Regional Technology Foresight for Material Technologies

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Abstract: The Silesian Voivodeship is undergoing rapid technological transformation and industrial restructuring. This necessitates a systematic, evidence-based approach to identifying priority technologies that will drive regional development by 2050. The purpose of this article is to present the key results from the initial diagnostic phase of the technology foresight project conducted in the Silesian Voivodeship, focusing on the material production and processing sector. The research employs a multi-method approach, PESTEL analysis, integrating Porter's Diamond Model, the emerald model and SWOT analysis, supported by desk research, expert consultations and focus group discussions to assess technological potential and strategic priorities. The study identifies three critical technology groups: metallic, polymeric, and ceramic materials, as key enablers of industrial innovation. These technologies are of particular importance in several strategic sectors, including but not limited to the automotive, aerospace, chemical, steel, pharmaceutical, renewable energy and advanced manufacturing industries. The detailed analyses were summarized in a synthetic technology assessment using four key criteria: effectiveness of technology, market age, scope of application, and impact on the technology landscape. The results indicate that global trends are increasingly shaping the world within the BANI (Brittle, Anxious, Nonlinear, Incomprehensible) framework. These trends highlight several critical challenges for future scenarios, including the green revolution, achieving climate neutrality, reducing energy and material consumption, advancing automation and digitization, and localizing supply chains while better understanding global markets. The Silesian Voivodeship's robust industrial foundation, cutting-edge research infrastructure, and a highly skilled workforce provide a solid foundation for technological innovation and commercialisation, thereby ensuring sustained economic growth. The analysis emphasises the importance of strategic investments in high-performance materials, additive manufacturing, smart materials, green technologies and advanced recycling solutions. Furthermore, the promotion of collaboration between industry, academia, and local authorities is imperative for the acceleration of technology transfer, R&D commercialisation, and the development of regional innovation ecosystems. Furthermore, the enhancement of interdisciplinary synergies and knowledge-sharing platforms will promote the adoption of emerging technologies. To guarantee a sustainable and competitive position in the global market, the Silesian Voivodeship must develop a long-term innovation strategy that integrates technological foresight with industrial policy frameworks.

Keywords: Technology foresight, Regional policy, Material production, Sustainable development

1. Introduction

For some time, a reality characterised by dynamism, volatility and unpredictability has been referred to by the term VUCA or RUPT. More recently, however, another concept has emerged that most often describes how we look at the future - the world of BANI (Cascio, 2020, Menaria, 2024). In the context of these developments, it appears that the traditional methods of analysis and planning that are commonly used are proving insufficient to effectively diagnose and forecast the development processes of a region. In response to these challenges, the foresight method is introduced, which makes it possible to anticipate changes over a longer time horizon. In addition, this method offers regional authorities the opportunity to look into the future and anticipate the needs related to the development of the innovative capacity of the regions and provides companies with important information on the processes taking place in their regional environment.

The rapid technological progress and industrial restructuring taking place in the Silesian Voivodeship (Poland) require a systematic, evidence-based approach to identifying priority technologies that will drive regional development up to 2050. The activities undertaken as part of the 'Technologies Foresight for the Silesian Voivodeship 2050' project are focused on identifying future directions of technological development in the region. Among the 12 technological areas, a group of material production was singled out, with the technology groups: metallic, polymeric, and ceramic materials, as key enablers of industrial innovation. The technological foresight of the Silesian Voivodeship carried out in the years 2024-2026 assumes the implementation of 3 stages: identification of technological areas and their diagnosis, development of scenarios and strategic findings. In this paper we concentrate on presenting the results of the research of the first stage concerning the identification of technological groups and their diagnosis. Therefore, the main purpose of this paper is a comprehensive technological foresight analysis focused on the material production and processing sector, aiming to enhance regional competitiveness, sustainability and industrial resilience. The research employs a multi-method approach, integrating PESTEL analysis, Porter's Diamond Model (Porter, 1990), the emerald model (Akpinar et al., 2015) and SWOT analysis, supported by desk research, expert consultations and focus group discussions to assess technological potential and strategic priorities.

