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FINANCIAL DIMENSION OF STRATEGIC DEVELOPMENT OF NANOTECHNOLOGIES IN INDUSTRY

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ABSTRACT

The object of the study is the growing interest in visualizing the data of publications on nanotechnology in industrial activities, represented by scientific papers in scientometric databases, in particular Scopus. In scientific practice, the strategic directions of nanotechnology development in industry using modern methodological approaches are not widely represented.

The purpose of the study is to formulate strategic directions for the development of nanotechnology in the industry using the Hoshin Kanri model by conducting a bibliometric analysis and researching market trends, which allows for assessing the financial capabilities of countries.

As a result of the study, it was found that the Scopus scientometric database contains (n=13164) documents such as articles, abstracts, reviews, and books in various subject areas. The processed document data was used to form a network map of the interconnection of scientific interests in nanotechnology in the industry using the VOSviewer software. It was found that there are 13 such clusters, which include an overview of nanotechnology by life cycle changes, impact on the food industry, chemical and microbiological processes, ecology, biotechnology, nanomedicine, and specialized nanotechnology. It has been established that the countries with the highest financial investments in nanotechnology are the United States, China, India, South Korea, and Japan.

The proposed original Hoshin Kanri model of strategic directions of nanotechnology development in the industry will ensure the development of scientific views and their further implementation in the practice of business entities. The described components in such groups as advantages of nanotechnology by industry, priorities, tasks and risks - can be used in practice in any industry to move to a new stage of the technology life cycle. This will speed up the management of business processes, rationalize the use of resources and make effective management decisions.

Keywords: bibliometric analysis, visualization map, funding, research cluster, management, process, technology, Hoshin Kanri model

JEL Classification: L10, L11, O33

INTRODUCTION

The most promising areas for increasing the competitiveness of industrial enterprises are nanotechnology, information technology, and biotechnology, which are in great demand on the way to developing production processes in the XXII century. As is known, in terms of financial capacity and development of scientific research, some countries are leaders in the field of nanotechnology, such as China, Japan and the USA.

At the same time, the lack of awareness of civil society about nanotechnology can polarize the perception of risk in relation to this technology. Public discussion and engagement are essential for policy-making and responsible development of any innovative technology. Although developing countries have now joined the discussion on public perceptions of new technologies, as have developed countries, there has been no survey comparing the perception of nanotechnology among developing and developed countries (Rathore & Mahesh, 2021). Nanotechnology involves the design of complex "structures from the molecular or atomic stage to develop high-quality and high-performance

products at a lower cost. It is a revolutionary and useful technology that is used in all industrial sectors, such as agriculture, pharmaceuticals, transportation, communications, manufacturing, etc. The increasing adoption of nanomaterials in various end-use industries such as aerospace, healthcare, electronics, and textiles is expected to drive the growth of the global nanotechnology market over the forecast period. Nanomaterials have gained rapid adoption in the aforementioned industries due to their special physical and chemical properties" (Nanotechnology Market Size, Share, and Trends 2024 to 2034). Working with nanomaterials and nanoparticles has long been used in the creation of various items, but there is always a strategic scope for improvement and development. The extremely rapid pace of development of new and advanced technologies is making adjustments to the activities of industrial sector enterprises, which increases the country's financial level and its position in the world. Nanotechnologies are designed to improve living standards, but their safety for consumers and the environment should be taken into account.

The relevance of the study is to review scientific papers describing changes in the nanotechnology market. The bibliometric review will allow us to identify current trends in nanotechnology in various industries and to formulate trends in their further development.

LITERATURE REVIEW

An interesting perspective is that of Rambaran, T., & Schirhagl, R. (2022), who examine current trends in the implementation of nanotechnology from the laboratory to industry. The article describes current examples of nanotechnologies that have been successfully introduced to the market, as well as their relevance and geographical distribution. The authors review the various approaches required to bring nanotechnology to market, highlight the numerous challenges associated with these approaches, and provide a roadmap for the journey from the laboratory to industry that may be useful to researchers. The proposals presented are relevant for many industries, and they also contribute to the expansion of opportunities in business process management. However, the authors do not focus on the benefits of nanotechnology for specific industries. This is a significant drawback when it comes to the possibility of using such precise components as nanoparticles.

Instead, Pang et al. (2024) describe nanotechnology and nanomaterials for the oil and gas industry. The presented results of the study allow us to get acquainted with nanotechnologies to nanodevices, which include various nanosensors for use in the oil and gas industry. The limitation of this study is that it aims to fully understand the latest implementations of nanomaterials in the oil and gas industry, but such methods are not relevant to other industries.

Similar is the work of Ferdous et al. (2024), where the authors study nanotechnology in the petrochemical industry. It is proved that the growing demand for energy resources stimulates the search for new sources of production and increases the efficiency of the oil industry. The disadvantage of this study is that the presented nanotechnologies are relevant exclusively for petrochemical and gas systems.

An interesting perspective is that of Shah et al. (2023), who review nanotechnology in the agricultural and food industries. It is substantiated that nanotechnology catalyzes sustainable agriculture, filling the agricultural sector with efficiency, precision, ecological and environmental care. This paper does not address the possibility of reducing technological innovations, such as pesticides, synthetic fertilizers, and hybrid varieties, that depend on environmentally friendly nanomaterials.

A critical review of the application of nanotechnology in the automated textile industry can be found in Shah et al. (2022), where the authors describe the technologies for the manufacture and modification of textile fibres based on nanotechnology. As a result of studying a significant number of literature sources, the authors found that there are prospects for creating smart clothing in the future. However, given the rapid globalization changes and digital trends, the formation of a long-term strategy raises certain doubts about their implementation.

The relevance of the study of nanotechnology in industry is proved by Jiménez et al. (2022), where the authors describe Safe(r) recommendations for the nanotechnology industry. SbD has been proven to maintain a timely balance of functionality, human health and safety, the environment, and economic impact and costs. Such a practical approach can be adapted to the specific needs and circumstances of both the enterprise and the industry.

Hamad et al. (2018) describe the introduction of nanotechnology in the food industry, which has facilitated the transportation of food products to different countries of the world, extending their shelf life. The peculiarity of this work is that it describes the role of nanotechnology at different levels of the food industry, and therefore the proposed methods are relevant only for: storage, transportation or extension of food shelf life. De Francisco, E.V., & García-Estepa, R.M. (2018)

presents nanotechnology in the agri-food industry in a slightly different way. This study clarifies the fundamental concepts of nanotechnology, focusing on its primary application and health and environmental risk assessment.

Innovative approaches and technologies are increasingly used in pharmacy. Biliavska et al. (2024) describe one of these approaches on the example of category management for pharmacy retail. Al-Nemrawi et al. (2020) identified the benefits of nanotechnology in pharmacy. The authors emphasize the need for students to study nanotechnology in pharmacy. This is due to the fact that there are numerous pharmaceutical products based on nanotechnology on the drug market. The disadvantage of this study is the lack of substantiation of specific nanotechnologies in pharmacy; the paper only proves the need to study this issue.

