engineering industry are a key tool for implementing this strategy. Among such projects, it is worth highlighting the creation of experimental factories, educational and scientific clusters, innovation and technology parks, "smart cities" initiatives and public-private partnerships. Their feature is that they allow for the simultaneous implementation of advanced technologies and modernization of organizational and management models. Such projects provide training of highly qualified personnel, stimulate the commercialization of innovations, strengthen international cooperation and contribute to the ecological transformation of production.

The modern development of the instrumentation engineering industry in Ukraine requires a systemic and at the same time innovative approach that combines technological, organizational and institutional aspects. The novelty of the recommendations presented in the article lies in the comprehensive project-oriented approach that integrates the development of industrial ecosystems, political experiments and the formation of institutional conditions, thus creating a unique model of industrial policy for Ukraine. It is advisable to consider instrumentation engineering industry not only as the production of individual devices, but as the basis for the functioning of "smart" industrial ecosystems, where digitalization, intelligent management systems and integration into global value chains become central factors of development.

Particular attention should be paid to an interdisciplinary approach to innovation, where scientific developments in the field of materials science, microelectronics, biomedicine and information technologies are quickly transformed into high-tech products with high added value. The given recommendations are based on providing of combination of technological development with commercialization mechanisms, which include pilot projects, support for technology transfer and the formation of partnerships between universities and industrial companies. This approach allows to overcome the traditional gap between scientific potential and market products, creating new niche markets and increasing the global competitiveness of Ukraine.

ЛІТЕРАТУРА

Добровська С. В., Овсієнко Л. М. Дослідження динаміки публікацій з машинобудування та приладобудування в наукових виданнях України. *Наука України у світовому інформаційному просторі*. Вип. 15. Київ: Академперіодика, 2018. С. 80—82. https://www.old.nas.gov.ua/publications/books/series/9789660247048/Documents/2018_15/18_15_Dobr.pdf

Залознова Ю. С., Чекіна В. Д. Стимулювання розвитку смарт-промисловості в просторовому аспекті: досвід для України. *Економіка промисловості.* 2025. № 1 (109). С. 3—19. http://doi.org/10.15407/econindustry2025.01.003

Підоричева І. Ю., Баш А. С. Смарт-спеціалізація промислових регіонів України: організаційно-економічний супровід. *Економіка промисловості.* 2024. № 2 (106). С. 5—28. http://doi.org/10.15407/econindustry2024.02.005

Analytical instrumentation market size, share & trends analysis report by product, by technology, by application, by region and segment forecasts, 2025—2033. Report No. GVR-4-68040-028-9. Grand View Research, 2025. URL: https://www.grandviewresearch.com/industry-analysis/analytical-instrumentation-market-report (accessed: 27.09.2025).

Asif M., Shen H., Zhou C., Guo Y., Yuan Y., Shao P., Xie L., Bhutta M. S. Recent Trends, Developments and Emerging Technologies towards Sustainable Intelligent Machining: A Critical Review, Perspectives and Future Directions. *Sustainability*. 2023. Vol. 15, Iss. 10. Art. 8298. https://doi.org/10.3390/su15108298

Bothare V. Instrumentation Services Market Size, Share and Growth by Forecast 2032. *Straits Research*, 2023. URL: https://straitsresearch.com/report/instrumentation-services-market (accessed: 27.09.2025).

Hamilton-Hart N., Yeung H. W. Institutions under pressure: East Asian states, global markets and national firms. *Review of International Political Economy*. 2019. Vol. 28, Iss. 1. P. 11—35. https://doi.org/10.1080/09692290.2019.1702571

Hsu L. F. State's role in shaping the smart city industry development. *International Journal of Urban Sciences.* 2024. P. 1—29. https://doi.org/10.1080/12265934.2024.2438249

Hu Q., Zheng Y. Smart city initiatives: A comparative study of American and Chinese cities. *Journal of Urban Affairs*. 2021. Vol. 43, No. 4. P. 504—525. https://doi.org/10.1080/07352166.2019.1694413

Instrumentation service market size, share & forecast 2034. *Market Research Future*, 2025. URL: https://www.marketresearchfuture.com/reports/instrumentation-service-market-26049 (accessed: 03.09.2025).

