Roadmapping in Regional Technology Foresight: A Contribution to Nanotechnology Development Strategy

Joanicjusz Nazarko, *Senior Member, IEEE*, Joanna Ejdys, *Member, IEEE*, Alicja E. Gudanowska, *Member, IEEE*, Katarzyna Halicka, *Senior Member, IEEE*, Anna Kononiuk, Andrzej Magruk, and Łukasz Nazarko, *Member, IEEE*

***Abstract*—In the article, the authors describe their approach to creating regional nanotechnology development roadmaps. Original visualization and roadmaps for selected nanotechnologies are showcased. The creation of roadmaps was preceded by technology mapping and the selection of priority technologies, for which technology characteristics sheets were developed. Human resources (skills), financial resources, and tangible assets were a basis for the creation of the roadmaps specifying the development of priority nanotechnologies in the studied region (Podlaskie, Poland). The development of the technologies described in the roadmaps is stimulated by the R&D domain, which constitutes one of the roadmap layers. Potential technology application areas form the background for the "market" layer of the roadmaps. Segments related to the general development of a particular technology in time are additional elements enriching the roadmaps. All layers were presented in three-time perspectives. The conducted analysis served as a basis for the integration of the selected priority nanotechnologies into four nanotechnology development scenarios of the region. The obtained results contributed to the formulation of the Regional Nanotechnology Development Strategy. The research was conducted in a framework of the "Technological foresight 'NT FOR Podlaskie 2020' Regional strategy of nanotechnology development" project.**

***Index Terms*—Foresight, nanotechnology, NT FOR Podlaskie 2020, post-transition economy, regional policy, roadmapping, strategic management, technology development, technology mapping.**

I. Introduction

TECHNOLOGY roadmapping is a comprehensive approach to strategic planning, the idea of which is expressed in the integration of science and technology with business practice, as well as in identifying opportunities for the development of new technologies [1].

Despite its high anticipatory capability, roadmapping is relatively rarely employed in regional technology foresight exercises. The full potential of roadmapping as a strategic management tool at a regional level remains to be fully appreciated, especially when it comes to supporting regional policies directed at fostering the development of selected technologies. In the authors' opinion, intensive support for the implementation of breakthrough technologies is particularly important for economically underdeveloped regions.

This article presents an original methodology integrating roadmapping, technology mapping and scenarios, and describes its application in a project entitled "Technological foresight 'NT FOR Podlaskie 2020' Regional strategy of nanotechnology development". Using the feed-forward logic as a basis, the project attempted to chart unconventional development directions for the lagging Polish region of Podlaskie. The methodological framework of the project was embedded in the foresight approach. The presented concept is the result of the cooperation of many experts coming from domestic and foreign scientific centers and a large group of stakeholders representing entrepreneurs, local authorities, NGOs, media, and students.

The intention of the research carried out in the project was to define strategic directions for the development of Podlaskie region based on the postulate of a leap in productivity growth, resulting from mastering and implementing innovative production, processing and service processes utilizing the achievements of nanotechnology, while protecting the environmental values of the region.

Hence, the scientific problem tackled by the authors of the article is to determine how to integrate scenario building, technology mapping, and roadmapping in the form of a comprehensive methodology for assessing the potential for nanotechnology development in the region. This approach made it possible to design—in an anticipative and participative way—regional strategy through the identification of nanotechnologies that offer high socioeconomics benefits in the long-run.

The rest of this article is organized as followed. Section II presents an overview of background literature. Section III discusses the role of foresight studies in shaping the regional technological development strategy. Section IV describes the rationale of the project "NT FOR Podlaskie 2020" and the used research methodology. Section V establishes a methodological framework for roadmap development. The subsequent sections

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The authors are with the Faculty of Engineering Management, Politechnika Bialostocka, 15-351 Bialystok, Poland (e-mail: j.nazarko@pb.edu.pl; j.ejdys@pb.edu.pl; a.gudanowska@pb.edu.pl; k.halicka@pb.edu.pl; a.kononiuk@pb.edu.pl; a.magruk@pb.edu.pl; l.nazarko@pb.edu.pl).

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describe the elements used in the process of roadmap creation, i.e., technology mapping, the selection of priority technologies, and roadmap visualization. Section VI presents the results of the project. The subsequent sections characterize the main components of the project outcomes: priority nanotechnologies, technology sheets, scenarios of nanotechnology development, roadmaps, and regional strategy of nanotechnology development. Section VII presents a discussion on the contribution of the results of the conducted research on the development of roadmapping methodology and the managerial relevance of the project findings. Finally, Section VIII concludes this articles.

II. Background Literature

Although the roadmapping method was developed more than twenty-five years ago by the concern Motorola in the area of production planning, it is still very popular in top-quality journals on technology management.

Based on a search in databases of scientific publications such as *Emerald, Elsevier, Academic Search Complete, ISI Web of Science*, using keywords such as roadmap, roadmapping, region, foresight, and considering the publication date and availability, sixty-three scientific publications presenting the roadmapping method in the context of foresight research and/or region were identified. The analysis of the existing published works allowed the authors of the article to conclude that the essence of roadmapping was expressed in the visualization of mutual relations between the spheres of science, technology, and practice, and according to Daim and Oliver [1]—in identifying new opportunities in the field of new technology development. As noted by Galvin [2], roadmapping provides a broad perspective on the future of an investigated issue, possible to achieve thanks to collegial knowledge [1]. In practice, the idea of roadmapping is manifested in the agreed understanding of future conditions and in the definition of objectives to be achieved in the future [3], [4].

A characteristic element for roadmapping is the time factor. The time axis, regardless of the form of a given roadmap, whether in the simplified version of the T-plan or the multilayered graphs, should be always considered, giving the visualizations a dynamic character. Although diverse ways can be used to visualize the technology roadmapping, they ultimately lead to the ordering of the directions of scientific research and technology in their broad context in a dynamic perspective. Fig. 1 presents an exemplary way, in which technology can be related to product development, research and development, available resources, and market opportunities.

Visualization is intended to support the research team in recognizing and understanding the company's goals and the ways of achieving them [5]. Roadmapping should enable immediate access to information concerning five areas (market, products, technology, R&D, resources). A correctly executed document presents several layers of a different level of detail, at the same time constituting a tool supporting the planning process through the analysis of the industry carried out at a specific time [6]. The

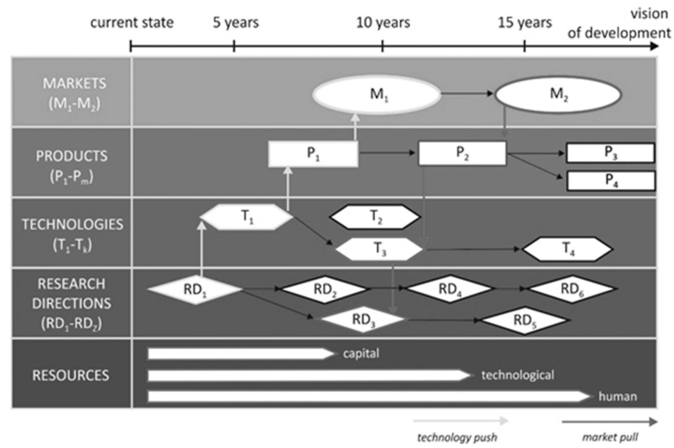

Fig. 1. Scheme of an exemplary roadmap. Source: Adapted from [7].

method allows indicating the normative direction of technology development in the context of the key resources necessary for this development, which in effect enables providing the recommendations for decisions concerning investments and allocation of financial resources.

Roadmaps can also take different graphic forms. One of the main difficulties in the implementation of roadmapping is the variety of specific forms of roadmaps, which often have to be adapted to specific needs and contexts [8]. In the literature on the subject, several visualizations can be distinguished. Apart from layer-type graphs, these can also be graphs in the form of bars, histograms, tables, diagrams, pictograms, flow schemes, single layers, or text [8].

The method of technology roadmapping is still developing, through adaptation of new concepts, links with other methods of strategic analysis or new areas of application, including foresight research. The most recent publications in this field touch upon issues such as developing new standardization framework for photovoltaic technology [9], technology roadmapping in security and defence [10], modularity in roadmapping [11], new approaches in depicting emerging technologies [12], [13], e.g., consolidated methods such as text mining and roadmapping and novel ones such as web content mining, with special attention given to forecasting activities. The links between roadmapping and systems perspectives are also discussed [14].

According to the authors of this article, the most promising approach to roadmapping is posited by Sauer, Thielman, and Isenman who describe the concept of modular roadmapping. Their concept is depicted in a roadmapping framework so that from a set of stand-alone roadmaps, each could be applied as an interlinked module, *vertically and horizontally perfectly fitting together in an overall integrated roadmap describing a broad landscape of corresponding developments in technologies, products, applications, markets, and society* [11]. The idea of modular roadmapping is illustrated by an example of a huge project accompanying the innovation alliance "Lithium-ion batteries" [11]. The authors of the article agree with Sauer, Thielman, and Isenman who claim that modularity for integrated roadmapping helps to systematically link expertise on technologies, products, applications, markets, and society in regards to overreaching national challenges [11].

The literature review also contributed to the design of roadmap visualization in the project. The graphical layout of the roadmap was inspired by the visualization of megatrends shaping reality in sixteen thematic areas, such as society, culture, geopolitics, science and technology, economy, transport, tourism, and media. The presented trend development is widely documented in the publication of Watson entitled *Future Files. A brief history of the next 50 years* [15]. The formation of megatrends and subtrends was presented by the author in five time zones, which became a direct inspiration for the presentation of time zones in roadmaps for nanotechnology development.