In the literature, publications are presented in various subject areas, such as the food industry, medicine, construction industry, agriculture and ecology. This makes it necessary to conduct research not only from a practical point of view, namely the application of the concept of nanotechnology in the activities of enterprises but also to analyze bibliometric data represented by scientific papers in international databases.

Despite the variety of practical solutions to nanotechnology issues, research approaches require a more thorough systematization, which should be carried out using bibliometric analysis. This analysis reveals research areas and the intellectual structure of the field, internal connections between articles, authors, and keywords, existing collaboration networks, new trends and the most influential authors, publications, and sources (Trinidad et al. 2021). The issue of bibliometric analysis of works on nanotechnology in the publications of the Scopus scientometric database began in 2002 (Zhu, D., & Porter, A.L., 2002), which was the first attempt to visualize information for technological intelligence and forecasting. Mapping of the intersection of nanotechnology and SARS-CoV-2/COVID as a bibliometric analysis was carried out by Zhang et al. (2022) to stimulate further research on nanotechnology aimed at overcoming the threats of COVID-19.

Li et al. (2022) conducted a bibliometric analysis of nanotechnology for the diagnosis and treatment of Alzheimer's disease. The in-depth study consisted of sorting out the publication trend, country/institution, reference sources, and studies related to AD nanotechnology using bibliometric analysis and visualization methods.

The use of nanosilica in the construction industry: bibliometric analysis using Methodi Ordinatio is presented by Hernández-Contreras et al. (2024), where the authors obtained information from the Scopus and Web of Science (WoS) databases to compare the bibliometric indicators of publications.

Biliavskyi et al. (2024) identify the main trends in the development of digital technologies in the context of rapid globalization, digitalization and the transition to digital ecosystems by 2032, the implementation of which is impossible without the use of nanotechnology. In the face of change, it is also important to adhere to digital competencies (Shestack et al. 2023) as significant changes in the labour market are taking place, which is associated with a significant reduction in professions. Zhu et al. (2021) describe trends in nanoscience and nanotechnology research using bibliometric analysis. The authors conducted a bibliometric review of the literature, but the paper lacks a comparative analysis of data on nanotechnology in the industry.

As a result of the literature review, it should be noted that in practice, various variations of bibliometric analysis are more often used, and nanotechnology is developing due to significant globalization changes.

AIMS AND OBJECTIVES

The purpose of the study is to formulate strategic directions for the development of nanotechnology in industry using a bibliometric review. This will allow to form the Hoshin Kanri model with the definition of advantages by industry, priorities, tasks and risks of nanotechnology in industry. In addition, it is envisaged to attract resources such as software, personnel, capital, and material and technical base.

To achieve the goal, the following tasks have been identified

- to conduct a bibliometric analysis of publications on nanotechnology in industry, which are presented in the Scopus scientometric database;
- to analyze the market of nanotechnologies in industry, to determine the current state, financial capabilities and trends of its development;
- to substantiate the directions of development of nanotechnologies in the industry using the Hoshin Kanri strategic model.

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METHODS

The object of the study is the process of forming a visualization of data from publications on nanotechnology in industrial activities. The main hypothesis of the study is that, firstly, a bibliometric review of scientific papers can determine the prospects of nanotechnology in industry, which, if used effectively and appropriately, can lead to the development of various areas of activity. Secondly, the bibliometric analysis will deepen the theoretical understanding of the concept of nanotechnology in industry, which will ensure the development of scientific thought.

In solving the tasks set, the bibliometric method was used to review the literature in the Scopus scientometric database. No filters or restrictions were set in the analysis regarding the language of publication, country, subject matter, or affiliation. A significant number of publications on nanotechnology were limited by the key indicator "nanotechnology AND industry", which allowed us to identify works directly focused on industry. A more detailed identification of publications for the bibliometric analysis of works using the keyword "nanotechnology AND industry" is presented in Figure 1.

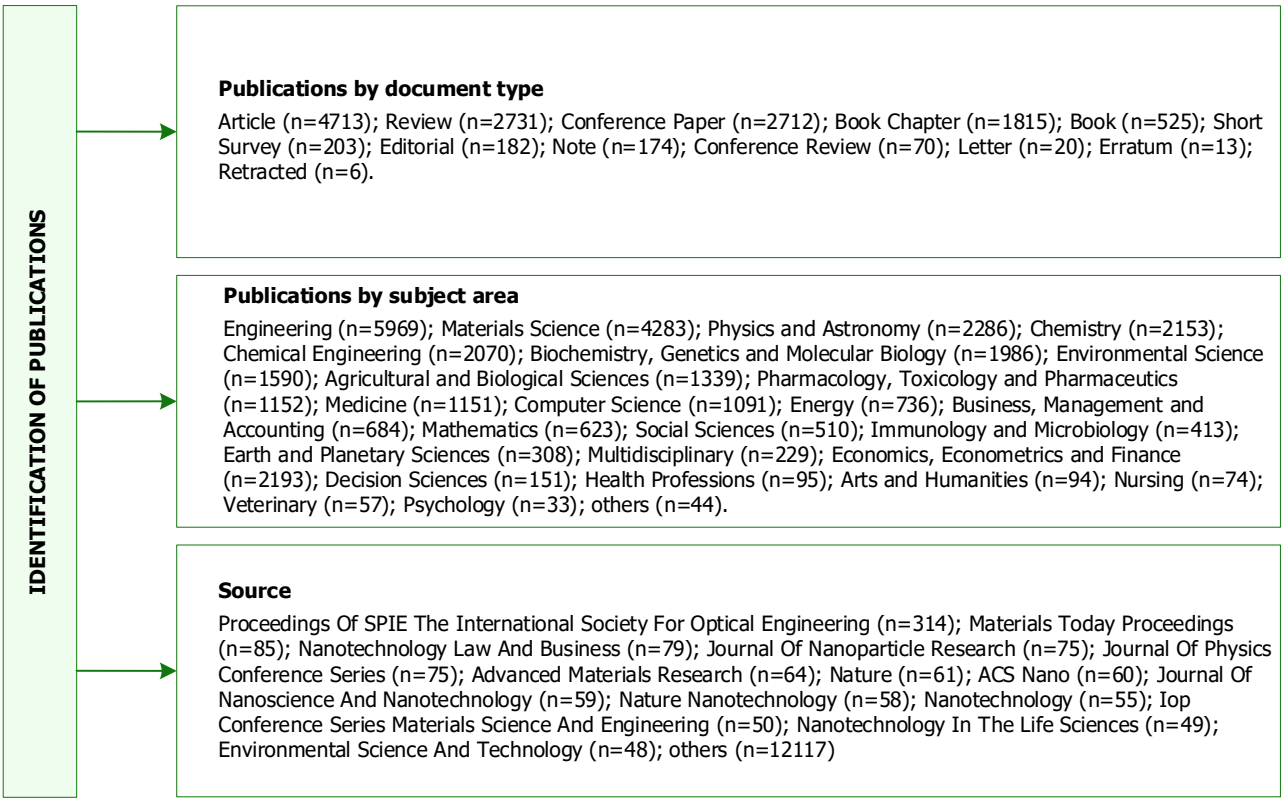

Figure 1. Identification of publications for bibliometric analysis by the keyword "nanotechnology AND industry" in the Scopus scientometric database. Note: n - number of publications. *(Source: compiled by the authors according to the Scopus science-based database)*

Thus, for the bibliometric analysis, we chose an online platform for monitoring and analyzing international scientific research using visualization tools and modern Scopus citation metrics. In addition, the VOSviewer tool (version 1.6.20) was used to build and visualize bibliometric networks. The use of the software made it possible to identify the main links between existing data visualization concepts and to identify new and little-studied aspects of nanotechnology in industry.

