LATVIAN JOURNAL OF PHYSICS AND TECHNICAL SCIENCES
2017, N 5

DOI: 10.1515/lpts-2017-0029

PHYSICAL AND TECHNICAL ENERGY PROBLEMS

THE DEVELOPMENT OF NANOTECHNOLOGIES AND ADVANCED MATERIALS INDUSTRY IN SCIENCE AND ENTREPRENEURSHIP: SCIENTIFIC INDICATORS. A CASE STUDY OF LATVIA (PART THREE)

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The present scientific paper is the third part and continuation of the in-depth scientific study of the developed system of engineering economic indicators, where the authors obtain results from the scientific research presented in a series of works on the development of the nanotechnologies and advanced materials industry in science and entrepreneurship in Latvia. Part three determines the crucial scientific indicators of the development of nano-field at the macro, micro, and meso development levels of the economic environment in Latvia. The paper provides the interaction of new identified indicators of nano-field in terms of further scientific and practical activities. Latvia is analysed in comparison with other countries in the world.

Keywords: *advanced materials, development of science, economic environment level, engineering economic indicator system, nanotechnologies, research, scientific indicators*

1. INTRODUCTION

We are at the beginning of a global transformation that is characterised by the convergence of digital, physical, and biological technologies in ways that are changing both the world around us and our very idea of what it means to be human. The Fourth Industrial Revolution is not defined by any particular set of emerging technologies themselves, but rather by the transition to new systems that are being built on the infrastructure of the digital revolution. The fundamental and global nature of this revolution also poses new threats related to the disruptions it may cause – affecting labour markets and the future of work, income inequality, and geopolitical security as well as social value systems and ethical frameworks [1].

In accordance with the above-mentioned topicality and the continuation of the present study, which follows and correlates with the in-depth analysis of the previous two studies [2], [3], the development of the nano-field can also be identified and revealed from the perspective of scientific indicators. With regard to the structure of the research on nanotechnologies and advanced materials industry in science and entrepreneurship, it should be noted that the research will reveal crucial scientific indicators of the development of the nano-field at the macro, micro, and meso development levels of economic environment in Latvia.

The authors have conducted in-depth research on scientific indicators from the perspective of nano-field because they consider that the key aspects determining the competitiveness and productivity of every country are the quality of higher education, skilled labour force, R&D level and development of innovations, which are crucial factors for any economy that follow global trends and modernise simple production processes and create the added value for their products. In the era of innovative technologies and digital revolution, there is also a need for an environment that will foster innovative activities and ideas supported by both the public and private sectors. Investment in R&D is important and necessary, in general, and in the private sector, in particular, where there is an increasing need for high-quality research institutions that can provide the basic knowledge necessary for the development of new technologies, extensive cooperation in research and technological development between universities and the industry. Thus, the development and analysis of scientific indicators at the macro, micro, and meso development levels are topical and relevant.

The **aim** of the research is to develop the scientific indicators at the macro, micro, and meso development levels, evaluate them at the level of Latvia and compare them with the indicators of other countries if applicable to the nano-field in science and entrepreneurship.

To reach the aim of the study – to analyse the scientific indicators characterising the level of development of nano-field in quantitative terms in Latvia, the following research **methods** have been used: statistical, logical, data processing and comparative analysis, the study of the primary and secondary sources of the scientific literature, induction and deduction, scientific overview of theoretical aspects of the issue under consideration, as well as the study of a set of indicators.

The **results** of the research can be used to determine further enhancement of the Latvian nano-field in science and entrepreneurship, and R&D policy, as well as ensure further areas of research.

2. RESULTS AND DISCUSSION

Assessment of the Scientific Indicators

At the macro or global level, the group of scientific indicators includes indicators characterising the development of science, such as the total number of citations to nano-articles and average citation per nano-article, which are the main indicators evaluating the state's scientific excellence. According to the statistical report by Stat-Nano on the total number of citations to nano-articles, in 2016 Latvia was ranked only 67th out of 105 countries in the world, demonstrating 108 cited nano-articles in compliance with the data of the Web of Science (ISI Web of Knowledge). According to this report, Latvia holds similar positions with Lebanon, Belarus and Jordan [4]. However, in the report on average citation per nano-article, in 2016, Latvia was ranked 53rd out of 106 countries in the world, demonstrating an index of 1.07 that was also achieved by North Korea, the Czech Republic, Lebanon and the UAE [5].