The authors' ambition was to present technology roadmapping against the context of other foresight methods such as STEEPVL analysis, SWOT analysis, technology mapping, key technologies selection, bibliometrics, brainstorming, and moderated discussions which are well established and described in the existing works on foresight methodology [16]–[19].

III. Foresight in Shaping the Technological Development Strategy of a Region

The high complexity of factors that determine regional development requires a systematic method of anticipation and vision building [20]. The introduction of the concepts of learning region and smart specialization strategy has increased even more the need for open, participatory and action-oriented processes that could result in propositions of nontrivial regional innovation strategies [21].

In this context, foresight methodology offers its potential as an effective tool informing the strategic management of a region. Foresight's key role is to stimulate and support various entities in formulating their policies and strategies. Its aim is—through the identification of trends, phenomena, and technologies—to point at the strategic areas that offer high socioeconomics benefits in the longer run.

As it is true for all types of foresight exercises, there is no single universal regional foresight methodology although certain reference approaches have been developed [22], [23] and best practices codified [24]. Roadmapping has been recognized as suitable for building strategic knowledge necessary for politicians, government institutions, and research centers to exploit the opportunities associated with nanotechnologies [25]. In turn, experience from projects such as *Transforming our regional economy—action plan 2006 roadmaps* [26] and *Asset mapping roadmap: a guide to assessing regional development resources* [27] and successful case studies of roadmapping implementation documented in the existing published works [28]–[31] indicate that roadmaps can be successfully used in regional development management. However, roadmapping should be preceded by a thorough assessment of the regional potential [32].

In the Polish context of a post-transition economy, roadmapping has not been used extensively in the foresight projects carried out so far. Evaluation study of foresight initiatives commissioned by the Ministry of Science and Higher Education identified 18 projects of a regional character (dealing either with the holistic development of a region or focusing on a specific aspect of region's socioeconomic life) [33], [24]. Out of them, only five applied roadmapping method [7]. "Technological foresight 'NT FOR Podlaskie 2020' Regional strategy of nanotechnology development" project is one of them.

The authors intended to combine existing experiences of regional strategy formulation using forward-looking methods (regional foresight) with more focused, technology-oriented studies (technology foresight and technology roadmapping). It was assumed that such an approach would prove valuable on both scientific and policy levels. This way, the authors anticipated the emergence Smart Specialization Strategy concept which was promoted by the European Commission in the following years.

IV. "NT FOR Podlaskie 2020": Rationale and Methodology

A. Rationale, Scope, and Aims of the Project

The project "'NT FOR Podlaskie 2020' Regional strategy of nanotechnology development" was granted the financial support from the EU Operational Programme "Innovative Economy 2007–2013." The project was carried out in the years 2009–2013 and its time perspective reaches 2020 [35].

The research conducted in the project intended to determine the strategic directions of development of the Podlaskie Voivodeship based on the postulate of a rapid increase in productivity resulting from the mastery and implementation of innovative production and processing processes using the achievements of nanotechnology. In the project, attempts were made to promote breakthrough technologies in a situation where traditional industries are unable to accelerate the development of the region.

According to the accepted assumptions of the project "NT FOR Podlaskie 2020," its basic objectives included the following.

1) Developing scenarios for desirable socioeconomic development of the Podlaskie Voivodeship aimed at the use of nanotechnologies.
2) Developing technology roadmaps for the development of nanotechnologies in the region.
3) Projecting the Podlaskie strategy for the development of nanotechnologies until 2020.

The partial objectives of the project were formulated as follows: first, setting priority development directions for the Podlaskie Voivodeship, oriented towards the use of nanotechnologies; second, identifying scientific and research trajectories in nanotechnology key to the development of the Podlaskie region.

The research conducted within the project "NT FOR Podlaskie 2020" was based on the work of expert panels, whose task was to generate, analyze, and synthesize knowledge relevant to the issue. In total, more than one hundred and sixty experts representing the scientific community, regional authorities, entrepreneurs, media, NGOs, and inhabitants of the province were involved in the implementation of the project.

The expert panels created in the project were divided into methodological panels and panels of research areas. The adopted model of their cooperation assumed that the methodological panels could be used for the integration of the results achieved by the panels of research areas.

Methodological panels corresponding to the main research methods were the STEEPVL and SWOT Panel (SSP), the Technology Mapping and Key Technologies Panel (TMKTP), and the Scenarios and Roadmapping Panel (SRP).

The main objective of the SSP panel was to identify the conditions for the development of nanotechnology in the Podlaskie Voivodeship. Research works carried out within the TMKTP panel allowed separating the catalog of nanotechnologies, which can have the highest degree of contribution to the sustainable socioeconomic development of the Podlaskie Voivodeship. The main objective of the research work of the SRP panel was to develop alternative scenarios for the development of nanotechnology in the Podlaskie Voivodeship and to determine the route for the development of key nanotechnologies for the region. This panel integrated and synthesized the knowledge obtained as a result of the work of all other expert methodological panels and research areas.

The project defined three research fields: Nanotechnologies in the Podlaskie economy (RF1); Nanotechnology research for the Podlaskie development (RF2); Key factors of nanotechnology development (RF3).

The research tasks were possible to complete because of the interaction between six expert panels: SSP, TMKTP, SRP, RF1, RF2, and RF3. The results of the six panels were integrated by the Key Research Team (KRT) also acting as a platform of interaction and knowledge transfer between the panels [36].

B. Research Methodology Implemented in the Project

In the project "NT FOR Podlaskie 2020," the initial assumptions for the work of the panels RF1, RF2, RF3, TMKTP, and the results to be achieved were the main premise for the selection of the adopted research methods. Among a wide range of foresight methods, the following research methods were used [37].

1) Bibliometric analysis.
2) STEEPVL analysis.
3) SWOT analysis.
4) Technology mapping.
5) Key technology.
6) Scenarios.
7) Roadmapping.
8) Brainstorming.
9) Moderated discussions.

The diagram of the research process employed in the project is shown in Fig. 2.

The selection and the sequence of the methods used were dictated by the project objectives and the logic of the research process. They were a composition of methods based on both the experience and intuition of researchers, making it possible to identify seeds of change, which are often ignored when obtaining information about the future with the help of traditional forecasting methods based on extrapolation of a trend [38], [39].

Intuitive school of scenario construction was the theoretical framework of the research methodology [40]–[44]. This school is well established in the existing works on scenario building

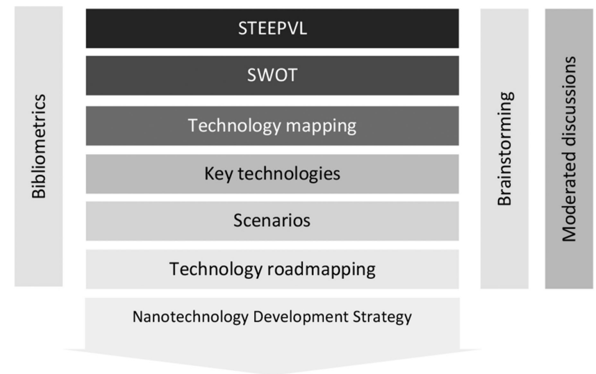

Fig. 2. Research methodology implemented in the "NT FOR Podlaskie 2020" project. Source: Adapted from [31].

and presents a process approach by showing the relationship and flow of information between the state of the factors shaping a given phenomenon and four qualitatively different scenarios. The state of the art of the application of nanotechnology to the regional context was achieved through the implementation of STEEPVL, SWOT analysis, technology mapping, key technologies prioritization (supported by bibliometrics, brainstorming, and moderated discussions).

In turn, the application of the roadmapping method allowed the introduction of time dimension into the research process and was the basis of the formulation of a nanotechnology development strategy. The authors extended the scope of scenario construction by adding relevant technologies into each scenario on the one hand and creating roadmaps for the most desired one on the other.

A direct premise for including roadmapping in the research process was the need to demonstrate the interrelationship between resources (human, financial, and material), the R&D sphere, and potential market applications of nanotechnology. In the opinion of the authors, roadmapping fits perfectly within the concept of foresight research, showing, on the one hand, the connections between the roadmap layers, and, on the other hand, allowing to look at the potential reconfiguration of these resources in selected time perspectives. Not without significance for the inclusion of roadmapping in the project methodology is the possibility to link this method with technology mapping and scenarios for the development of nanotechnology in the region. Roadmapping has also enabled an attractive form of visualization of the data generated by the project.

V. Methodological Framework for Roadmap Development

A. Technology Mapping

Next to technology prioritization, the technology mapping method was the subject of work of the TMKTP panel, the overarching goal of which was the identification nanotechnologies that would make the greatest contribution to the sustainable social and economic development of the Podlaskie Voivodeship [7].

The technology mapping method does not have an unambiguous, well-established definition, and the available literature allows only to extract this concept in the foresight methodology. In foresight studies, technology mapping is rather often associated with the creation of technology roadmapping [45]. However, these are distinct, although related methods. Technology roadmapping is an analysis of future directions of technology development, and technology mapping is an in-depth diagnosis of its current state [37]. The methodological approach proposed by the authors proves and underlines this distinction.

In the context of global foresight research, technology mapping is defined as the characteristics of a research domain, i.e. the initial stage of the foresight process, which has a significant impact on the structure of subsequent stages [57], a tool for strategic investment development [47], or an instrument used in the first phase of foresight—the understanding phase, which includes the creation of a relatively complete picture of the situation [48]. It is also defined as the categorization and classification of technologies used to review the object of analysis and define its boundaries [37], [49], [50].