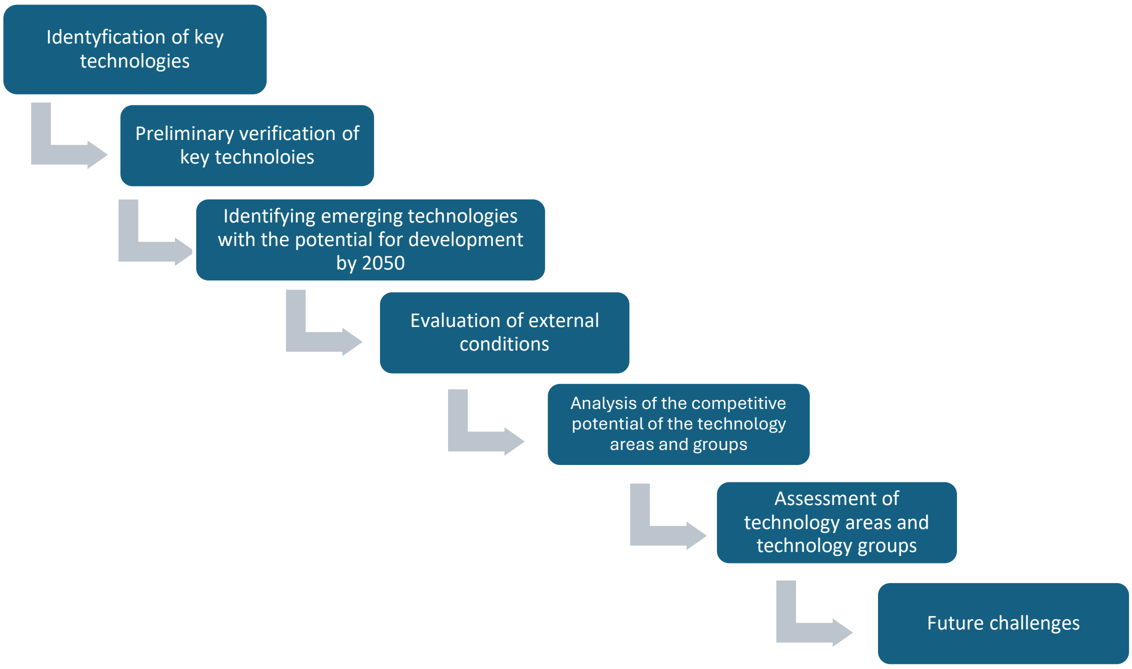
The paper consists of 4 parts: theoretical background, research methodology, results of research and conclusion.

2. Theoretical Background

The term VUCA gained popularity as a tool to describe a dynamic world after the end of the Cold War. The acronym VUCA (Volatility, Uncertainty, Complexity, Ambiguity) was coined to capture the increasing volatility, uncertainty, complexity and ambiguity that characterise contemporary global threats and challenges. In contrast, the BANI Concept, or Brittle, Anxious, Non-linear, Incomprehensible, was created by anthropologist Cascio to capture the increasing complexity and uncertainty of the contemporary world. Introduced in 2020, the concept addresses global challenges such as climate change, the COVID-19 pandemic, political instability and the dynamic development of technology. Cascio introduces BANI as a more appropriate framework for today's landscape, aiming not only to explain current choices, but also to anticipate their wider consequences. He argues that VUCA and BANI are not mutually exclusive; rather, they can coexist and provide complementary insights for navigating the complexity of future scenarios (Cascio, 2020). Research shows that in view of the increasing complexity, dynamism and unpredictability of the environment that the number of regional foresight studies undertaken has increased significantly since 2014 (Amini et al. 2021). Foresight is a method to collaboratively explore, forecast and shape the future (Li, 2017; Marinković, 2022). Foresight is a structured, long-term way of continuously improving collaboration between different communities to create a shared vision of development for the medium and long term, to define its directions and priorities. In this context, foresight involves ongoing decision-making and the mobilisation of collective action (Lozano Platonoff, 2009: 209). The term "Foresight" has been used more often in the sense Martin defined technology foresight is the process involved in systematically attempting to look into the longer-term future of science, technology, the economy and society with the aim of identifying the areas of strategic research and the emerging of generic technologies likely to yield the greatest economic and social benefits (Martin, 1995). Often equated with prediction (Jasiński 2007: 1), foresight is seen as a tool for forecasting the future. However, its main purpose is to build a vision of the future, create an enabling environment for collaboration between stakeholders and stimulate action to shape the future. This difference is important and affects the way foresight programmes are implemented, which follows directly from the definition provided. Foresight is of particular importance in the region, helping to identify directions for technological development at the regional level. It allows opportunities and threats to be identified and development strategies to be developed. There are many definitions of technology foresight. An already established classic definition describes technology foresight as the process for bringing partnership scientists, engineers, industrialists, government officials and others together to identify domains of strategic research and the emerging technologies likely to yield the greatest economic and social benefit and which in the long term will sustain industrial competitiveness (Martin & Johnston 1999). Subsequent attempts to define foresight have placed even more emphasis on the process and benefit aspect, e.g. a systematic, participatory process of gathering knowledge about the future and building medium- and long-term visions to make decisions in the present and mobilise collective action (Gavigan & Scapolo, 2001). Nowadays, it is emphasised that technological foresight activities are participatory, resulting from the interaction of a wide range of stakeholders and experts. At the same time, they are prospective in that they focus on identifying new technological opportunities, assessing potential challenges and forecasting future trends (Cuhls et al., 2024). Research confirms the effectiveness of technological foresight (TF) implemented in a collaborative open foresight model, which not only adopts a participatory approach but also promotes openness in terms of collaboration (Wiener, 2020). The foresight programme cycle consists of three iterative stages: thinking through the problem conditions, debating and shaping the future conditions. In the first phase, participants individually analyse different scenarios, then in the second phase they have an open discussion to broaden their thinking and develop a shared vision (High Level Expert Group, 2002). The final phase focuses on initiating decision-making processes and supporting leaders, which influences regional policy and socio-economic development. In the context of technological foresight, technology assessment is extremely important in the Thinking stage. Therefore, the diagnosis (thinking) stage assesses its key parameters, such as: the life cycle of the technology in terms of its competitiveness or efficiency, market age, application or impact on the technological landscape of the region.