Juhász R., Lane N., Rodrik D. The new economics of industrial policy. *Annual Review of Economics*. 2024. Vol. 16, No. 1. P. 213—242. https://doi.org/10.1146/annurev-economics-081023-024638

Kyle P. B., McVoy L. Current trends in instrumentation and technology: A look toward the future. *Clinical Laboratory Management*. Wiley, 2024. P. 674—689. https://doi.org/10.1002/9781683673941.ch48

Lai Y., Zhao H. Comparative analysis of smart city scientific research trends in the USA and China. *Nat Cities*. 2025. https://doi.org/10.1038/s44284-025-00305-y

Lane J. Assessing the impact of science funding. *Science*. 2009. Vol. 324. P. 1273—1275. URL: https://users.nber.org/~confer/2009/SI2009/PRIPE/J-Lane%20-%20Science%20(2009).pdf (accessed: 03.09.2025).

Ma J., Wang W., Zhou C. Developing a Manufacturing Industrial Brain in a Smart City: Analysis of fsQCA Based on Yiwu Knitting Industry Platform. *Buildings*. 2024. Vol. 14, No. 5. Art. 1404. https://doi.org/10.3390/buildings14051404

Manyika J., Chui M., Miremadi M., Bughin J., George K., Willmott P., Dewhurst M. A future that works: Automation, employment and productivity. McKinsey Global Institute, 2017. URL: https://www.mckinsey.com/~/media/mckinsey/featured%20insights/Digital%20Disruption/Harnessing%20automation%20for%20a%20future%20that%20works/MGI-A-future-that-works-Executive-summary.ashx (accessed: 01.10.2025).

Maus G. Recent trends in measurement & instrumentation. *LinkedIn*, 2025. URL: https://www.linkedin.com/pulse/recent-trends-measurement-instrumentation-gary-maus-3zzbc (accessed: 05.09.2025).

Narayanan S., Schuetz A. N. Current trends in instrumentation and technology: Outlook for the future (Chapter 54). *Clinical laboratory management*. Ed. by L. S. Garcia. ASM Press, 2014. P. 933—965. https://doi.org/10.1128/9781555817282.ch54

Prokopenko O., Järvis M., Bielialov T., Omelyanenko V., Malheiro T. The Future of Entrepreneurship: Bridging the Innovation Skills Gap Through Digital Learning / Eds. by J. Machado et al. *Innovations in Industrial Engineering III. ICIENG 2024. Lecture Notes in Mechanical Engineering*. Springer, Cham, 2024. P. 206—230. https://doi.org/10.1007/978-3-031-61582-5_18

Prokopenko O., Järvis M., Omelyanenko V., Maslov A., Lopes H. The Convergence of IoT, Cyber-Physical Systems and Mechatronics in Industry 4.0 Digitalization / Eds. by J. Machado, J. Trojanowska, K. Antosz, C. P. Leão, L. Knapcikova, A. Sover. *Innovations in Industrial Engineering IV. ICIENG 2025. Lecture Notes in Mechanical Engineering.* Springer, Cham, 2025. P. 48—65. https://doi.org/10.1007/978-3-031-94484-0_5

Singh H. Exploring the future of instrumentation & sensors. *BCC Research Blog*, 2025. URL: https://blog.bccresearch.com/exploring-the-future-of-instrumentation-sensors (accessed: 27.09.2025).

Top 5 instrumentation trends to watch in 2024. General Instruments Consortium. *LinkedIn*, 2024. URL: https://www.linkedin.com/pulse/top-5-instrumentation-trends-watch-oim4f (accessed: 27.09.2025).