In a broad sense, technology mapping is the process of creating visualizations of elements related to technologies. A fixed image of a given technology, or its aspects, is presented on a plane using contractual markings [51]. The essence of technology mapping is contained in an in-depth diagnosis of the current state of technology, in a way that allows to identification, categorization, and spatial location of technology, while taking into account possible connections between technologies [37]. As a result of the technology mapping method, a series of maps and visualizations should be created, enriched with descriptive or collected data in the form of tables, showing the current state of technology. One of the measurable effects of using technology mapping should be the most complete knowledge base about technologies in the area covered by the research. The conducted procedure also includes analysis and visualization of the collected information, which highlights the relations among technologies or related entities, which would be difficult to see in-text descriptions [7].

In the "NT FOR Podlaskie 2020" project, technology mapping has been carried out for the narrowest set of key nanotechnologies considered in the project as priority technologies [7].

In the project-designed methodology of technology mapping, seven research stages can be distinguished. Their realization has been entrusted to the KRT team supported by the know-how of eminent experts in the field of nanotechnology. The first stage—literature studies—made it possible to identify good practices in the field of diagnosis of the current state of technologies. The second stage aimed to characterize the idea of technology mapping based on literature studies. A measurable result of the implementation of the third task was technology sheets and the technology relation matrix. In the next stage, using the created tools, information from experts was collected. During the categorization and selection of the collected data (fifth stage), the expert notes were also used to assess the attractiveness and feasibility of the technology. The sixth stage aimed at analyzing the links among all the key technologies that distinguished themselves by their high level of attractiveness and feasibility in the Podlaskie Voivodeship [7].

In the final phase of the study, the relations among priority technologies were analyzed graphically as well by technology location maps [7].

These maps, as well as other visualizations, concerned seven individual priority technologies. As part of the research process, collective visualizations were also prepared [7].

It should be noted that all visualizations were the result of data collected in a narrow group of experts, which was ensured by the high specialization of the subject of the project, namely nanotechnology. The prepared maps of relations were not imperative to decide on the choice of one of the most important technologies, centers or experts. Their task was to provide a wide range of knowledge about priority nanotechnologies for the Podlaskie Voivodeship and units and persons related to them [7].

B. *Roadmap Development Methodology*

The development of the original roadmapping methodology was assigned to an expert team established within the framework of the SRP panel, who integrated the work of the other five expert panels of the project. The expected result of the panel's work was the implementation of the assumed research tasks, and, in particular, the creation of scenarios for nanotechnology development in the region and the development of nanotechnology roadmaps. Since the specific nature of the panel's work focused mainly on the synthesis of the work of the remaining panels, the panel's experts were recruited from the members of the KRT. The work of the members of the KRT on the implementation of the roadmapping focused on the synthesis of works of leading experts in the field of priority technologies recruited from the TMKTP panel and the analytical work produced by members of the KRP on the roadmapping methodology and megatrends potentially shaping the development of nanotechnology in the Podlaskie Voivodeship.

A detailed methodology of roadmapping in the project is presented in Fig. 3.

The process of roadmapping in the project consisted of seven complimentary research tasks [7].

1) Synthesis of studies on roadmapping and the possibilities of its use in technology management in the region.
2) Studies and conceptual works in the field of graphic presentation of roadmaps.
3) Construction of a questionnaire on the development of priority technologies in three-time perspectives.
4) Collecting data on the possibilities of technology development among experts.
5) Designing a basic roadmap.
6) Developing priority technology roadmaps.
7) Linking technologies with scenarios.

The implementation of tasks 1–3 and 5–7 was assigned to the members of the KRT, while the implementation of the research task 4 was possible thanks to the involvement of leading experts of priority technologies in Poland. Measurable results of the first, second, and fifth research tasks allowed the identification of good practices in the field of roadmapping and contributed

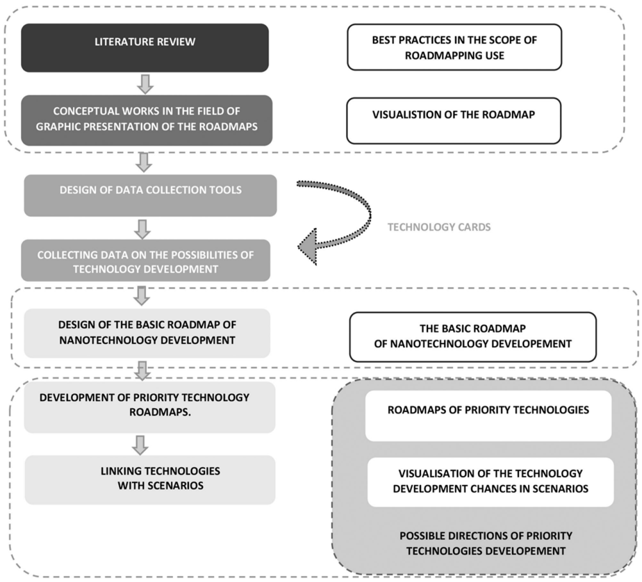

Fig. 3. Methodology of roadmapping employed in the "NT FOR Podlaskie 2020" project. Source: Adapted from [7].

to the development of the final form of its visualization. In turn, the results of tasks 6 and 7 led to the development of a roadmap for the priority technologies and the visualization of opportunities for technology development in scenarios, which allowed determining possible directions for the development of priority technologies in the Podlaskie Voivodship.

The research process was supported by research methods such as: critical analysis of the literature, method of analysis and logical construction, brainstorming, and questionnaire survey. The selection of research methods was mainly motivated by the need to structure foresight projects [52], adopted methodology, and availability of data sources.

The construction of the project's research methodology was backed up by Magruk's concept of hybridity in the process of selection of complementary foresight research methods belonging to different classes. The selected methods belong to six different classes. Balance has been maintained between references to technological, social, and cognitive contexts. This approach has enabled a positive cognitive synergy. Using methods from just one class could lead to an undesirable situation in which the selected methods would share similar information resources, generating results in a comparable way [52], [53].

Expert work during the technology roadmaps and scenarios development required the knowledge of the results of each stage of the project. The task of the expert panel of the scenario and technology roadmaps was to integrate and synthesize the work of the remaining five expert panels in the project. These panels included three panels of research areas (RF1, RF2, and RF3) and three methodological panels (the scope of work of the methodological panels corresponded to the main research methods used in the project.

1) STEEPVL and SWOT.
2) Technology mapping and key technologies.
3) Scenario building and technology roadmapping.

The expert panel responsible for the implementation of technology roadmaps included hand-picked leading experts in the field of seven priority technologies identified in the project. After the publication analysis in the area of nanotechnology and the verification of the availability of individual experts, a team comprised 11 technology experts was formed. The experts represented various nanotechnology centers in Poland (8 representatives of technical universities, 1 representative of a research institute, 1 representative of the Polish Academy of Sciences, and 1 representative of the National Science Centre). Fourteen researchers, recruited mainly from the members of the KRT, coordinated, and integrated the work of the panel.

The results of the work of the KRT served as a contribution to the projection of a strategy for the development of nanotechnology until 2020.

C. *Visualization of Technology Development Roadmaps*

Visualization of the nanotechnology roadmap in the project was based on the concept of Phaal *et al*. [54] indicating the need to separate layers in the roadmap and Watson's concept of graphical presentation of time zones. The basis for the development of the technology roadmap in the project was the technology planning framework, in which the following aspects were distinguished [55].

1) The needs of the industrial and R&D sector, country, organization (considering the market pull).
2) Products, services, and undertakings that meet the identified needs.
3) Technologies and research directions allowing the production of new products and services (technology push).
4) Potential and resources that allow the implementation of the desired development vision.

The members of the KRT intended to present a general possible trajectory for the development of a given priority technology in the context of resources, research and development, potential technology developers, and potential application areas. Hence, the roadmap layers were originally intended to create such elements as "resources," "R&D sphere," "entities creating given technologies," "technologies," and "potential application areas." As a result of the discussion among the members of the KRT, it was decided to exclude the "product" layer as less important in the area of issues not aimed at building the philosophy of product development. Therefore, it was also decided to limit the "market" layer to the areas of potential applications of the given technologies.

Due to the highly specialized nature of the identified key technologies, the project adopted an expert approach. The construction of the final roadmap for the development of given nanotechnology was possible thanks to an in-depth analysis of a questionnaire addressed to leading experts in the field of priority technologies. The questionnaire forms were sent to seven key technology experts. The key experts were those who had identified the technology as a candidate technology in the technology mapping process or, if the final technology name was changed, whose proposals were similar to the final priority technology selected.