As the next scientific indicator, the authors propose the number and quality of publications and studies by science sectors that indicates the development of scientific productivity and the citation impact of a researcher. To reflect this indicator, the authors use both h-Index of nano-articles according to Web of Science and h-Index in Nanoscience and Nanotechnology according to Scopus and ISI indexed nano-articles. In the report on h-Index of nano-articles according to Web of Science, in 2016 Latvia was ranked 53rd out of 106 countries in the world, obtaining the index of 6.00. Bulgaria, Croatia, Hungary, Luxembourg, Morocco, Nigeria, Norway etc. also demonstrated the same index as Latvia [6]. H-Index in Nanoscience and Nanotechnology according to Scopus shows the following: In 2016, Latvia was ranked 74th out of 131 countries in the world with an h-index of 19, i.e., a number of articles (h) that received at least h citations. Similar indicators were also obtained by Qatar, Indonesia, Luxembourg, Lebanon, Armenia and Venezuela in 2016 [7]. In terms of ISI indexed nano-articles (Web of Science), the authors note that in 2016 Latvia was ranked 68th out of 106 countries with 101 ISI indexed nano-articles. Lebanon, Kazakhstan, and Jordan showed the highest results with regard to this indicator [8]. The analysis of these data and the position of Latvia in the competition of the world's countries demonstrate that the low state funding in R&D, inadequate public and private investment, as well as problems with human resources analysed in the previous two studies are the main factors that hinder the development of scientific research in Latvia.

A more positive trend is observed with respect to the national priority in nanoscience, i.e., the ratio of the total number of nano-articles to the share of articles of the country of the same period. In 2016, by the index of national priority in nanoscience, Latvia was ranked 29th out of 106 countries in the world, by holding the position between Thailand (28th place) and the Czech Republic (30th place). Other countries by the statistical level of a similar indicator are Vietnam, Russia and Taiwan, which have a higher index than Latvia. However, the adjacent countries, according to the lowest ranking, are Bulgaria, Tunisia, Kazakhstan and Azerbaijan. Since 2000, the index of national priority in nanoscience has reached its highest level in 2006, i.e., 2.20. This indicator has been achieved by Latvia, and it is the highest level in statistics of all the above-mentioned countries. In spite of high fluctuations, dynamic changes have been observed in all countries, and at present all these countries, including Latvia, have achieved the index of national priority in nanoscience between 1 and 1.5. This is a decline for Latvia, while Qatar, Egypt, Romania and Vietnam experience high growth [9].

At the global level, it is worth mentioning the number of nano-articles per million people, by which Latvia was ranked 37th in 2016 (51.52 – ratio of nano-articles to country population (per million people)) out of 106 countries in the world, demonstrating a high growth rate in 2015 and 2016, respectively. However, Cyprus was ranked 36th, while Serbia – 38th. It is interesting to mention the results of the neighbouring countries of Latvia – Estonia was ranked 19th in this rating group, while Lithuania – 33rd [10].

With regard to the group of scientific indicators, the authors have also chosen the share of international collaboration in nanoscience (share of joint nano-articles between one country and other countries, %). In the ranking of 106 countries in the world in 2016, Latvia was ranked 57th with 69.23 %, which compared to 2009 (75 %) means the reduction in the number of international scientific publications in cooperation with foreign authors. Slightly better results were demonstrated in 2016 by Singapore (69.63 %), Bangladesh (69.66 %), Iraq (70.54 %), and slightly lower – by Jordan (68.75 %), Croatia (68.35 %), New Zealand (68.33 %) and France (68.12 %) [11].

As the final scientific indicator at the global level, the number of nano-articles per GDP (article per billion $) should be mentioned, which shows that Latvia in 2016 was ranked 33rd (1.98 number of nano-articles per billion $ GDP) out of 106 countries in the world, demonstrating moderate growth rate from 2005 (0.90 number of nano-articles per billion $ GDP) to 2014 with some fluctuations in the time series. In 2016, slightly better places, i.e., 32nd place and 31st place were taken by Romania and Lithuania, respectively. However, slightly lower positions were occupied by the UK (34th place) and Italy (35th place). It is interesting to note that Estonia was ranked 9th in this ranking [12].

There are a variety of publications concerning nanotechnologies and nanoscience development in general, in oldest and latest publications. For instance, European applications of micro/nanotechnologies were analysed by Antonio Martinez de Aragón (2000) [13], application of nanoscience in construction was analysed by David Tetlow et al. (2017) [14], its environmental applications were analysed by Henning Wigger, Michael Steinfeldt, and Alvise Bianchin (2017) [15] and other scientists. Studies in this area are of high importance. Countries that produce most publications in nanoscience play an important role in the technological development of the country.