Vyshnevskyi O. S., Anufriiev M. Yu., Bozhyk M. S., Gulchuk T. O. Artificial intelligence as a core of the new industrial revolution: prospects and limitations. *Econ. promisl.* 2024. No. 3 (107). P. 5—21. http://doi.org/10.15407/econindustry2024.03.005

Wang X., Zhang L. Development Trends for China's Instrumentation Engineering Science and Technology to 2035. *Strategic Study of CAE*. 2017. Vol. 19, No. 1. P. 103—107. https://doi.org/10.15302/J-SSCAE-2017.01.015

Zhu J., Liu X., Shi Q., He T., Sun Z., Guo X., Liu W., Sulaiman O. B., Dong B., Lee C. Development Trends and Perspectives of Future Sensors and MEMS/NEMS. *Micromachines*. 2020. Vol. 11, No. 1. Art. 7. https://doi.org/10.3390/mi11010007

Надійшла до редакції 01.10.2025 р.
Прийнята до друку 22.10.2025 р.

REFERENCES

Dobrovska, S. V., & Ovsienko, L. M. (2018). Research on the dynamics of publications on mechanical engineering and instrument making in scientific publications of Ukraine. *Ukrainian science in the world information space*, 15, 80—82. Kyiv: Akademperiodyka. https://www.old.nas.gov.ua/publications/books/series/9789660247048/Documents/2018_15/18_15_Dobr.pdf [in Ukrainian].

Zaloznova, Yu. S., & Chekina, V. D. (2025). Stimulating the development of smart industry in the spatial aspect: experience for Ukraine. *Econ. promisl.*, 1 (109), 3—19. http://doi.org/10.15407/econindustry2025.01.003 [in Ukrainian].

Pidorycheva, I. Yu., & Bash, A. S. (2024). Smart specialization of industrial regions of Ukraine: organizational and economic support. *Econ. promisl.*, 2 (106), 5—28. http://doi.org/10.15407/econindustry2024.02.005 [in Ukrainian].

Grand View Research (2025). Analytical instrumentation market size, share & trends analysis report by product, by technology, by application, by region and segment forecasts, 2025—2033. Report No. GVR-4-68040-028-9. https://www.grandviewresearch.com/industry-analysis/analytical-instrumentation-market-report

Asif, M., Shen, H., Zhou, C., Guo, Y., Yuan, Y., Shao, P., Xie, L., & Bhutta, M. S. (2023). Recent Trends, Developments and Emerging Technologies towards Sustainable Intelligent Machining: A Critical Review, Perspectives and Future Directions. *Sustainability*, 15 (10), 8298. https://doi.org/10.3390/su15108298

Bothare, V. (2023). Instrumentation Services Market Size, Share and Growth by Forecast 2032. *Straits Research.* https://straitsresearch.com/report/instrumentation-services-market

Hamilton-Hart, N., & Yeung, H. W. (2021). Institutions under pressure: East Asian states, global markets and national firms. *Review of International Political Economy*, 28 (1), 11—35. https://doi.org/10.1080/09692290.2019.1702571

Hsu, L. F. (2024). State's role in shaping the smart city industry development. *International Journal of Urban Sciences*, 1—29. https://doi.org/10.1080/12265934.2024.2438249

Hu, Q., & Zheng, Y. (2021). Smart city initiatives: A comparative study of American and Chinese cities. *Journal of Urban Affairs*, 43 (4), 504—525. https://doi.org/10.1080/07352166.2019.1694413

Market Research Future (2025). Instrumentation service market size, share & forecast 2034. https://www.marketresearchfuture.com/reports/instrumentation-service-market-26049

Juhász, R., Lane, N., & Rodrik, D. (2024). The new economics of industrial policy. *Annual Review of Economics*, 16 (1), 213—242. https://doi.org/10.1146/annurev-economics-081023-024638