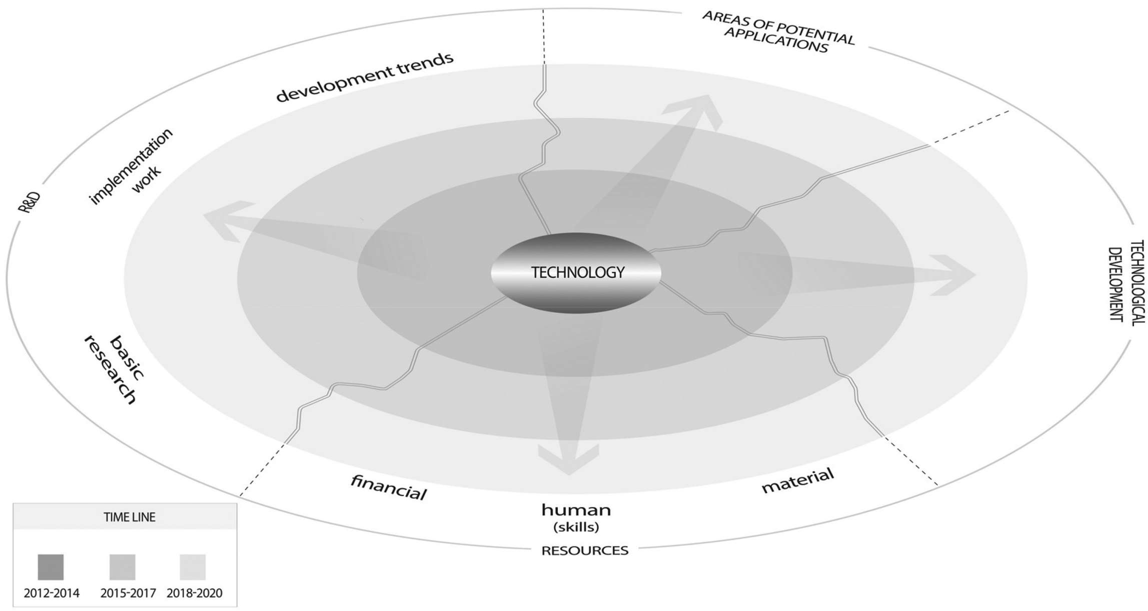

Fig. 4. Basic concept of the technology roadmap prepared in the "NT FOR Podlaskie 2020" project. Source: Adapted from [7].

The task of the experts was to evaluate the five layers of the roadmap in three time-perspectives (2012–2014, 2015–2017, and 2018–2020). The layers included the following.

1) Resources (human, material, and financial).
2) R&D (basic research, implementation work, and directions of development).
3) Entities creating a given technology.
4) Areas of potential applications.
5) Presented the development of technology over time.

Based on the final results of the questionnaire in the final version of the technology roadmap, the KRT decided to consider four layers: "resources," "R&D sphere," "areas of potential applications," and "technologies." The layer "entities creating a given technology" was omitted because the majority of experts gave such general answers as companies, universities, and consortiums.

The graphical layout of the technology development route was inspired by the visualization of megatrends shaping reality in sixteen thematic areas, such as, among others, society, culture, geopolitics, science and technology, economy, transport, tourism, and media. They are widely documented in the publication by Watson [15]. The author presented the formation of megatrends and derived trends in five time zones, which became a direct inspiration for the presentation of time zones in the roadmaps of nanotechnology development. The basic concept of the graphic layout of the technology roadmap for the project "NT FOR Podlaskie 2020" is presented in Fig. 4.

The technology roadmap was based on human resources (qualifications), financial resources, and material resources, which form the basis for the development of nanotechnology. It was decided to place them in the lower layer of the figure. The development of given technologies is stimulated by the R&D sphere (the left side of Fig. 4). In the upper part of the figure, potential application areas are presented. They form the background for the "market" layer. In the right part of the figure, the general development of given nanotechnology was presented.

All layers were presented in three time-perspectives: 2012–2014, 2015–2017, and 2018–2020 (according to the legend in Fig. 4). The leading technology experts, who completed the survey on technology development perspectives, indicated possible technology development in three predefined time perspectives. The gathered information allowed to supplement the technology roadmap layers in terms of resources, research and development, technology, and potential areas of application.

VI. Results

A. Key Nanotechnologies

As a tool for prioritizing technology, a modified (extended) system of assessing the Technology Readiness Level (TRL) was used [56], which consisted of systematically checking the level of technology development to reduce the risk of its further development [56], [57]. It assumes an assessment of technology readiness by assigning it to one of 10 defined levels.

The 10-level TRL approach is derived from the 9-stage technology planning process carried out in NASA [57]. An extension of the TRL scale was the inclusion of a 10-stage index of technological readiness used in the assessment of the degree of radicalization of research/technology directions [56], [58].

The individual levels reflect the successive stages of development in which the technology is located, divided into three phases [56].

1) Research and development (TRL1–TRL3).
2) Testing and demonstration (TRL4–TRL7).
3) Realization and implementation (TRL8–TRL10).

All key technologies had an average rating of between levels of maturity 5 and 7, which places all key technologies in phase II of the technology development—testing and demonstration [56].

The final group of priority technologies was formed by those technologies which were at the 6th or higher development level according to the adopted scale [7]:

1) Nanotechnologies for cutting tools and wood processing (PVD methods, nanostructured coatings of multicomponent nitrides Ti-Al-N, Ti-Cr-Al-N, and Cr-N/Cr-Cr-N multilayer coatings on tools made of high-speed steel and sintered carbides).
2) Composite materials-permanent dental fillings (nanomaterials based on polymer-modified acrylic resins–with powder fillers with nanopowders, reduced polymerization shrinkage, and excellent tribological characteristics).
3) Nanomaterials and nanocoatings in medical equipment (layers of nanocrystalline material on the surface of the second material; the most commonly used are diamond-like and hydroxyapatite layers).
4) Topcoat nanotechnologies for biomedical applications (a relatively wide range of surface treatment technologies to improve biocompatibility and other functional features of implants).
5) Nanotechnologies related to special textiles such as dressings (the electrospinning manufacture of fabrics and membranes from modified micro and polymeric nanofibers).
6) Nanopowder technologies for the use in plastics processing, paint, and varnish compositions (enabling the application of powder paint with a particle size of 10–100 nm on a metal coating, most often by electrostatic spraying, which allows obtaining a coating of up to 180 nm thickness).
7) Nano-structuring technologies for metals and light alloys, including those based on high plastic deformation methods (based on the concept of transforming the micrometric granular structure of conventional metallic materials into a nanometric structure by reorganizing the dislocation structure formed by plastic deformation).

Each of the priority technologies, which were selected as a result of the research procedure, was characterized by a selected expert supplementing the technology description sheet (see Table I).

Due to the high degree of specialization of nanotechnology, the information provided by the experts in the technology description sheet was mostly in the form of answers to open questions. Therefore, not all the data made it possible to compare the contents but rather constituted a different, qualitative knowledge characteristic for the specific described technology [7].

TABLE I
EXAMPLE OF PRIORITY TECHNOLOGY SHEET

T20	AREA: MEDICINE CATEGORY: NANOLAYERS FOR MEDICINE
BRIEF DESCRIPTION OF THE TECHNOLOGY	
Layers of nanocrystalline material on the surface of the second material. The most commonly used are diamond-like and hydroxyapatite layers.	
PURPOSE OF THE APPLICATION OF THE TECHNOLOGY	
Improve the biocompatibility of the material and increase its resistance to abrasion and corrosion.	
EXAMPLES OF CURRENT USE	
Hypoallergic and non-inflammatory medical implants, cutting tools, precision mechanics, machine parts and devices	
NECESSARY LABORATORY EQUIPMENT	
Reactors for the application of diamond-like layers; an apparatus for testing the structure of layers; an apparatus for testing their biocompatibility; laser equipment for applying hydroxyapatite layers	
TECHNOLOGY COMPONENTS	
Plasma reactors; CVD Process Reactors	
T20 TECHNOLOGY DETERMINANTS AND T20 DEPENDENT TECHNOLOGIES IN DIRECT EXPERT EVALUATION	
A reactor for chemical and plasma synthesis at reduced pressure and high temperature	Cutting tools; medical implants; anti-corrosion layers; precision mechanics
BENEFITS OF T20 TECHNOLOGY DEVELOPMENT	
Biocompatibility; no undesirable effects of implants; corrosion protection; increased tool life, reduced friction, reduced friction; increased corrosion resistance improvement of the quality of cut parts — the reduction of deficiencies	
BARRIERS TO TECHNOLOGY DEVELOPMENT T20	
Market fragmentation; Fierce competition of finished products from other countries	
ALTERNATIVE TECHNOLOGIES AND POTENTIAL ADVANTAGES OF T20 TECHNOLOGY	
Coating of materials other than diamond: boron nitride, zirconium oxide; nanomaterials and nanocoating in medical equipment. Diamond has the highest hardness, biocompatibility and chemical resistance.	
T20 TECHNOLOGY EXPERTS	
Expert 1; Expert 2…; Expert K	
LIST OF BASIC LITERATURE RELATED TO T20 TECHNOLOGY	
Reference 1; Reference 2…; Reference M	
NATIONAL AND/OR EU T20 TECHNOLOGY REGULATIONS	
Norm PN-EN 45502-2-3:2010	
SCIENTIFIC CENTRES	
Centre 1; Centre 2…; Centre N	
PRODUCERS	
Producer 1; Producer 2…; Producer P	

Source: Adapted from [7].

B. Technology Sheets

The results of the work presented in this article are complemented by the Priority Technology Sheets. Priority technologies have been selected from among the key technologies based on the following criteria.

1) The average of expert assessments of the level of technological readiness (as the main criterion).
2) The average of the level of attractiveness of the technology (according to 13 attractiveness criteria) and the feasibility of the technology (according to 8 feasibility criteria).
3) The relationship between the technologies as shown on the map of key technology relationships.

Each of the seven technologies classified as priorities is characterized by aspects such as technology components, benefits, and barriers associated with its use, or the determinant of development. The entities (research centers and producers) associated with each technology were also identified. The relations of priority nanotechnologies defined in the course of works, separated from the map of key technology relations, were not only one of the effects of technology mapping but also a knowledge base, useful in the creation of technology development roadmap.