3. Research Methodology

The research presented here forms part of a larger project, entitled "Technological Foresight of the Silesian Voivodeship 2050". The objective of this study is to establish a novel vision for the advancement of technology in the region, with a focus on the year 2050. The study encompasses three distinct phases: the identification of technologies and their diagnosis, the development of future scenarios, and the formulation of strategic findings. The initial phase of the identification and diagnosis study comprised seven stages (cf. Figure 1).



Source: Own work.

Figure 1: Initail phase in process of technological foresight of the Silesian Voivodeship 2050

The process adopted was based on deductive reasoning, i.e. the process of deriving conclusions from what is already known. The process was supported by several methods. Extensive desk research was required for the PESTEL analysis, Porter's diamond, emerald model and SWOT. The data presented were verified during expert interviews and focus studies.

As illustrated in Figure 1, the entire process was divided into seven related stages. The first was the identification of key technologies already being developed in the region, which was achieved by analysing secondary data (desk research) including strategic documents, scientific literature and sectoral reports. This was followed by preliminary verification of these technologies through interviews with industry experts, enabling the identification of the most active actors in the region's technology ecosystem. The third stage was to identify the technologies with the potential for development in the 2050 horizon. To this end, a focus group research method was used with specialists from various fields, allowing for a multi-faceted assessment of future developments. This was followed by an analysis of PESTEL, which was conducted to assess the determinants of technology development in the context of political, economic, social, technological, environmental and legislative factors. A key step in the process was the analysis of competitive potential, carried out using a mix of Porter's diamond model and the emerald model. This allowed the identification of the structural and resource advantages of the region, taking into account demand conditions, supply conditions and supporting sectors. The research tools used at this stage of the research include economic indicators, document analyses of the industry, sector and technology area in question, and statistical data. The sixth stage of the research is the assessment of the technological area and technology group using the SWOT analysis method and synthetic technology assessment using four key criteria: effectiveness, market age, scope of application and impact on the technology landscape. The results of these analyses were validated during subsequent expert sessions, allowing the final diagnosis to be refined. The final stage of the research process aimed to validate the results of the technological area assessment and identify future challenges. It was accomplished by conducting focus groups again with the expert teams that had previously participated in the identification and analysis of the technology potential.

4. Results of the Research

4.1 Scope of the Technological Area

The Silesian Voivodeship is a dynamic region that has been undergoing intensive change for many years due to technological and economic transformation. The challenges of transformation have been joined by a pandemic, followed by the war in Ukraine. Poland's 2021 Industrial Policy sets out five development axes for the postcovid world: digitalisation, green deal, security, localisation and high-competence society. Policy directions, objectives and instruments are formulated around these axes. The document also identifies key industries, divided into four categories (Industrial Policy of Poland, 2021):

1. traditionally strong industries facing challenges (automotive, steel, chemicals, furniture, paper);
2. industries with high growth potential and dynamics (industries: pharmaceuticals, biotechnology and medical devices, food processing, cosmetics, building materials, electrical engineering, machinery, rail transport);
3. industries with new growth prospects (industries: specialised shipbuilding and yachts, aerospace, BSP, recycling, batteries, advanced energy technologies);
4. services to industry (transport, ICT, business services).