At the meso level, the group of scientific indicators includes: the total amount of fundamental studies in materials science per year; persons employed in science and technology; government procurement of advanced technology products; statistics on the creation of new research working groups, which characterise the scientific and research capacity in Latvia at the national level.

In Latvia, fundamental studies related to materials science are mainly carried out by higher education and research institutions, e.g., the University of Latvia, Riga Technical University, as well as separate national research institutes. Several materials science-related centres of excellence, research institutes, laboratories and other academic organisations have also been established, participating in many European and international projects on various topics of materials science. In a number of 27 nano-field programmes from 2002 to 2012 [16], Latvia has participated in 18 scientific projects with a total funding of 30 million EUR, with average EU contribution rate of 77 %. The projects' sum is 30 % larger than one contract value in the USA [17]. It should be noted that in 2016 the Latvian Council of Science funded fundamental and applied research projects in the amount of 4,388,212 EUR, which amounted to approximately 11 % of the total financing of scientific projects in Latvia [18]. However, according to the Central Statistical Bureau of the Republic of Latvia, in 2015, 152.3 million EUR were invested in research in Latvia, which amounted to 6.5 % less than in 2014. In 2015, foreign funding still made the largest part – 45.0 % – of the total funding in research, 32.7 % was state funding, 20.1 % – private financing, and 2.2 % – university funding. Of the total expenditure on research, the largest part of the expenditure – 67.2 mln. EUR or 44.2 % – was spent on applied research. Total expenditure on fundamental research, compared to 2014, increased by 9.6 %, and in 2015 it amounted to 52.5 mln. EUR [19]. Taking into account that statistical data on projects implemented in Latvia in the field of innovative materials production and high technology industry in the nano-field are difficult to collect and their number may be inaccurate due to a lack of statistics, the authors of the study suggest carrying out a separate study on the level of scientists' awareness about the availability of fundamental research and its evaluation with other European countries.

It is interesting to note that at present strategic plans in nanotechnology development are elaborated and enhanced in countries such as Australia, Austria, Canada, China, Denmark, Finland, Germany, Iran, Ireland, Netherlands, New Zealand, Norway, Pakistan, Poland, Russia, Saudi Arabia, South Africa, South Korea, Switzerland, Thailand, the UK and the USA [20]. For nanoscience development, it should be crucial to develop environmentally-friendly solutions in the development of many industries.

With regard to the next indicator of persons employed in science and technology, the authors state that in the ranking of 28 EU countries in 2016 according to the classification of economic activities – NACE Rev.2 "High-technology sectors (high-technology manufacturing and knowledge-intensive high-technology services" Latvia was ranked 21st (7.0 % of total employment) and held a similar position with the Netherlands (7.0 %) leaving behind Portugal (6.8 %), Germany (6.3 %), Poland (6.0 %) and other EU countries. It should be noted that the EU average indicator in this category was 7.7 % of total employment. However, in the sample data on persons employed in science and technology "High and medium high-tech manufacturing" in the ranking of 28 EU countries in 2016, Latvia was ranked 25th (2.0 % of total employment), followed by Lithuania (1.4 %), Luxembourg (0.9 %) and Cyprus (0.7 %), while the other EU countries were ranked higher. In this category, the EU average indicator was 5.8 % of total employment [21]. It should also be noted that, according to the data of the Central Statistical Bureau of the Republic of Latvia, in 2016 in Latvia 5,120 employees worked in scientific research according to the full-time equivalent, of which 3,147 – in the higher education sector, 1,077 – in the public sector, and 896 – worked in the business sector [22]. Unfortunately, the authors of the study do not have access to the information on how many people work in the nano-field and business in Latvia. The analysis in this indicator group demonstrates the known problems with human resources, as evidenced by the previously analysed indicators in the groups of economic, social and technical indicators, which show that workers "drain" from the R&D sector due to the lack of motivation compared to other EU countries.