The methodological basis of the study is represented by general and special scientific approaches and methods. The general scientific approach is the basis for the formation of the following: prerequisites, trends, patterns and trends in the sustainable development of nanotechnology in industry. The dialectical approach allowed us to formulate the philosophical aspects, factors and conditions of nanotechnology. Based on the critical (evaluative) approach, the following contradictions, critical aspects and paradoxes of the industrial complex were identified, which are focused on the strategic directions of nanotechnology development. The application of systemic and synergistic approaches allowed to form a holistic view of strategy formation.

That is why the paper applies the Hoshin Kanri methodology to formulate a strategy for nanotechnology in industry. The built model will help to harmonize strategies at enterprises, as well as improve business processes for the purpose of cross-functional management. The Hoshin Kanri model for the strategic development of nanotechnology in industry has feedback

and continuous improvement mechanisms. The constant search for consensus between the vision and its realization makes it possible to adapt the vision to changing conditions, taking into account feedback, and thus creating an optimal set of goals. This requires constant feedback between all components defined by groups, as well as the necessary resources for their functioning.

RESULTS

Bibliometric analysis of publications on the topic of nanotechnology in industry, presented in the Scopus scientometric database

The bibliometric analysis of publications allows for a quantitative analysis of scientific papers on the selected topic presented in the scientometric database. The result is a generalization of expert opinion on relevance, novelty of information, monitoring or identification of areas for the development of nanotechnology in industry. However, the greatest practical benefit is obtaining a new and original research result that contains a reliable analysis and synthesis of the information obtained.

Given the rapid increase in the number of publications in the Scopus scientometric database, we consider it appropriate to analyze their network connections by keyword and country. As a result of the search for the keyword "nanotechnology AND industry", 13164 documents were found (without any restrictions on the type of document). Automatic creation and export of the document to CSV format allowed us to summarize data such as author, document title, year of publication, affiliation, and keywords. By using the functionality of the VOSviewer program, a bibliometric map of the interrelationships of publications was built and obtained (Figure 2).

In the course of the bibliometric review, the keyword used as a unit of analysis was a keyword that occurred 22283 times and, in turn, allowed us to identify 1254 citations.

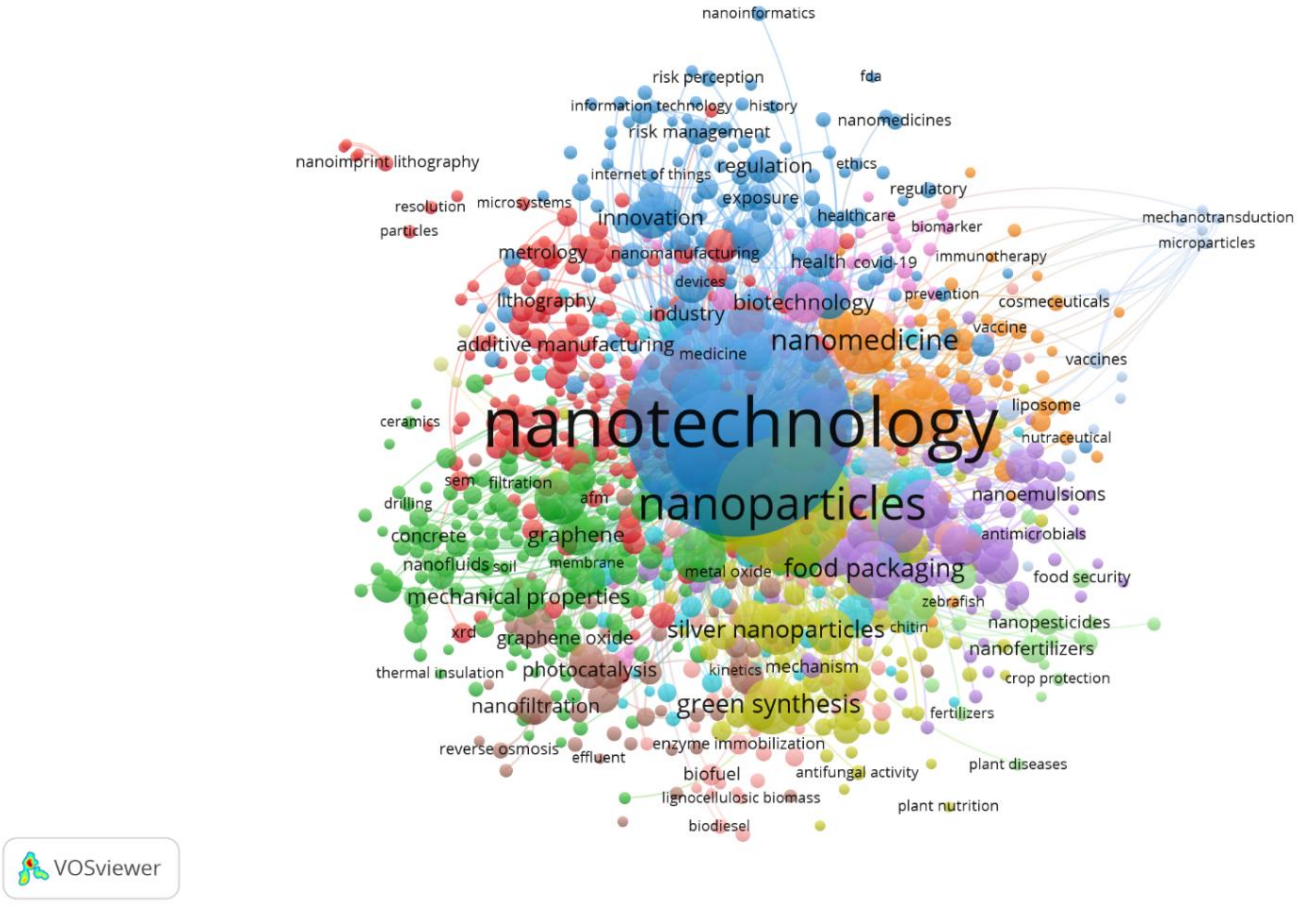

Figure 2. Author keyword co-occurrence network for "nanotechnology AND industry". *(Source: created by the authors using VOSviwer software based on the Scopus database)*

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Using the capabilities of the VOSviewer software, we have distributed the keywords into 13 main clusters using the method of relationship density. Such clusters can be seen as a result of grouping scientific papers presented in the Scopus scientometric database by similarity. As a result of network data visualization, clusters were automatically formed that contain generalizations of scientific papers in a particular area (Table 1).