The sheets gather the most important information about the analyzed technologies. The technology sheets create a knowledge base—presented in a synthetic and clear form—on the subject of the analyzed technologies. They constitute a kind of portfolio of priority nanotechnologies in Poland.

Information prepared in this way may facilitate further analyses or comparison of technologies. An example of a technology sheet, developed for nanomaterials and nanocoatings nanotechnologies in T20 medical equipment, is presented in Table I.

TABLE II
SCENARIOS OF NANOTECHNOLOGY DEVELOPMENT IN THE PODLASKIE REGION

	Key drivers	Scenario name	Narrative (shortened)
S_1	• High R&D • Effective regional collaboration of business, science and administration	*NANO: New Dimension of Podlaskie*	Unprecedented development opportunity emerges in the region due to the radical rise in the R&D potential in nanotechnology. The potential increases both in quantitative (number of research teams and labs dealing with nanotechnology, amount of specialised research infrastructure number of projects) and qualitative aspects (internationally recognised research teams, profound research results, development of breakthrough solutions). Regional nano-innovation ecosystem consists of active actors from academia, business and administration. Their collaboration is directed at obtaining cutting edge nanotechnologies for businesses located in the region (textiles, wood processing, furniture, food processing, agriculture, medical). This scenario assumes considerable progress in studying the impact of nanotechnology on humans and the environment. Responsible approach to innovation is practised by all stakeholders who engage in constructive dialogue on the directions of nanotechnology development in the region.
S_2	• High R&D • Ineffective regional collaboration of business, science and administration	*NANO-scattered Podlaskie*	Regional R&D potential in the field of nanotechnology raises significantly, induced mainly by public funding. Social perception of nanotechnology is mainly positive with openness and curiosity being dominant values. Participation of the local industry in both generating and benefitting from nano-innovations is however very limited. In consequence, the research and innovation potential of teams and labs located in the region will be primarily used to meet the needs of external actors (nationally and internationally). Regional authorities don't recognise nanotechnology as a factor that may put the region's economy on a new development trajectory. The triple helix of Podlaskie remains weak and static.
S_3	• Low R&D • Ineffective regional collaboration of business, science and administration	*NANO Indifference in Podlaskie*	The socio-economic disparity between Podlaskie and other regions in Poland and Europe deepens. Stagnation in R&D activity, low attractiveness for external investors coupled with low capital strength of local enterprises provides little opportunity for saturating region's economy with innovative solutions based on nanotechnology. Public awareness of risks related to nanotechnology's interaction with living organisms is relatively high, spurring the calls for strong precaution in R&D activity and in launching new products based on nanotechnology. Legal frameworks for the collaboration between science, industry and administration are developed. Unfortunately, local enterprises are unable to benefit from these opportunities due to low innovation potential, low competitiveness and the lack of legal competence.
S_4	• Low R&D • Effective regional collaboration of business, science and administration	*NANO-enthusiastic Podlaskie*	Inability to attract highly specialised human resources is the main barrier for the growth of nanotechnology R&D potential in the region. Local research institutions and enterprises are not able to offer satisfactory remuneration and rewarding working environment to top-level specialists who could become engines of scientific and technological progress in the region. Nevertheless, the actors of the regional innovation ecosystem do their best to harmonise the efforts and (limited) resources for the best possible effect. Effective regional networks of research centres, companies, public institutions and civil society organisations are successful in securing public support from the national level and European Union programmes. There is a growing number of nanotechnology-related R&I projects. Regional vocational and university curricula are adapted to grow local intellectual potential for nanotechnology development.

Source: Adapted from [59].

C. Scenarios for Nanotechnology Development

The scenario approach was employed in the project to create consistent, compelling, and qualitatively diverse alternative visions of the future with regards to nanotechnology development in the Podlaskie region. Furthermore, the priority technologies identified in the previous stages of the research were also embedded in the scenarios, which provided additional input to the roadmaps developed in the following project phase.

The basis of the scenarios consisted of 65 social, technological, economic, environmental, political, legal, and value-related factors that—according to experts' judgment—influenced the development of nanotechnology in the Podlaskie region (STEEPVL method followed by enhanced SWOT analysis) [60]. Experts engaged in the project evaluated those factors according to their importance and uncertainty to select the factors that are important and uncertain at the same time. A total of 27 factors with the above-average scores of importance and uncertainty were further processed with structural analysis to uncover direct and indirect interrelations between the factors [61]. As a result of that process, two key factors were named the driving forces of nanotechnology development in the Podlaskie region: first, level of R&D potential for nanotechnology and second, effectiveness of collaboration in the academia-business-administration triad. These two factors constituted the two scenario axes.

Four qualitatively different paths (scenarios) of nanotechnology development in the region were formulated. Each scenario was given a distinctive title and a narrative (see Table II).

In the next step, KRT members and the leading technology experts attempted to embed the priority nanotechnologies in the four scenarios. This was an important stage that allowed the fusion of the knowledge related to the factors influencing the nanotechnology development (scenarios) with the knowledge related to the technologies that might develop in the region (technology mapping and roadmapping). As a result, the four scenarios were enriched with the assessment of the development prospects of the priority nanotechnologies as well as with the interrelations between those technologies.

Leading technology experts and the research team judged the chances of each technology's development in the context of a particular scenario. In Fig. 5, the expert assessment of development chances is illustrated together with the influence of one technology on the others. Experts concluded that the growth of one technology may positively stimulate the growth of some other technologies. Such analysis allowed to identify technologies that are heavily interdependent (nanomaterials and nanocoatings in medical equipment and topcoat nanotechnologies for biomedical applications) as well as technologies that follow a relatively autonomous development path (nanopowder technologies for use in plastics processing, paint and varnish compositions and nanotechnologies related to special textiles such as dressings and sportswear).

S_1 scenario—describing the situation of the region in the context of high R&D potential and the effective collaboration networks of science-business-administration—was naturally pointed out as a desirable future that creates the most

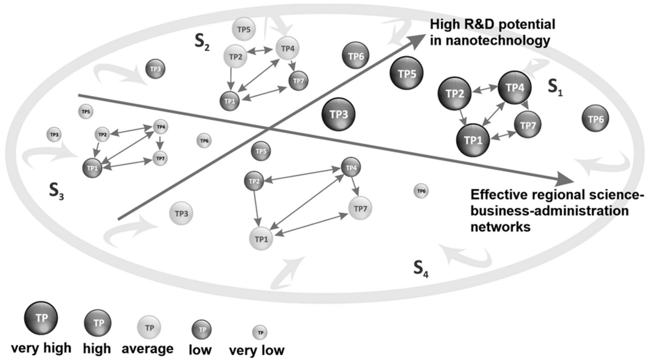

Fig. 5. Expert assessment of the chances of priority technologies development in the context of four scenarios. Source: Adapted from [59].

favorable conditions for the development of priority technologies. Thus, the technology roadmaps and the following regional strategy of nanotechnology development were elaborated to increase the likelihood of the occurrence of the S_1 scenario.

D. Roadmaps

Seven technology roadmaps for priority nanotechnologies have been developed as part of the project work. The results of each roadmap made it possible to draw up a collective roadmap for the development of nanotechnologies confronted with development scenarios. The visualizations included technology roadmaps for the following.

1) Nanomaterials and nanocoating in medical equipment.
2) Nanotechnologies for cutting tools and wood processing.
3) Composite materials for permanent dental fillings.
4) Topcoat nanotechnologies for biomedical applications.
5) Nanotechnologies related to special fabrics.
6) Powder technologies for the use in plastics processing, paint, and varnish compositions.
7) Nano-structuring technologies for metals and light alloys, in particular, those based on high plastic deformation methods.

All roadmaps have been described in detail in the project report [7]. One of the prepared visualizations of development, chosen for presentation in the publication, was the technology roadmap for nanomaterials and nanocoatings in medical equipment. Nanolayers and nano-coating are layers of nanocrystalline material on the surface of the second material. The most frequently used are diamond-like and hydroxyapatite layers. Nanomaterials are used in many areas of medicine, such as medical equipment, dentistry, orthopaedics, and surgery. This nanotechnology is also used in the treatment of vascular, cardiac, and neoplastic diseases. There are data on the use of nanomaterials in the manufacture of artificial organs and retinal prostheses. Research is underway to ensure the best possible adhesion of nanoparticles to the substrate so that the number of nanoparticles does not decrease during the use or washing. Nanomaterials have also been used in the coating of surgical instruments to reduce, among other things, the invasiveness of operations. For example, incisions made with a scalpel coated with a manometric diamond coating (DLC), (20–40 nm) are smaller and more precise due to reduced friction. In addition, the high mechanical properties and chemical and biological inertia of the DLC coating significantly increases the tool life. Nanomaterials can also be used in neurosurgery. The use of internal and external catheters to drain cerebrospinal fluid can cause bacterial infections that can spread to the brain and brain meninges. The use of silver nanoparticles as an addition to catheters can prevent infections and complications. Clinical trials are planned to confirm the initial tests. Thanks to nanotechnology, surgical operations have reached a new level of precision. Femtosecond lasers can be used to perform treatments on single cells or chromosomes. The development of micro/nano electromechanical systems can lead to the development of nano-devices that will help the surgeon operate at the nanoscale. The aim is to reduce the invasiveness of surgical procedures [5]. The projected technology roadmap of nanomaterials and nanocoating in medical equipment is shown in Fig. 6.