Kyle, P. B., & McVoy, L. (2024). Current trends in instrumentation and technology: A look toward the future. In *Clinical Laboratory Management* (pp. 674—689). Wiley. https://doi.org/10.1002/9781683673941.ch48

Lai, Y., & Zhao, H. (2025). Comparative analysis of smart city scientific research trends in the USA and China. *Nat Cities.* https://doi.org/10.1038/s44284-025-00305-y

Lane, J. (2009). Assessing the impact of science funding. *Science*, 324, 1273—1275. https://users.nber.org/~confer/2009/SI2009/PRIPE/J-Lane%20-%20Science%20(2009).pdf

Ma, J., Wang, W., & Zhou, C. (2024). Developing a Manufacturing Industrial Brain in a Smart City: Analysis of fsQCA Based on Yiwu Knitting Industry Platform. *Buildings*, 14 (5), 1404. https://doi.org/10.3390/buildings14051404

Manyika, J., Chui, M., Miremadi, M., Bughin, J., George, K., Willmott, P., & Dewhurst, M. (2017). A future that works: Automation, employment and productivity. McKinsey Global Institute. https://www.mckinsey.com/~/media/mckinsey/featured%20insights/Digital%20Disruption/Harnessing%20automation%20for%20a%20future%20that%20works/MGI-A-future-that-works-Executive-summary.ashx

Maus, G. (2025). Recent trends in measurement & instrumentation. *LinkedIn*. https://www.linkedin.com/pulse/recent-trends-measurement-instrumentation-gary-maus-3zzbc

Narayanan, S., & Schuetz, A. N. (2014). Current trends in instrumentation and technology: Outlook for the future (Chapter 54). B L. S. Garcia (Ed.), *Clinical laboratory management* (pp. 933—965). ASM Press. https://doi.org/10.1128/9781555817282.ch54

Prokopenko, O., Järvis, M., Bielialov, T., Omelyanenko, V., & Malheiro, T. (2024). The Future of Entrepreneurship: Bridging the Innovation Skills Gap Through Digital Learning. In Machado, J., et al. (Eds.) *Innovations in Industrial Engineering III. ICIENG 2024. Lecture Notes in Mechanical Engineering* (pp. 206–230). Springer, Cham. https://doi.org/10.1007/978-3-031-61582-5_18

Prokopenko, O., Järvis, M., Omelyanenko, V., Maslov, A., & Lopes, H. (2025). The Convergence of IoT, Cyber-Physical Systems and Mechatronics in Industry 4.0 Digitalization. In Machado, J., Trojanowska, J., Antosz, K., Leão, C.P., Knapcikova, L., & Sover, A. (Eds). *Innovations in Industrial Engineering IV. ICIENG 2025. Lecture Notes in Mechanical Engineering. Springer, Cham*. https://doi.org/10.1007/978-3-031-94484-0_5

Singh, H. (2025). Exploring the future of instrumentation & sensors. *BCC Research Blog.* https://blog.bccresearch.com/exploring-the-future-of-instrumentation-sensors

General Instruments Consortium (2024). Top 5 instrumentation trends to watch in 2024. *LinkedIn*. https://www.linkedin.com/pulse/top-5-instrumentation-trends-watch-oim4f

Vyshnevskyi, O. S., Anufriiev, M. Yu., Bozhyk, M. S., & Gulchuk, T. O. (2024). Artificial intelligence as a core of the new industrial revolution: prospects and limitations. *Econ. promisl.*, 3 (107), 5—21. http://doi.org/10.15407/econindustry2024.03.005

Wang, X., & Zhang, L. (2017). Development Trends for China's Instrumentation Engineering Science and Technology to 2035. *Strategic Study of CAE*, 19 (1), 103—107. https://doi.org/10.15302/J-SSCAE-2017.01.015