At the meso level, the government procurement of advanced technology products is of importance in the group of scientific indicators. The implementation of public procurement is essential for the development of both business and public institutions (such as research institutions, centres, incubators, prototype laboratories and experimental facilities). If the results of the procurement contest are appealed, a particular research institution cannot implement the future plans for the implementation of the product or services in a certain project until the decision on the legality of the procurement procedure is made by the Procurement Monitoring Bureau of the Republic of Latvia. To reflect public procurement activities of Latvia in the nano-field, the authors have collected data for the period of 2014–2016 on the results published by the Procurement Monitoring Bureau according to the keyword "nano", procurement subject and procurement winners. According to the publicly available information of the Procurement Monitoring Bureau, within this period 32 procurements were made in the nano-field in Latvia, of which 8 winners were research institutes (Ventspils University College, the University of Daugavpils, Riga Stradins University, the University of Latvia, Riga Technical University, Agency of the University of Latvia "Institute of Physics of the University of Latvia", Latvian State Institute of Wood Chemistry and state research institute – derived public entity "Institute of Electronics and Computer Science"), one winner – commercial company POLYMERS Ltd. and autonomous body governed by public law – Public Utilities Commission [23]. It should also be noted that according to the Global Competitiveness Report 2016–2017, Latvia was ranked 98th out of 138 countries in the world [1] by the indicator characterising innovation – government procurement of advanced technology products –, which shows that there is not enough public funding in innovation development that is also confirmed by public funding in R&D analysed in previous studies, low indicator of university-industry collaboration in R&D, human resources and other issues.

As the final indicator in this group at the meso level, the authors have included statistics on the creation of new research working group, which means that in 2014 10 working groups were established in Latvia within the framework of the EU Structural Funds [24]. The latest statistical data are not available to the authors of the study, as well as comparative statistical information on other countries.

At the same time, the authors also acknowledge that the indicators proposed at the meso level deserve deeper study in order to assess the potential and find conceptual solutions to R&D activities by determining science and technology strategies at the national level in the future.

At the micro or enterprise level, the authors put forward the following indicators in the group of scientific indicators: the number of start-up companies in alliance with universities and valorisation indicators, as well as ratio of employees involved in research and innovation activities.

The number of people employed in science, research, technological development and innovation is too small in Latvia, as well as there is insufficient renewal of the personnel involved in these areas and limited funding. The research, technological development and especially innovation infrastructure are underdeveloped. As a result, there is a small number of spin offs and start-up companies based on developments in the public research sector [25]. According to the Global Competitiveness Report 2016–2017, Latvia has been ranked 99th out of 138 countries in the world by the availability of scientists and engineers [1], which also justifies and complements the previously analysed information. The afore-mentioned problem proves that the disproportionately low proportion of basic funding in R&D does not contribute to a strategic and science-intensive development of the country and, accordingly, entrepreneurship in Latvia.

Start-up companies and the valorisation process in the area of nanotechnologies are of high scientific and practical significance. Currently, the studies and statistical development tendencies show that both the higher education sector and the business sector receive investments in R&D. The analysis [26] shows that some universities actively participate in valorisation, business incubator creation, establish innovative centres and perform other activities [27], [28]. The loans issued from banks to non-bank institutions to professional, scientific and technical services in Latvia in 2017Q2 are one of the lowest; however, the activities of enterprises in the nano-field can be integrated into construction, after supply and waste management and other areas as well [29]. According to the public information available at the Labs of Latvia – a start-up community platform, the problems of Latvian tech start-up ecosystem are the following: insufficient external networking, lack of smart money, weak deal flow, funding gap, technical skills and knowledge, unique ideas, entrepreneurial skillset etc. [30].

Despite the fact that according to the Global Competitiveness Report 2016–2017 Latvia ranked only 96th out of 138 countries in the world by the market size with relatively small population and other previously described problems, as well as taking into account the transition of Latvia from the efficiency-driven stage to innovation-driven stage [1], Latvia can boast of five start-ups in the nano-field – Catalyco (early stage), Naco Technologies (existed), Nano 55 (early stage), Nano RAY-T (early stage) NanoOptoMetrics (early stage) [30]. Despite the problems encountered in science, business development and cooperation in the nano-field in Latvia, the authors believe that, according to the experience and fundamental research carried out by Latvian research institutes and enterprises, Latvia has untapped potential for improving existing materials, production, technology methods and developing new innovations in high-technology and the medium-high-technology industry, which determines the efficient use of products in a particular economic sector, promotes the development of science-intensive production and interdisciplinarity of research.

The final scientific indicator at the micro level is the ratio of employees involved in research and innovation activities that illustrates the ratio of employees working in research (see at the meso level) to those working in the field of innovation. Unfortunately, data on employment in the field of innovation are not made public. Taking into account the position of Latvia among other countries in the world by the pillars of labour market efficiency, business sophistication and innovation of the Global Competitiveness Report 2016–2017 [1], the innovative performance of Latvia in the development of the nanotechnology and smart materials industry is still at the developing stage, which is influenced by the factors analysed above.