Based on the analysis of the questionnaire supplemented by a leading expert on the development of nanomaterials and nanocoating in medical equipment, general directions of development in terms of resources, R&D, technology, and application areas can be deduced. Human qualifications necessary for the development of priority technology will evolve from material engineering, biology, medicine from the perspective of 2012–2014, through chemistry and chemical engineering from the perspective of 2015–2017 to bio-nanotechnology from the perspective of 2018–2020.

The necessary increase in financial outlays in all three time-perspectives has been estimated by the expert at an average level, i.e., from ca. USD 1.5–15 million. The necessary equipment for the laboratory developing given technology (material resources) includes reactors, biological testing equipment, mechanical layer testing equipment, nano-tribological equipment, scanning and atomic force microscopes, and laser layer application techniques from the perspective of 2012–2014. In 2015–2017, the necessary equipment will be plasma reactors and laser technologies, and from the perspective of 2018–2020—hybrid technologies of layer application. The basic research directions necessary for the development of nanomaterials and nanocoatings in medical devices are the processes of nucleation of nanocrystals, the phenomena of their interaction, namely between them and other materials in the perspective of 2012–2014, the interaction of tissues and layers (2015–2017) and the resorption mechanisms in the perspective of 2018–2020. The necessary implementation works stimulating the development of these nanotechnologies include coating complex profiles, durability studies, development of standards, and nanometrology from the perspective of 2012–2014.

Implementation works will evolve over the period 2015–2017 to reduce the costs of production, nano-characterization and nano-metrology, and nano-toxicity. In the perspective of 2018–2020, they will focus on the development of medical certification. The necessary directions of the development of research and application works supporting the development of nanomaterials and nanocoatings in medical equipment include mechanisms of nanolayer growth, mechanisms of their degradation, optimization of adhesion, interaction with tissues

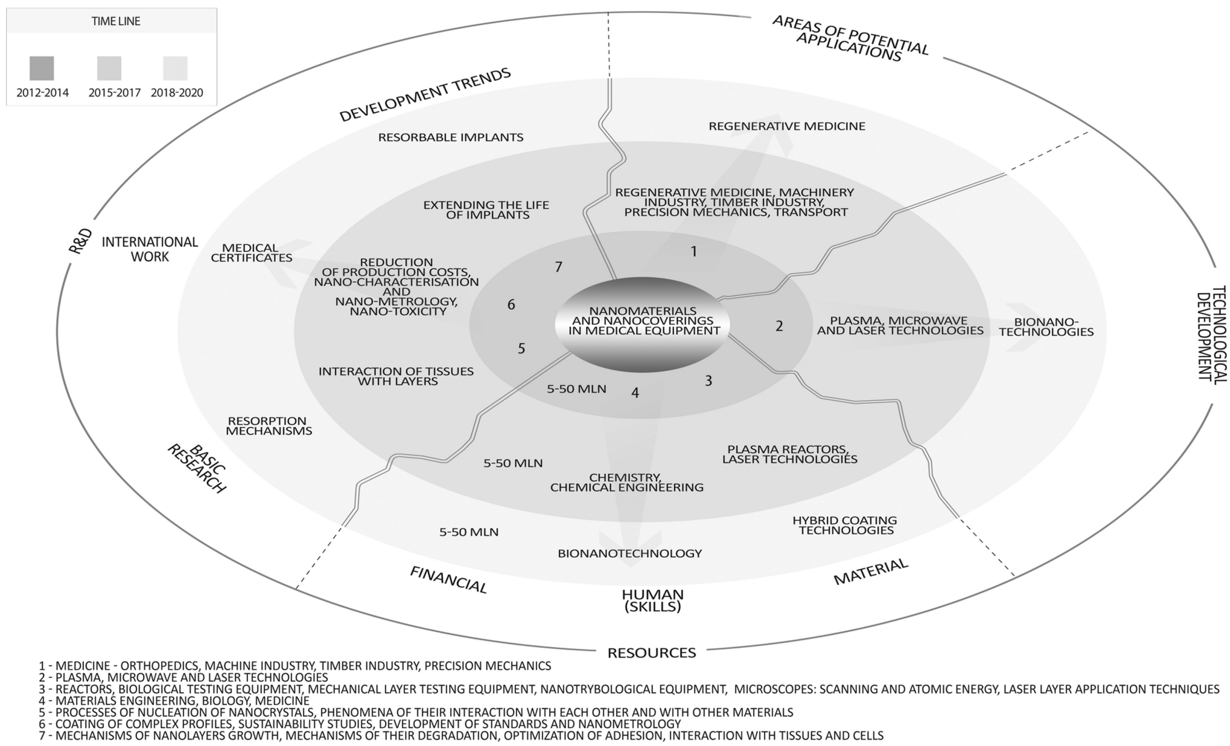

Fig. 6. Technology roadmap for nanomaterials and nanocoatings in medical equipment. Source: Adapted from [7].

and cells in the perspective of 2012–2014. In 2015–2017, the necessary directions for development of these works should focus on extending the life of implants, and in 2018–2020, on resorbable implants. The necessary technology components for the development of nanomaterials and nanocoatings in medical equipment include plasma, microwave, and laser technologies in 2012–2014 and 2015–2017, and bionanotechnologies in 2018–2020. According to the expert, the potential areas of nanomaterials and nanocoatings in medical devices will also be evaluated in other research areas, such as orthopaedics, machinery industry, timber industry, and precision mechanics in 2012–2014. In 2015–2017, the potential application catalog will be extended to regenerative medicine and transport. In 2018–2020, the area of application of nanomaterials and nanocoatings in medical equipment seems to be regenerative medicine.

As part of the project work, a collective roadmap for technology development in the Podlaskie Voivodeship in the perspective of 2020 has also been prepared (presented in Fig. 7).

The collective technology roadmap was compiled only for the "technology" layer of six out of seven priority technologies, excluding topcoat nanotechnologies for biomedical applications, where, according to the key expert, it was difficult to estimate the development of technology over time due to the problem of identifying technology components. According to the expert, the technology is "uniform". The analysis of Fig. 7 demonstrates that nanotechnologies for cutting tools and coal processing are not differentiated according to time horizon either, or there is a technology differentiation in only two time-horizons. In the case of powder technologies used in plastics processing and paint and lacquer compositions, there is a visible lack of identification of new technology components in the perspective of 2018–2020; the situation is similar for nanomaterials and nanocoatings in medical equipment (no new components in the perspective of 2015–2017). This can be explained by two reasons. First, the technology needs more time to be enriched with new components or, second, the expert surveyed has not been able to determine the direction of technology evolution due to the current state of nanotechnology research.

E. Strategy of Nanotechnology Development

The main rationale for formulating a proposal for a nanotechnology development strategy for the Podlaskie Voivodeship was the reflection on the need to overcome the economic and social backwardness of the region through a rapid increase in productivity, which can only result from mastering and implementing innovative production, processing, and service processes using breakthrough technologies, with particular emphasis on nanotechnologies [59].

The basic elements of the strategy and their mutual relations are graphically presented using a nanotechnology development map. It supports the decision-making process, creates the possibility to classify issues, and plays an important role in influencing the perception of the audience (see Fig. 8). The map is based on a circle, the plane of which is divided into four parts corresponding to the areas of nanotechnology activity: research (ANA1), nanotechnology (ANA2), commercialization of nanotechnology (ANA3), and education for nanotechnology (ANA4). Its central point is the adopted assumption on the development of the Podlaskie Voivodeship based on breakthrough technologies, which include nanotechnology.

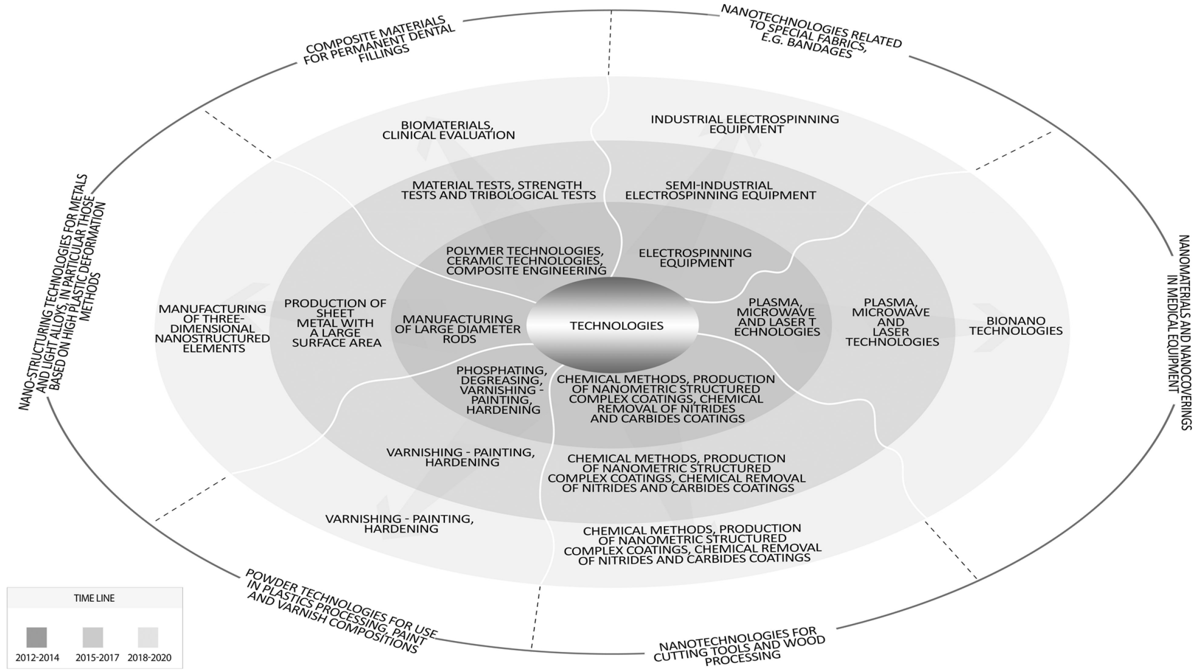

Fig. 7. Technology roadmap for nanomaterials and nanocoatings in medical equipment. Source: Adapted from [7].