Table 1. Clustering and generalized characterization by the keyword "nanotechnology AND industry". *(Source: created by the authors using VOSviwer software based on the Scopus database)*

Clusters	Keywords of the cluster	Generalized characteristics of the cluster
Cluster 1 (180 items)	Additive manufacturing, life cycle assessment, metrology, optimization, lithography, nanoelectronics, nanoengineering, nanoimprint lithography, particles	Changing the technology life cycle with nanomaterials
Cluster 2 (146 items)	Nano-composite, mechanical properties, carbon nanotube, wood, strength, microstructure, graphene, nano-silica	Classification of nanomaterials used in production
Cluster 3 (133 items)	Nanotechnologies, nanomaterials, nanoproducts, nanomedicines, bionics, COVID-19, innovation, industry 4.0, life cycle, nanotoxicology, nanotoxicology, risk management, robotics, methodology	Management approaches and methodology for nanotechnology
Cluster4 (97 items)	Green synthesis, silver nanoparticles, antioxidant, antibiotics, antifungal activity, biological synthesis, biomedical, clinical trials, food sector, genotoxicity	The result-oriented process of nanotechnology
Cluster 5 (95 items)	Nanoemulsions, nutraceuticals, nanoliposomes, nano-food, nanoencapsulation, food technology, food industry, antimicrobials	Nanotechnology in the food industry
Cluster 6 (72 items)	Chitosan, starch, starch, bionanocomposites, bionanocomposites, cyclodextrin, hydrophobicity, nano-emulsions, nanosponges	Chemical and microbiological components of nanomaterials
Cluster 7 (65 items)	Cosmeceutical, cosmeceuticals, biomedicine, diagnosis, nanomedicine, biocompatible, homogenization, nanocrystal, liposomes	Nanotechnology and the cosmetics industry
Cluster 8 (59 items)	Biogenic nanoparticles, green nanotechnology, green technology, industrial applications, nanofiltration, nanoremediation, biosurfactant, organic dyes, biogenic nanoparticles	Nanotechnology and ecology
Cluster 9 (57 items)	Biomolecules, biotechnology, chemical engineering, food analysis, genomics, magnetic nanoparticles, laboratory instruction, materials in biotechnology, nanoceramics, pharmacology, pharmacy, systems biology, toxicology	Biotechnology in the nanotechnology industry
Cluster10 (52 items)	Toxicology, biocomposite, biohydrogen, biomaterial, biotransformation, diagnostic, bioenergy, microalgae, nanobiocatalyst, nanobiosensor, nanocarriers, waste management, climate change	Biotransformation
Cluster 11 (21 items)	Food security, nano-coating, nano-encapsulation, nano-fertilizers, nano-packaging, nano-sensors, nanopesticide, nanopesticides, nanosensors, pharmaceutical industry, plant growth	Food security
Cluster12 (20 items)	Antimicrobial agent, bioactive components, bioimaging, mechanotransduction, microneedles, osseointegration, soft-lithography, tissue engineering, vaccines	Nanomedicine
Cluster 13 (3 items)	Lung, multi-walled carbon nanotubes, single-walled carbon nanotubes	Specialized nanotechnologies

We can observe that the clusters summarized in Table 1 are directly or indirectly interconnected with various industries. This is confirmed by the scientific papers in which the authors describe the role, importance and risks of nanotechnology in various fields of activity from different perspectives. Waldron et al. (2006) examine the application of nanotechnology in vital industries around the world and its implications for future industrial progress. Bi et al. (2021) focus on the combination of nanotechnology with a specific industry sector. Cellulosic nanomaterials have nanofibrillar structures that can be made multifunctional for use in construction, furniture, food, pharmaceuticals, and other types of wood-based industries. Nanotechnology has the potential to be implemented in all spheres of society. This primarily concerns nanomaterials science, nanoelectronics and nanomedicine, which are being introduced into all dimensions of chemistry and the physical and biological world (Singh, 2017). Thus, it would not be wrong to predict that nanotechnology will become a mandatory subject of study for future generations (El Naschie, 2006). Studies are emerging that predict promising results in various industries that use: nanofibers, nanofillers, nanoemulsions, nanocomposites, and nanoscale chemicals to increase the potential benefits of manufactured wood products (Papadopoulos & Taghiyari, 2019).

The application of nanotechnology in industry suggests that soon nanotechnology proposals will be implemented in every industry. However, there is a need to take precautionary measures to be aware and educated about the possible environmental and health risks (Malik 2023). The papers selected by the Scopus scientometric database (n=13164) using the

keyword "nanotechnology AND industry" were filtered by the number of citations. Table 2 summarizes the results of the TOP-5 most cited papers that investigate the issue of nanotechnology in industry.

Table 2. TOP-5 sources in most cited papers for the keyword "Nanotechnology and Industry". *(Source: created by the authors using VOSviewer software based on the Scopus database)*

Document title	Authors/ Year	Total citation (Scopus)
Room-temperature transistor based on a single carbon nanotube	Tans, S. et al. (1998)	5312
Drug delivery systems: entering the mainstream	Allen, T. M., & Cullis, P. R. (2004)	3965
Review on zinc oxide nanoparticles: antibacterial activity and toxicity mechanism	Sirelkhatim, A. et al. (2015)	3186
Growth of nanowire superlattice structures for nanoscale photonics and electronics	Gudiksen, M. S. et al. (2002)	2638
Supramolecular nanotube architectures based on amphiphilic molecules	Shimizu, T. (2005)	1389

As can be seen from the table, the most influential authors in the scientific field of nanotechnology in the industry are Tans, S. J., Verschueren, A. R., & Dekker, C., who in 1998 published a paper on conceptually new miniaturization strategies in the electronics and computer industries. Further study of bibliometric data allowed us to build a network map of interactions in Figure 3 to build a network map of relationships between scientists by country. Additionally, a search in the Scopus database for the term "nanotechnology AND industry" in the titles of journals, conferences, and books allowed us to process 13164 sources, most of which were published in the United States (21.75%), India (23.71%), China (9.65%), United Kingdom (5.47%), Germany (4.07%), Iran (3.72%), Italy (3.12%), South Korea (3.15%), Canada (2.59%), Malaysia (2.59%), Japan (2.53%), Saudi Arabia (2.42%), and other countries (less than 2%).