Zhu, J., Liu, X., Shi, Q., He, T., Sun, Z., Guo, X., Liu, W., Sulaiman, O. B., Dong, B., & Lee, C. (2020). Development Trends and Perspectives of Future Sensors and MEMS/NEMS. *Micromachines*, 11 (1), 7. https://doi.org/10.3390/mi11010007

Received: 01.10.2025
Accepted: 22.10.2025

Віталій Анатолійович Омельяненко, д-р екон. наук, ст. дослідник, професор
https://orcid.org/0000-0003-0713-1444
E-mail: omvitaliy@gmail.com

Інститут економіки промисловості НАН України
вул. Марії Капніст, 2, м. Київ, 03057, Україна

ГАЛУЗЕВИЙ АСПЕКТ ПРОМИСЛОВОЇ ПОЛІТИКИ В УМОВАХ ІНДУСТРІЇ 4.0 та 5.0
(НА ПРИКЛАДІ ПРИЛАДОБУДУВАННЯ)

Сучасне приладобудування розвивається на основі глобальних індустріальних трендів конвергенції цифрових технологій і є важливою складовою кіберфізичних систем, що підтримують Індустрію 4.0 та поступовий перехід до Індустрії 5.0. Інтеграція «розумних» сенсорів, штучного інтелекту, цифрових двійників і рішень Інтернету речей фундаментально змінила логіку функціонування приладів, забезпечуючи збір даних у реальному часі, автономний аналіз, прогнозне обслуговування та оптимізацію виробничих і дослідницьких процесів. Це сприяє формуванню «розумних», взаємопов'язаних екосистем, де фізичні вимірювання безпосередньо інтегруються у віртуальні моделі для підтримки процесу прийняття рішень. Розвиток приладобудівної промисловості в контексті Індустрії 4.0 та 5.0 формує нову логіку функціонування галузі, де аналітичні системи стають невід'ємною частиною кіберфізичного простору, сприяючи сталому, технологічно гнучкому та орієнтованому на людину розвитку. Проєкти у приладобудуванні є ключовим інструментом розвитку галузі в контексті переходу до Індустрії 4.0 та 5.0. Створення експериментальних фабрик, освітньо-наукових кластерів, інноваційних і технологічних парків, ініціатив «розумних міст» і публічно-приватних партнерств дозволяє одночасно впроваджувати передові технології та вдосконалювати організаційні й управлінські моделі. Розвиток приладобудування визначається не лише технологічними інноваціями, а й специфікою національної промислової політики. Досліджено моделі розвитку приладобудівної індустрії крізь призму промислової політики в контексті переходу до Індустрії 4.0 та 5.0. Аналіз моделей розвитку галузі (американської, європейської, японської та китайської) свідчить, що кожна країна формує унікальний підхід до розвитку приладобудування, який поєднує стратегічні пріоритети держави, роль приватного бізнесу, наукові школи та міжнародну інтеграцію. Для України перспективним є формування гібридної моделі, що поєднуватиме європейські підходи до стандартизації та «зеленої» трансформації, американсько-японську орієнтацію на комерціалізацію, китайський підхід до масштабного виробництва. Така модель дозволить інтегрувати українське приладобудування у глобальні ланцюги Індустрії 4.0 і підготувати його до вимог Індустрії 5.0. Для забезпечення ефективного розвитку приладобудівної галузі України доцільно реалізувати промислову політику, що поєднує підтримку наукових досліджень, розвиток людського потенціалу та створення сучасної нормативно-інституційної бази, адаптованої до вимог Індустрії 4.0 та 5.0. Промислова політика має охоплювати стимулювання міжнародної кооперації, підтримку цифрової трансформації виробництва та інтеграції у глобальні інноваційні мережі, а також оновлення галузевих стандартів. При цьому важливо орієнтувати розвиток приладобудування на принципи сталого розвитку, поєднуючи індустріальне зростання з екологічною відповідальністю та «зеленою» модернізацією.

Ключові слова: приладобудування, Індустрія 4.0 та 5.0, проєкти, промислова політика.