Referring to the previous research on scientific indicators at all levels, it can be concluded that the indicators characterising the development of scientific research are closely related to the amount of funding allocated to the research activity (see assessment in the group of economic indicators [2]) and the number of people employed in science. Although the scientific development indicators of Latvia in comparison with other countries of the world are average, the performance of scientific development indicators actually corresponds to the amount of financing invested in science and even would be higher if public funding in R&D were at the level of developed countries of the EU. Despite the problems encountered in the development of Latvian science, in general, science in Latvia is considered to be sufficiently active and innovation-driven, although it is at the developing stage. Thus, the analysis of the indicators characterising the development of the scientific environment indicates the potential for research development, directions for attracting investment and the need for state funding in order to find conceptual solutions, increase competitiveness and potential opportunities for improving the performance of the research and innovation environment.

3. CONCLUSION

1. Within the framework of the development of the system of engineering economic indicators, scientific indicators have been identified at the macro, micro, and meso development levels and assessed at the level of Latvia and compared with those of other countries in the world, if applicable to the nano-field in science and entrepreneurship.
2. The analytical assessment of scientific indicators substantiates and can indicate the competitiveness and productivity of each country, as well as in the age of new technologies and digital revolution highlights the importance of high quality higher education, skilled labour force, R&D level and innovation development for any economy. High-quality research institutions can create fundamental knowledge necessary for the development of new technologies, while universities in cooperation with the industry can modernise simple production processes and create additional added value for existing products.
3. In the field of nanotechnologies and nanoscience at the macro development level, the level of scientific excellence and the development of its productivity in a particular economy can be assessed using the following indicators: the total number of citations to nano-articles; average citation per nano-article; number and quality of publications and studies by science sectors; national priority in nanoscience; number of nano-articles per million people; share of international cooperation in nanoscience; number of nano-articles per GDP. The analysis and comparison of these indicators with other countries of the world indicate that the development and performance of Latvia in this group of scientific indicators is considered average, and there are still factors hindering the development of scientific research in Latvia.
4. The scientific indicators analysed at the meso level describe the national (Latvia's) level of science and research capacity and provide data for the promotion of the national development in accordance with the extent of nano-industry and science development at the local level. It should be noted that in this group of indicators, the authors have encountered the lack of availability of data on projects implemented in Latvia in the field of innovative materials production and high technology in the nano-field,

number of employees in the field of nanoscience and entrepreneurship, as well as the lack of current statistics on the creation of new scientific research working groups. Based on publicly available information, the analysis demonstrates the ongoing human resource problems in Latvia. According to the assessment performed and the findings revealed in this discipline, the authors propose that the evaluation of the effectiveness of fundamental and applied research projects in specific sectors of the national economy should be ensured at the national (Latvia's) level.

5. A disproportionately low proportion of base financing in R&D does not contribute to strategic and science-intensive development and entrepreneurship in Latvia. Thus, the indicators identified at the micro level demonstrate the capacities of the domestic producers, the capital capacity of entrepreneurs and the degree of readiness for the development and use of the next generation of nano-technologies.
6. The analysis of the conducted research, its main results and the conclusions formulated substantiate the need to continue the research on the development possibilities of nanotechnologies and advanced materials industries in science and entrepreneurship in Latvia in several directions, by reducing the factors hindering the development of scientific research in Latvia, envisaging environmentally-friendly solutions in the development of many industries and promoting the development of science-intensive production, as well as ensuring interdisciplinarity of research.

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NANOTEHNOLOĢIJU UN VIEDO MATERIĀLU INDUSTRIJAS ATTĪSTĪBA ZINĀTNES UN UZŅĒMĒJDARBĪBAS JOMĀS: ZINĀTNISKIE RĀDĪTĀJI. LATVIJAS PIEREDZE (TREŠĀ DAĻA)

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K o p s a v i l k u m s

Dotais zinātniskais pētījums ir turpinājums jau diviem nopublicētajiem pētījumiem par padziļinātu un atsevišķu inženierekonomisko rādītāju sistēmas grupu izpēti, kurā autori apkopo zinātniskā pētījuma gaitā iegūtos rezultātus nanotehnoloģiju un viedo materiālu industrijas attīstības līmeņa noteikšanai un paaugstināšanai zinātnē un uzņēmējdarbības jomā Latvijā. Pētījums ietver zinātnisko rādītāju izvērtējumu Latvijas makro, mezo un mikro ekonomiskās vides attīstības līmeņos, kā arī izstrādāto zinātnisko rādītāju salīdzinājumu ar pasaules, tai skaitā Eiropas, valstīm, ja dati bija pieejami. Pētījuma rezultāti norāda uz zinātnisko rādītāju aktualitāti un potenciālu, ja tiks atrisinātas pētījumā konstatētās problēmas.

20.09.2017.