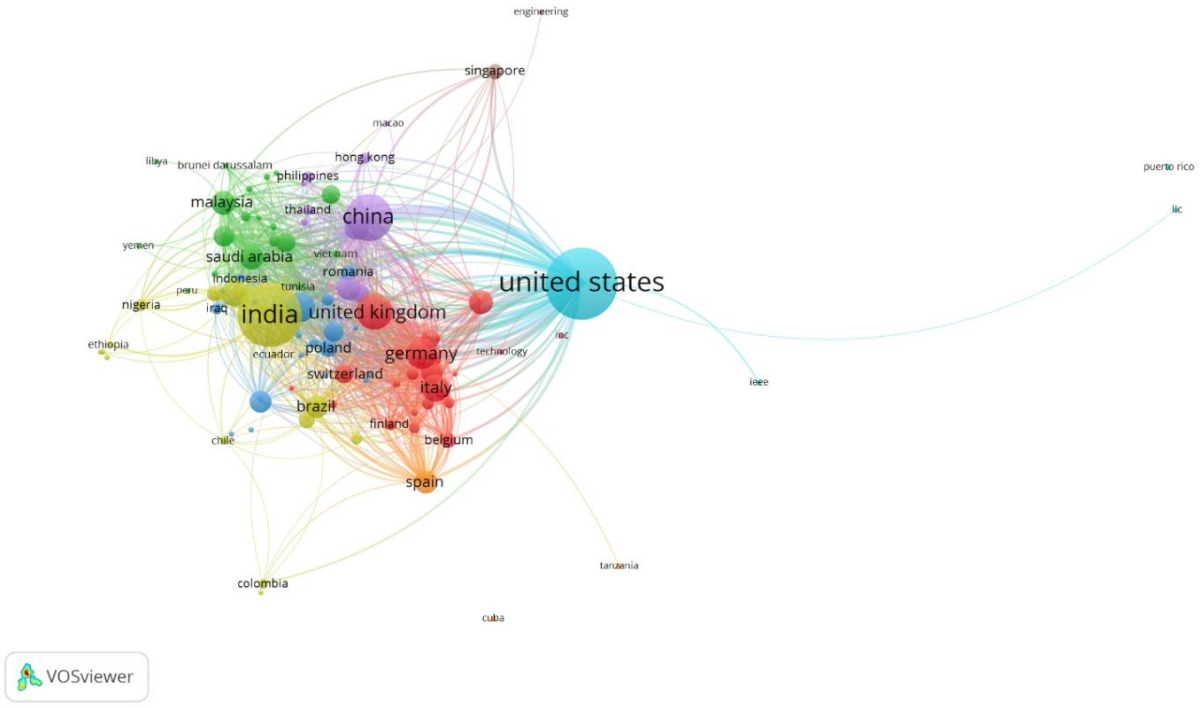

Figure 3. Network map of connections between scientists in different countries of the world. *(Source: compiled by the authors based on scientific publications indexed by the international scientometric database Scopus, using the VOSviewer)*

The study of mutual citations between representatives of different countries requires the identification of key authors and their affiliation with institutions. The following authors are among the most influential in the world in terms of the number of publications on nanotechnology in the industry: Grumezescu, A.M. (n=30), Jafari, S.M. (n=25), Wang, Z.L. (n=24), Iqbal, H.M.N. (n=23), McClements, D.J. (n=22), and others. Thus, the leader in terms of activity in publications is Grumezescu, A.M. (University Politehnica of BucharestThis link is disabled., Bucharest), who explores the concept of nanotechnology in the production of products.

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In the course of the bibliometric analysis, graphical data from the Scopus scientometric database allowed us to see the affiliation of authors working on scientific papers on nanotechnology in industry (Figure 4).

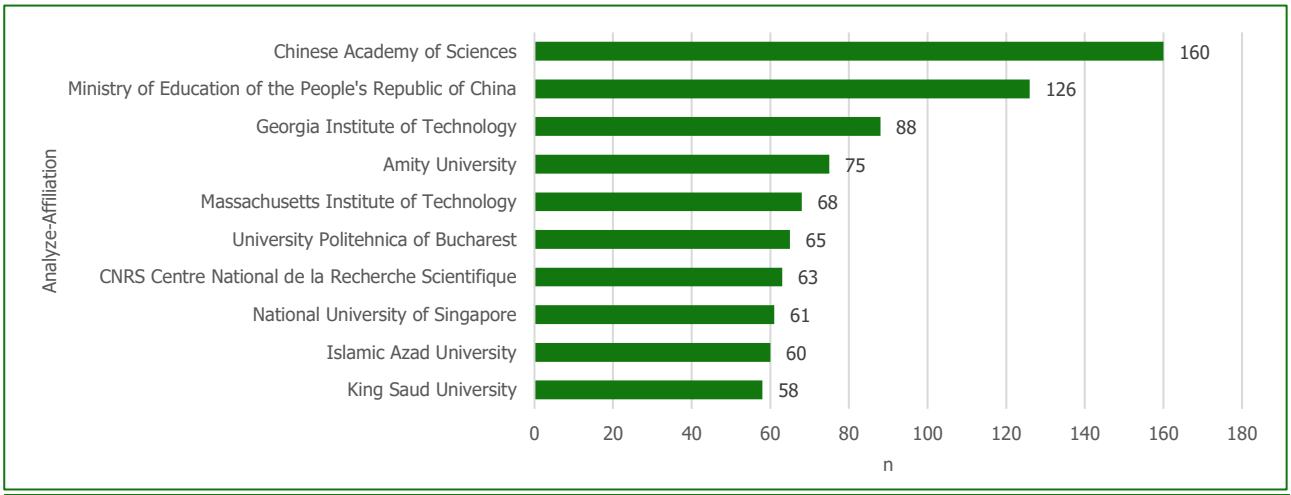

Figure 4. Publications of documents on nanotechnology in industry by affiliation. *(Source: obtained at the author's request in the international scientometric database Scopus)*

Thus, it was found that the following institutions are the most common in terms of authors' affiliation: Chinese Academy of Sciences (1.22 %), Ministry of Education of the People's Republic of China (0.96 %), Georgia Institute of Technology (0.67 %), Amity University (0.57 %), Massachusetts Institute of Technology (0, 52%), University Politehnica of Bucharest (0.49%), CNRS Centre National de la Recherche Scientifique (0.48%), National University of Singapore (0.46%), Islamic Azad University (0.45%), King Saud University (0.44%).

The conducted bibliometric analysis shows a wide range and interest in scientific research of industrial nanotechnology worldwide. This is due to the use of innovative technologies, economic development, and branding of individual enterprises and territories.

Analysis of the nanotechnology market in industry: current state, financial capacity and development trends

Nanotechnology is a branch of science that deals with the study and manipulation of materials at the nanoscale. It involves working with materials as small as 100 nanometers. At this size, the characteristics and behaviour of materials can differ significantly from their larger counterparts. Engineers and scientists can create new materials and technologies with unique properties and functions by designing and building materials and devices at the nanoscale.

These breakthroughs have the potential to change a wide range of industries, from healthcare and electronics to energy and more. Nanotechnology is an exciting and fast-growing field that has the potential to change the future of technology and improve lives in many ways. We expect to see more and more inventive applications of nanotechnology in many fields as scientists continue to make advances in the field, making it a key area of research and development in the future.