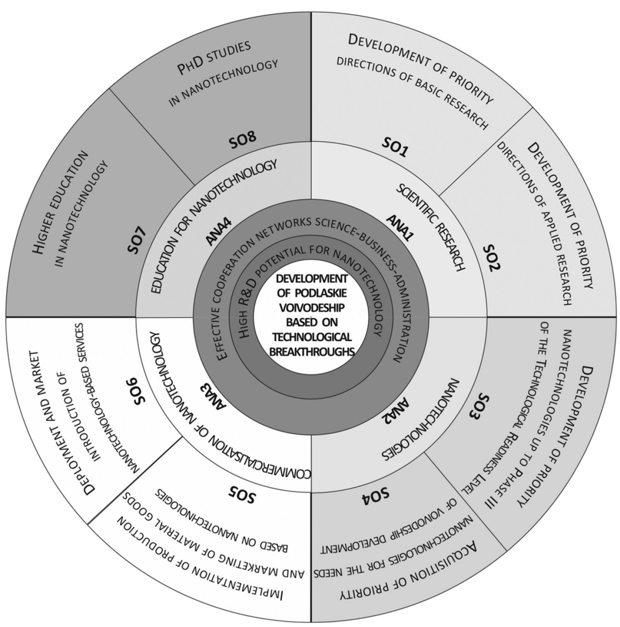

Fig. 8. Map of nanotechnology development in the Podlaskie Voivodeship. Source: Adapted from [59].

The following circles point to two key success factors for nanotechnology: a high R&D potential for nanotechnology and effective regional networks of actors, i.e., science–business–administration. The outer circle presents two strategic objectives (marked from SO1 to SO8, respectively) for each of the areas of activity. In addition, for each strategic objective, several supporting objectives have been identified (see Table III).

The presented concept of the strategy of nanotechnology development is the result of the cooperation of many experts from numerous national and foreign scientific centers and a large group of stakeholders representing entrepreneurs, local authorities, NGOs, media, and students. It should be emphasized that the previous studies and strategic documents concerning the development of the Podlaskie Voivodeship usually did not analyze the economic growth of the region from the perspective of breakthrough technologies. In this context, the novelty of looking at the future of the voivodeship is particularly evident. An important novelty in the approach to the development of the Strategy was the foresight approach, enabling the development of a vision of the future: not the existing, possible, inevitable—but above all—desirable. Regional economic foresight is an effective yet still underestimated instrument of strategic management of the region, supporting the development of regional policies, development scenarios for the region, and development decisions.

VII. Discussion

The contribution of this article is manifested by the development of the roadmapping methodology, which demonstrates clear links between technology mapping and roadmapping as well as the clear connection between roadmapping and scenario building (with the support of the key technologies method, STEEPVL, and SWOT).

Mapped priority technologies identified in the project were included in four scenarios of nanotechnology development in the Podlaskie Voivodeship in the perspective of 2020, the matrix of which was formed by research and development potential for nanotechnology and regional cooperation networks of entities representing business, science, and administration.

The authors of this article also demonstrated clear links between priority technologies and strategy development for the region. Because the greatest chances for the development of nanotechnologies are in the conditions of high R&D potential

TABLE III
STRATEGIC AND SUPPORTIVE OBJECTIVES FOR THE DEVELOPMENT OF NANOTECHNOLOGY IN THE PODLASKIE REGION

Activity area	Strategic objective	Supporting objective
Scientific Research	Developing priority directions for basic research	Attracting scientists from Poland and abroad to conduct advanced basic research in nanotechnology
		Creating a network of research centres to jointly apply for funds for the implementation of research projects
		Creating a system of support for teams conducting basic research in priority areas
		Offering consulting services in grant applications for basic research in the priority areas
	Developing priority directions of applied research	Attracting scientists from Poland and abroad to conduct applied research in nanotechnology
		Creating a system of support for teams conducting applied research in priority areas
		Creating cooperation networks of research centres and industry to apply for funds for the joint research projects in priority directions of applied science
		Adopting priority nano-research directions by the Bialystok Science and Technology Park
Nanotechnologies	Developing priority nanotechnologies up to Phase III of the Technological Readiness Level	Supporting the cooperation of various regional stakeholders in implementing nanotechnologies with a high level of technological readiness
		Creating a system of support for science-industry teams carrying out works with nanotechnologies at a high level of technological readiness
		Supporting the development of R&D structure with the aim or increasing the level of technological readiness of nanotechnologies developed in the region
		Acquiring priority nanotechnologies for the needs of the voivodeship development
	Acquiring priority nanotechnologies for the needs of the voivodeship development	Supporting the cooperation of regional stakeholders in the dissemination of knowledge on nanotechnology
		Fostering contacts and cooperation of Podlaskie entrepreneurs and scientists with national and global manufacturers and suppliers of nanotechnologies
		Supporting and promoting companies that acquire and implement priority nanotechnologies for production
Commercialisation of Nanotechnology	Implementing the production and marketing of material goods based on nanotechnologies	Creating an effective system for assessing the innovative potential of nanotechnological solutions
		Supporting the development of nano-applications in the region's industries
		Attracting investments of foreign companies with nanotechnological potential
	Deploying nano-technology-based services and introducing them to the market	Supporting companies introducing nanotechnology-based services
		Promoting the region based on the offer of specific services using nanotechnologies
		Establishing the "Nano-Podlaskie" cooperation network
Education for Nanotechnology	Higher education in nanotechnology	Launching and developing nanotechnology-oriented fields of study and other key enabling technologies
		Developing cooperation between universities and enterprises in the field of training high-class specialists in nanotechnology
		Creating creative industries and services specialised in the fields of study oriented towards key enabling technologies (Nano-Bio-Info-Cogno)
		Developing education in the field of modern technology brokerage (Nano-Bio-Info-Cogno)
	PhD studies in nanotechnology	Developing education at the level of PhD studies in nanotechnology and other breakthrough technologies
		Training talents to work in interdisciplinary, international research teams in the field of nanotechnology
		Introducing PhD studies oriented at the needs of enterprises implementing breakthrough technologies
		Introducing PhD studies oriented at the needs of creative industries and services sector dealing with key enabling technologies

Source: Adapted from [7].

for nanotechnologies and effective regional networks of entities representing business, science, and administration, the main objectives of the project of the Podlaskie strategy for the development of nanotechnology in the Podlaskie Voivodeship should focus on activities aimed at building and strengthening the R&D potential for nanotechnologies as well as building effective regional networks of cooperation of entities representing business, science, and administration [7].

A good potential example is the establishment of the Centre for Synthesis and Analysis—BioNanoTechno at the University of Bialystok or the inclusion of nanotechnology among the preferred industries in the Bialystok Science and Technology Park [7]. The authors of this article claim that the development of effective cooperation networks can be significantly supported by the triple helix concept or its modification of the quadruple helix concept or even multiplied spiral [62]. This concept aims to highlight the function of investment in innovation transfer mechanisms in high technology sectors by highlighting the roles of universities and technological infrastructure, enterprises and innovation, government and local government, and civil society.

The technology roadmapping method can be used as an instrument in the process of building intelligent specialization in the region during the implementation of regional strategic foresight projects, posing an interesting academic challenge in further foresight research. The implementation of the method enables the analysis and identification of local leaders from the area of industry, science, public, and private centers, and then include them in the group of stakeholders of roadmaps. Especially valuable may be the focus on gaining their support as well as their opinion on the resources and directions of development of the region, which are useful for their activity. Such actions should support the definition of directions of technological development that are important for the region, support their subsequent implementation, and increase the level of integration of the research and innovation sphere with the market sphere.

Identification of the region's specialization during the implementation of strategic foresight projects may be finally presented in the form of a dynamic (taking into account the time factor) technology roadmap. Its creation preceded by an in-depth analysis of the current situation, such as the identification of local resources and gaps in them, the characteristics of the dynamics of change in the region or the analysis of benefits and costs of the considered elements of the roadmap, makes possible to build a comprehensive and extremely valuable database of knowledge related to the technological development of the region.

Properly prepared technology roadmaps can highlight the main challenges and opportunities for regional technological development and indicate its specific, key determinants, limited or strengthened by the potential of the region.

The dissemination plan of the "NT FOR Podlaskie 2020" project results was formulated to mobilize support for the developed strategy among the key stakeholder groups (universities, research and development centers, enterprises, research and development networks, local and regional media, planning, decision-making, and opinion-forming centers). Informational, educational, and promotional activities aimed at the following [59].

1) Increasing the awareness of the existence of the strategy among key stakeholders.
2) Increasing the knowledge of the strategy's objectives, expected results of its implementation and the desired impact on regional development and the selected stakeholder groups.

3) Ensuring the acceptance of the strategic objectives among the stakeholders.
4) Ensuring stakeholder participation in the implementation of the strategic objectives in the areas that concern them.
5) Popularizing and promoting progress in the implementation of the strategy.