Nanoclays, nanocomposites, nanotubes, nanotools, nanodevices, nanomaterials, and nanoparticles are the era of technologies that are pushing the world to a new stage of life without which further development is impossible: medicine, electronics, education, food and other industries.

The size of the global nanotechnology market in 2022 was estimated at USD 10 billion, and it is projected to reach approximately USD 38.23 billion by 2032 with a CAGR of 14.40% between 2023 and 2032 (Figure 5) (Canada/India based company and one of the leading providers of strategic market insights). Such forecasts indicate the rapid development and the need for nanotechnology in various basic and knowledge-intensive industries.

The global "market share was over 35% in 2022 and dominated the global nanotechnology market" (Nanotechnology Market Size, Share, and Trends 2024 to 2034). The Asia-Pacific region is the leading leader, covering a significant number of consumers of electronics, medical equipment, automotive equipment, and textiles. This, in turn, has led to demand for nanomaterials in production processes.

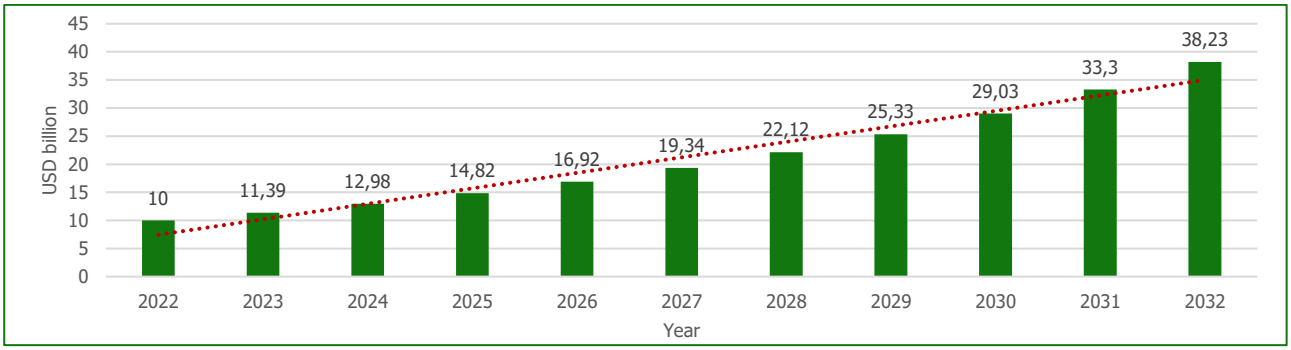

Figure 5. Dynamics of the global nanotechnology market by 2032, USD billion. *(Source: based on [6])*

In addition, rising government investment in the energy "sector in Asia Pacific is expected to drive demand for nanomaterials in the coming years.

The demand for nanomaterials in countries such as China, India, South Korea, and Japan, is relatively high due to the presence of strong production capacities in various industries" (Nanotechnology Market Size, Share, and Trends 2024 to 2034). This can be seen in the dynamics of patents filed in 2018-2023 (Table 3).

Table 3. Top 20 countries by the dynamics of nanotechnology (patents). *(Source: Provides the global and regional ranking of the main indicators of nanoscience, technology, and industry)*

Countries	Years					
	2018	2019	2020	2021	2022	2023
USA	5,646	5,962	6,369	6,388	6,714	6,926
South Korea	1,004	1,103	1,142	1,364	1,513	1,715
China	913	900	1,125	1,599	1,561	1,627
Taiwan	532	590	655	784	1,065	1,118
Japan	792	849	948	979	1,126	1,113
Germany	424	423	426	427	539	484
UK	224	234	247	266	315	331
France	295	252	289	269	351	323
Canada	194	218	272	283	276	290
Saudi Arabia	158	193	208	244	219	268
Switzerland	140	145	130	144	178	163
Netherlands	115	124	144	178	146	152
Belgium	82	81	56	84	71	102
Italy	71	70	91	84	86	99
Australia	60	68	69	94	102	97
Singapore	85	104	74	81	102	87
India	66	60	69	74	81	78
Spain	46	56	55	79	57	70
Finland	71	60	57	81	74	67
Sweden	52	51	62	70	84	65

Rising foreign direct investment "due to favourable industrial policies and the availability of cheap labour and other inputs is also expected to spur the manufacturing sector in Asia Pacific, driving the consumption of nanomaterials in the region. Rising employment rates, ever-increasing demand for technologically advanced electronics, and rising investment in infrastructure projects are significant drivers of the nanotechnology market in Asia Pacific" (Canada/India-based company and one of the leading providers of strategic market insights).

"Europe is the second largest market for nanotechnology in 2022. Industrial development in Europe and higher adoption of advanced and new technologies in production facilities have contributed to the growth of the nanotechnology market" (Nanotechnology Market Size, Share, and Trends 2024 to 2034). Increased disposable income of consumers and improved

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living standards have led to an increase in demand for various advanced electronic devices, sensors, and photonic devices. The presence of advanced healthcare infrastructure and increased access to developed medical facilities further fuel the growth of the nanotechnology market due to the high demand for miniature devices in the healthcare sector.

The recent outbreak of the COVID-19 pandemic in 2020 has led to increased investment in activities to develop new potential applications of nanotechnology in the prevention, diagnosis, and treatment of COVID-19 disease.

"Nanomaterials are increasingly being used in pharmaceutical and healthcare applications such as imaging, photothermal therapy, medical implants, and biomedical uses due to their antimicrobial, anti-tumor, and antioxidant properties. The demand for nanomaterials in the electronics industry is increasing significantly due to the growing demand for spintronics, quantum dots, and nanowires in the nanoelectronics sector. The growing demand for high-tech electronic products globally is expected to drive the growth of the global nanotechnology market" (Nanotechnology Market Size, Share, and Trends 2024 to 2034).

Directions of nanotechnology development in the industry using the strategic model of Hoshin Kanri

The bibliometric review and market research on nanotechnology indicate that it can contribute to solving some of the world's most challenging problems, such as climate change, water scarcity, food security, and disease prevention. Nanotechnology can also create new opportunities for innovation, competitiveness and growth for businesses of all sizes and sectors.

Nanotechnology in industry is focused on improving the performance and quality of existing products and processes, making them: stronger, lighter, faster, smarter or more efficient. In addition, nanotechnology can reduce the costs and waste of production and consumption, for example, by using less material, energy or water, or by allowing for recycling and reuse.

In today's world, nanotechnology can create new markets and applications that were not previously possible, for example, by providing new functions or delivery methods. Taking into account these key aspects, we believe it is appropriate to formulate the Hoshin Kanri model for the strategy of nanotechnology in industry (Figure 6).

*	*	*	Designed to help solve global environmental problems (8)	*	*		*	RESURCES		v	*	v
*	*	v	Improving energy production, storage and conversion (1, 2, 3, 9)	*	*		*		*	v	*	*
*	*	*	Revolutionize the diagnosis and treatment of diseases (7,9,10,12)	*		*	*		*	v	*	v
*	*	*	Development of faster, smaller and more intelligent devices and systems (1,2,3,4,6,13)	v		v	*		*	v	*	*
*	*	v	Food synthesis (4.5)	v	v	v	*			v	*	*
*	*	*	Creation of powerful, convenient and efficient machines and mechanisms (1,2,4,13)	*	v		*		*	v	*	*
*	*	*	Creating stronger, more durable and sustainable materials (1,2,4,9,10,12)	*	*		*		*	v	*	
*	*	*	Revolution in agricultural production (1,2,4,5,8)	v	v		*			v	*	*
*	*	*	Allows you to create fabrics that provide comfort and reduce production costs (1,2,3,9,13)	*	*	v	*		v	v	*	*
*	*	*	Robotics, unmanned systems and aircraft construction (1,3,4,13)	*			*		*	v	*	*
Used in a variety of processes and products	Benefits to various stakeholders such as consumers or producers	Improve the quality of life	Benefits of nanotechnology by industry / Priorities / Objectives / Risks from nanotechnology	More efficient use of energy	Environmental monitoring and protection	Reducing the number of diseases and increasing life expectancy	Increase production volumes by reducing costs		Software	Personnel	Capital, financing	Material and technical base
*	*		Adverse impact on the environment and human health	v	*							
*	v		Creating ethical and social obstacles									
*	v	*	Regulatory and legal inconsistency	*	*	*	*					
*	*		Impact on the economy and civil society	*	*		*					

Figure 6. Hoshin Kanri model of nanotechnology strategy in industry. Note: (1-13) scientific cluster according to the bibliometric map of network data visualization using the keyword "nanotechnology AND industry"; Conventional notation: * - direct dependence; v - indirect connection between the benefits, priorities, tasks and risks of nanotechnology when using appropriate resources.

The Hoshin Kanri model demonstrates the benefits of nanotechnology across a variety of industries. Some developments are already demonstrating solutions to environmental pollution, climate change, and the depletion of natural resources by using nanomaterials and nanosystems that can: monitor, repair, and prevent environmental damage. Nanotechnology is indispensable in the energy system due to the use of nanomaterials and nanostructures that have efficient electrical, thermal and optical properties. Thanks to their ability to manipulate materials at the molecular and atomic levels, breakthroughs in medicine and cosmetology are taking place. In the era of digitalization, it is impossible to do without creating devices that can process, store, and transmit information. The growth of the world's population has already contributed to the creation of artificial products in the food industry. This convenience and the possibility of avoiding a food crisis is a promising area of nanotechnology development. The revolution of nanotechnology in agricultural activities contributes to the improvement of efficiency, environmental friendliness and quality of final products. In the era of military conflicts, the development of unmanned aerial and robotic systems requires a special strategy, where robotics, drones and drones are integral in solving many problems.

Nanotechnology, as a special type of activity, has certain priorities. Regardless of the industry or industries, the priority is their use in various processes and products. In addition, they offer certain benefits to various market participants, such as consumers or producers, and improve their quality of life. The strategic prospects of nanotechnology in industry address a number of challenges, including more efficient energy consumption, environmental monitoring, healthcare, and increased production by reducing costs.

When formulating a strategy, one should not forget that there are always certain risks along with benefits. Timely identification of such obstacles will help avoid unnecessary costs by making timely and effective management decisions. Despite the benefits of nanotechnology, it can have an adverse impact on the environment and human health.

This factor may be related to a particular country, region, and economic opportunity. The creation of ethical and social obstacles, such as privacy, security and social justice, is an inherent risk in healthcare or processes that require the use of digital processes. Nanotechnology often causes controversy due to regulatory inconsistencies. This, in turn, affects the economy and civil society, such as inequality and conflicts, such as unemployment, displacement of population, changes in products and services based on nanotechnology.

DISCUSSION

The construction of a bibliometric map of network data visualization using the keyword "nanotechnology AND industry" allows us to form scientific clusters of nanotechnology in the industrial sector. This, in turn, demonstrates the interests of scientists and specialists who cover the results of their research in various publications included in scientometric databases, including Scopus. The applied methodological approach confirms its relevance but is broader than in (Li et al., 2022; Hernández-Contreras et al., 2024; Zhu et al., 2021) which focuses on certain industries such as medicine and construction. The network visualization map demonstrates inter-citation by related industries and nanotechnologies. The use of the VOSviewer software simplified the process of processing scientific papers (n=13164) and contributed to the identification of 13 clusters. The identified keywords in each of the clusters allow us to focus on the formation of strategic perspectives on the development of nanotechnology in industry. Changes in the life cycle of technologies (cluster 1) are the directions of development of the latest technologies and technology systems in the world, which is due to the emergence of nanomaterials. This is confirmed by the fact that cluster 2 defines the classification of nanomaterials used in production. The classification presented in (Rambaran & Schirhagl, 2022) can be developed and supplemented to meet the realities of the future and the emergence of new nanomaterials. Management approaches and methodology of nanotechnology (cluster 3) contain the most common keywords: "nanotechnologies", 'nanomaterials', 'nanoproducts', etc. The cluster is characterized 4 as a process of nanotechnology action aimed at a result that allows to develop gaps that are not taken into account by the authors in (Jiménez et al., 2022; Biliavska et al., 2024), to strengthen the methodology by involving nanotechnologies, which are not without the need for information support (Biliavskyi et al., 2024; Shestack et al., 2023). Related clusters 5, 6 and 11 include works where the authors consider the issues of food technology and food security (Shah et al., 2023; Hamad et al., 2018). Market changes and development trends, as well as globalization processes, require a strategic view of the implementation of nanotechnology in the food industry. In the course of the bibliometric analysis, it was found that nanotechnology has an impact on the environment (de Francisco et al., 2018; Malik et al., 2013), and this is confirmed by cluster 8. Separately formed clusters 7, 9, 10 and 12 are focused on healthcare and pharmacy. They are reflected in the works of scientists (Al-Nemrawi et al., 2020; Trinidad et al., 2021; Li et al., 2020), which highlight the unresolved parts of the tasks that can be realized through the development of nanotechnology. Cluster 13 defines specialized nanotechnologies, which are the focus of the authors' attention in (Pang et al., 2024; Ferdous et al., 2024). A signif-

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icant number of identified and analyzed papers (n=13164) in the Scopus scientometric database showed interest in identifying the most cited papers. Thus, it can be seen that the subject matter of the papers is focused mainly on nanotechnology in the manufacturing industry with the aim of creating products that accelerate the performance of certain types of work.

The TOP-5 most cited papers indicate a wide geography of scientists, which is confirmed by the construction of a network map of connections between different countries of the world. The figure clearly shows that the leaders of nanotechnology in industry are: the USA, India and China. The leadership of China is confirmed by the affiliation of scientists. The identified scientific interest and the wide geography of the study, as a result of the bibliometric analysis, require further development. That is why the paper considers the trends of the nanotechnology market in industry. The dynamics of the global nanotechnology market until 2032 show a positive trend, which indicates financial support for the development of nanotechnology in the world. According to statistics, it is possible to predict the countries with the greatest potential for the development of production facilities in various industries.