The project team conducted a short *ex-post* survey among the regional stakeholders. The respondents were asked about their opinions on the following three issues.

1) The possibility of commercial implementation of the technologies described in the strategy in the economy of Podlaskie.
2) The effect of the project implementation on the development of nanotechnology in the region.
3) The possibility of the nanotechnology development strategy being integrated into the official regional development strategy.

Nearly all of ca, 100 gathered responses were positive towards the three questions.

Naturally, such answers were not be treated as a prediction of what would happen with the project results and the strategy in the following years. However, it was an indication of a generally positive reception of the project results among most of the regional stakeholders. In reality, the major shortcoming of the project turned out to be the lack of policy impact. The project results have not been internalized by the regional decision-makers. Nanotechnology has not become a regional priority and has not made it to the list of Podlaskie's smart specialization areas. In turn, the dissemination of the project results in the scholarly community in the form of monographs, academic articles, and conference papers has been fairly effective.

VIII. Conclusion

Foresight, despite its many cognitive and managerial values as well as many cases of a successful application, still seems to be underestimated as an instrument of regional policy. The approach integrating roadmapping into regional technology foresight presented in the article was argued to be an effective tool supporting the development of regional policies, building scenarios of regional technological development, and making strategic decisions related to regional development.

The concept of methodology, research instruments, and an example of regional foresight implementation presented in this article create a solid research basis for wider implementation of this approach supporting strategic management of the region. The findings may be useful for political decision-makers, entrepreneurs, managers, and other key persons.

Apart from the contribution to the development of the methodology and visualization of roadmapping, the originality of this article lies in the demonstration of the importance of roadmapping for regional foresight studies and the formulation of regional technology development strategies.

On a practical level, a retrospective view on the events and processes that followed the formulation of the strategy of nanotechnology development in the Podlaskie region led to several conclusions. It was revealed that a robust and innovative methodology of the strategy formulation that combined regional foresight and technology foresight was an inspiration for academia. However, the recommendation to make nanotechnology development a regional priority never made it to the official strategic documents. The arbitrary choice of nanotechnology as a potential priority by the project authors, although well researched and motivated, might have influenced a relatively low level of the ownership of the results by some key regional stakeholders. The project's vision of the modernization of a lagging region has turned out to be too far-fetched, unconventional, and risky for the regional administration.

Nonetheless, the tacit impact of the project on the regional innovation ecosystem should be underscored. It consisted in the creation of new cooperation links in the regional Quadruple Helix and in the significant increase of awareness of the foresight concept.

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Joanicjusz Nazarko (Senior Member, IEEE) received the Ph.D. and D.Sc. degrees in electrical engineering from the Warsaw University of Technology, Poland.

He is a Full Professor of both technical and economic sciences, Ordinary Member of the Polish Academy of Engineering, and Member of the Production Engineering Committee of the Polish Academy of Sciences. He is currently serving as the Director of International China and Central-Eastern Europe Institute of Logistics and Service Science at the Bialystok University of Technology, Poland. He also holds the posts of *Professeur Associé* with the Université du Québec à Trois-Rivières, Trois-Rivières, QC, Canada, and Honorary Professor with Zhejiang University Ningbo Institute of Technology, Ningbo, China. He has authored or co-authored more than 300 technical and scholarly works published in reputable journals. He regularly speaks and presents his work at numerous international conferences. He has coordinated many research projects, obtained grants, and scholarships from national and international institutions. He has extensive experience in cooperation with industry especially in terms of transferring and employing new technologies. His current research interests include foresight, forecasting, productivity analysis, and benchmarking.

Prof. Nazarko serves as a Chair of the Poland Chapter of IEEE Technology and Engineering Management Society.

Joanna Ejdys (Member, IEEE) received the Habilitation degree from the Wroclaw University of Economics and Business, Poland, and the Ph.D. degree in economics from the Cracow University of Economics, Poland.

She received the Professor title in the field of organization and management from the President of Poland in 2020. She is a Full Professor with Bialystok University of Technology, Białystok, Poland. She is a Vice Rector for Development of Bialystok University of Technology, and Editor-in-Chief of Engineering Management in Production and Services (www.empas.pb.edu.pl). She has authored or co-authored more than 30 papers on foresight studies concerning regional and national science and technology innovation policy. She has coordinated many research projects and obtained grants and scholarships. She participated in many initiatives as a Member of research teams or an Expert. Her current research interests include technology management, foresight studies, and trust in technology.

Prof. Ejdys is a Member of several international organizations, including IEEE Technology and Engineering Management Society and Vice-Chair Research and Scientific Affairs IEEE Poland Section Technology and Engineering Management Society Chapter.

Alicja E. Gudanowska (Member, IEEE) received the Ph.D. degree in technical sciences in the field of production engineering from the Faculty of Mechanical Engineering, the Cracow University of Technology, Cracow, Poland, in 2015.

Since 2009, she has been a Scientific and Didactic employee of the Faculty of Engineering Management, the Bialystok University of Technology, Białystok, Poland. She has authored or co-authored more than 50 scientific publications in the field of identification and selection of technological solutions, technology management, data visualization, technology foresight, quality management, and competence network analysis. She is currently a Member of project research teams covering the topics of future studies, analysis of the directions of technology development, competence analysis and the factory of the future.

Dr. Gudanowska is a Member of the Polish Society for Production Management, International Society for Manufacturing, Service, and Management Engineering, Engineering, Production, and Project Management Association (general secretary), IEEE Young Professionals and IEEE Poland Section Chapter Technology Management Council.

Katarzyna Halicka (Senior Member, IEEE) received the Ph.D. degree in management sciences from the University of Warsaw, Poland, and habilitation degree in production engineering from Cracow University of Technology, Poland.

She is author of original method of Prospective Analysis of Technology. She has authored or coauthored more than 100 scientific publications. She has managed research projects, e.g., "Technological Foresight 'NT FOR Podlaskie 2020' Regional strategy for the development of nanotechnology" under the Operational Programme Innovative Economy; Multi-stakeholder Research Task Manager dialogues within the Nanotechnology Mutual Learning Action Plan For Transparent, and Nanotechnology project Responsible Understanding of Science and Technology, NANOTRUST (Union Framework Programme) European Horizon 2020). She is a Member of research teams and expert in international initiatives. She is currently the treasurer of the International Society for Manufacturing, Service, and Management Engineering and Polish Society for Production Management. She is also Vice-Chair of the IEEE Organisation and Programme, Polish Section of Technology and Engineering at the Management Society Chapter President of the Bialystok branch of the Polish Society for Production Management. Her current research interests concern the technical sciences as well as economic sciences and relate primarily to technology management, technology assessment, foresight and future management, the applications of quantitative methods, the artificial intelligence methods in forecasting and gerontechnology.

Anna Kononiuk received the Ph.D. degree in economics in the field of organization and management from the Faculty of Management, the University of Warsaw, Warsaw, Poland, in 2011.

She is a Scientific and Didactic employee of the Faculty of Engineering Management, the Białystok University of Technology, Białystok, Poland. She participated in numerous domestic and foreign foresight initiatives as a participant of research workshops, was a Member of research teams, a research task coordinator or an expert in the field of scenario method. She was also one of the originators of the Support Group, bringing together young scientists at the National Foresight Programme "Poland 2020." She is currently a Research Coordinator with the Białystok University of Technology in three research projects devoted to foresight research, two financed from the Funds for Science (granted by the Ministry of Science and Higher Education) and a project implemented within the Erasmus+ programme. Her current research interest include foresight research, and, in particular, in the scenario method, triangulation, wild cards and a diagnosis of foresight maturity of enterprises.

Andrzej Magruk received the M.S. degree in business informatics from the Bialystok University of Technology, Bialystok, Poland, in 2003, and the Ph.D. degree in economic sciences in the field of management sciences from The Poznan University of Technology, Poznan, Poland, in 2013.

He is Assistant Professor with the Faculty of Engineering Management, Bialystok University of Technology. Since 2003, he has been a Scientific and Didactic worker with Bialystok University of Technology. He has authored more than 60 articles. Hi current research interests focuses focus on the following areas: systemic uncertainty management in the foresight context; research methodology of technology foresight; methodological aspects of uncertainty management; analysis of selected areas of Industry 4.0; management of modern technologies, in particular concerning the Internet of Things; analysis of unprecedented events.

Dr. Magruk is an Editorial Reviewer of the Technology Management section in the *Journal Engineering Management in Production and Services*. He is a Member of the International Society for Manufacturing, Service and Management Engineering and Polish Society of Production Management.

Łukasz Nazarko (Member, IEEE) received the Ph.D. degree in economics from the University of Economics, Katowice, Poland.

He is an Assistant Professor with the Faculty of Engineering Management, Bialystok University of Technology, Bialystok, Poland. He has participated as a research team Member in many national and international research projects (e.g., NANO2ALL — Nanotechnology Mutual Learning Action Plan For Transparent and Responsible Understanding of Science and Technology). He has been a Visiting Research fellow with the University of Tokyo, Tokyo, Japan, and with Vilnius Gediminas Technical University, Vilnius, Lithuania. He serves as a Deputy Editor-in-Chief of "Engineering Management in Production and Services" and is a Board Member of the Polish Association for Technology Assessment. He has authored or co-authored more than 50 scientific papers in the area of his research. His current research interests include foresight, technology assessment, innovation policy, and responsible research and innovation.

Prof. Nazarko is a Vice-Chair Organization and Programme of IEEE, Technology and Engineering Management Society, Poland Chapter.