The analysis shows a generalized strategic model of Hoshin Kanri, which provides for the scope of scientific interests according to the network map and clusters. In addition, market trends and global financial capacity are taken into account, which is confirmed by the data.

Hoshin Kanri's strategic model allowed us to identify the benefits of nanotechnology by industry, priorities, tasks, and risks. We can observe that almost all components, including resources, are directly linked. This demonstrates the importance of nanotechnology for any industry, given its priorities and objectives. Also, we should not forget about possible risks, such as the regulatory framework, economic or social situation, because when analyzing market trends, it is obvious that nanotechnology is quite unevenly distributed in the world. In addition, each of the advantages of nanotechnology has found its relationship with scientific clusters, which indicates the systematic nature of the study and the relevance of further research on the development strategy.

The difference from previous studies (Shah et al., 2022; Jiménez et al., 2022; Malik et al., 2023) is that for the first time, the strategic changes of nanotechnology in the industry were determined using the Hoshin Kanri model. It allows not only to assess the real state of the nanotechnology market but also to develop an optimal plan for individual industries. A key component of the model is that, in addition to identifying opportunities, risks, and changes, it focuses on the need for resources. This is an integral part of any technology and the possibility of its further development for the final implementation of the project.

The limitation of the presented study is that the data for the Hoshin Kanri model was collected using bibliometric analysis of scientific papers exclusively in the Scopus scientometric database. Supplementing the data with data from the PubMed, Web of Science, OpenAlex, and Crossref databases would allow us to form scientific clusters somewhat differently and find other opportunities for the strategic development of nanotechnology in industry. However, this does not exclude the process of duplication of work, which affects the accuracy of the result. The number of papers reviewed (n=13164) is a significant number for obtaining a reliable result and developing effective strategic decisions.

The development of this study is that nanotechnology is a rather promising area for improving and making changes in the development of industry. Therefore, there is a need to formulate prospects that can be determined by modern methodological approaches, which include bibliometric analysis and the construction of the Hoshin Kanri model. This allows for accumulating significant resources, which will further contribute to the effective organization of the work of industrial enterprises. The tools presented in this article for analyzing nanotechnology in industry can be changed depending on various circumstances, namely, changes in market conditions, under the influence of force majeure, rapid globalization processes, and digitalization.

CONCLUSIONS

1. The scientific directions of nanotechnology in industry are systematized by means of bibliometric analysis and construction of a network map of data visualization using the keyword "nanotechnology AND industry". It has been established that the Scopus scientometric database contains (n=13164) papers without filters by year, language, country, or other parameters. Data processing by the VOSviewer software (version 1.6.20) formed 13 scientific clusters in which nanotechnology is interconnected with industry. The identified keywords made it possible to characterize the clusters, as well as to predict the strategic directions of development or the strategy of nanotechnology in industry, which are reflected in the Hoshin Kanri model.

2. The market of nanotechnologies in industry is analyzed with the definition of the current state and development trends. The dynamics of the global nanotechnology market until 2032, USD billion. The fact that the US market is worth more than USD 3.5 billion indicates the financial capacity of nanotechnology development, which allowed to predict the leading countries: USA, South Korea and China. In addition to the practical implementation of nanotechnology, the bibliometric analysis confirms the scientific interest of representatives of these countries in considering nanotechnology issues in the industry of the United States (21.75 %), China (9.65 %) and South Korea (3.15 %). Therefore, there is a need to develop nanotechnology taking into account: priorities, tasks and risks. This will expand the scope of scientific interests and find practical applications in many industries.
3. The author substantiates the directions of the development of nanotechnology in the industry using the Hoshin Kanri strategic model. Thus, the advantages of using nanotechnology by industry reveal the key strategic directions for each industry. Each of them confirms its relevance and is reflected in the scientific clusters that resulted from the bibliometric review. The identified priorities of nanotechnology demonstrate a direct correlation with the benefits, as they are used in various processes and products, have advantages for the producer and consumer, and improve the quality of life of civil society. The presented tasks of nanotechnology are necessary for organizing the implementation of certain priorities and obtaining the corresponding results. Strategic management of nanotechnology in industry is impossible without taking into account the risks that may arise in the process. The model presents general risks that are threatening to any industry. However, it is also possible to foresee specific risks according to the key features of any industry.

Thus, the recommendations are to expand the scientific and practical work in the field of nanotechnology for various industries, regardless of country, affiliations or industry. This will contribute to the further improvement of industrial technology systems, accelerate the implementation of the latest technologies, and develop the country's economy and science in world practice.

ADDITIONAL INFORMATION

AUTHOR CONTRIBUTIONS

All authors have contributed equally.

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CONFLICT OF INTEREST

The Authors declare that there is no conflict of interest.

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ФІНАНСОВИЙ ВИМІР СТРАТЕГІЧНОГО РОЗВИТКУ НАНОТЕХНОЛОГІЙ У ПРОМИСЛОВОСТІ

Об'єктом дослідження є зростання інтересу до візуалізації даних публікацій на тему нанотехнологій у промисловій діяльності, що представлені науковими роботами в наукометричних базах даних, зокрема Scopus. У науковій практиці недостатньо широко представлені стратегічні напрями розвитку нанотехнологій у промисловості із застосуванням сучасних методичних підходів.

Метою роботи є формування стратегічних напрямів розвитку нанотехнологій у промисловості за допомогою моделі Hoshin Kanri шляхом проведення бібліометричного аналізу та дослідження тенденцій ринку, що дозволяє оцінити фінансові можливості країн.

У результаті проведеного дослідження було виявлено, що в наукометричній базі Scopus представлено (n=13164) документів таких як: статті, тези, огляди, книги за різноманітними предметними царинами. Опрацьовані дані документів за допомогою програмного забезпечення VOSviewer сформували мережеву карту взаємозв'язку наукових інтересів нанотехнологій у промисловості. Установлено, що існує 13 таких кластерів, які включають огляд нанотехнологій за змінами життєвого циклу, вплив на харчову промисловість, хімічні й мікробіологічні процеси, екологію, біотехнології, наномедицину й спеціалізовані нанотехнології. Установлено, що країнами-фінансовими лідерами нанотехнологій є США, Китай, Індія, Південна Корея та Японія.

Запропонована оригінальна модель Hoshin Kanri стратегічних напрямів розвитку нанотехнологій у промисловості забезпечить розвиток наукових поглядів і їх подальше впровадження в практику діяльності суб'єктів господарювання. Описані складові за такими групами, як: переваги нанотехнологій за галузями, пріоритети, завдання та ризики – можуть бути використані на практиці в будь-якій галузі промисловості з метою переходу на новий етап життєвого циклу технологій. Це дозволить прискорити управління бізнес-процесами, здійснити раціональне використання ресурсів та ухвалити дієві управлінські рішення.

Ключові слова: бібліометричний аналіз, карта візуалізації, фінансування, науковий кластер, управління, процес, технологія, модель Hoshin Kanri

JEL Класифікація: L10, L11, O33

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