Unpredictable variables mean that the region has to be extremely flexible in dealing with a very rapidly changing market. The experience and know-how that Silesian players have allows them to implement changes also in the production and materials processing sector. Breakthroughs in materials technology have often meant a leap forward in civilisation. Progress in the functional properties of devices, machines or objects made from them depends on the improvement of materials. A strong research and education base in the area of technology and materials research creates a favourable environment for business development. In addition, based on the report Manufacturing of Industrial Products 2019-2023 in 2023, compared to 2019, an increase in the value of sold production was recorded in 24 divisions, including those related to the area under study: metals (by 44.8%), fabricated metal products, excluding machinery and equipment (by 44.3%), rubber and plastic products (by 40.4%), paper and paper products (by 40.1%), wood and products of wood, cork and straw (by 40.0%) and products of other non-metallic minerals (by 36.9%). Poland, and in particular the Silesian Voivodeship, boasts a considerable human resources base in the field of materials technology, and research infrastructure is currently undergoing rapid development, driven by research initiatives. The technological area of materials production and processing in the Silesian Voivodeship is distinguished by the work "Priority technologies for the sustainable development of the Silesian Voivodeship". The findings of these studies have been incorporated into the 'Technology Development Programme of the Silesian Voivodeship for 2019-2030'. Moreover, the Entrepreneurial Discovery Process has identified an additional smart specialisation for the Silesian Voivodeship, namely that of energy, medicine, information and communication technology, and the green economy. These emerging industries are encompassing new or existing economic sectors and value chains, and are evolving into new industries that are future-proof for the region. The concept of emerging industries is predicated on the development of novel products, services, technologies or ideas. The subjects are in an initial phase of development, yet they are demonstrating high growth dynamics. This suggests that they have the capacity to attain new global competitive advantages. The Regional Innovation Strategy (RIS), referring to emerging industries, identifies two specific industries: creative industries and mobility industries. The PPO has identified groups of technologies that are pivotal to the development of emerging industries. These include metallic materials, polymer materials, ceramic materials, nanotechnologies and nanomaterials, as well as design and manufacturing technologies in the aerospace industry, the automotive industry, machine tools and workshop equipment, power transmission systems, special machines and equipment, and the space industry.

The brainstorming and structured interviews with experts in the diagnosis process in the study were based on the traditional division of the field of materials production and processing: metallic materials, polymeric materials and ceramic materials. Composites as a technology combining different materials were distinguished into three basic ones. This division became the basis for a strategic diagnosis of the area of production and processing of materials in the context of the technological foresight of the Silesian Voivodeship.

Metallic materials are a fundamental group of materials in materials engineering, distinguished by their wide range of applications and unique mechanical, chemical and physical properties (García-Rojas et al., 2024). In the scientific literature, their properties are analysed, among others, in terms of fatigue life, which determines the service life of components subjected to cyclic loading (Sawlan et al., 2024). Metals and their alloys are obtained through complex metallurgical processes, divided into ferrous and non-ferrous metallurgy. In Poland, steel accounts for 91% of metallurgical production, copper 7%, and lead and zinc the remaining 2%. Aluminium production ceased in 2009. Steel remains globally essential: in 2022, global crude steel production reached 1885 million tonnes, with over 3,500 grades-75% developed in the last two decades. The Silesian Voivodeship plays a major role in Poland’s metal sector. Metals and metal products make up 22% of regional industry; over 11,000 enterprises (53% of the national sector) are based there (BDL, 2023, Materials management in 2023, 2024). At the diagnosis stage, based on desk research and discussions with experts, the following specific technologies were distinguished in the group of metallic materials technologies: steel production technologies, steel processing technologies, foundry technologies, non-ferrous metal and alloy production technologies, non-ferrous metal processing technologies, hydrometallurgical process technologies, metal structures and other finished metal products technologies, metal processing and metal coating technologies, composite production technologies, metal waste recycling technologies.

Polymeric materials and the plastics processing industry have been driving economic growth and technological and industrial development for more than a century. As complementary materials to metals, they are constantly being developed, e.g. through modifications of composition and improvements in processing technology. There has been a steady increase in the production of plastics on global and EU markets, although recent years have seen a slowdown due to a pandemic and the "plastics directive" restricting the sale of single-use products. The European plastics sector employs over 1.5 million people in almost 60 000 companies. In Poland, there are about 15 000 companies, of which more than 2 000 operate in the Silesian voivodeship (14% of the national share). Employment in the region exceeds 40 000 people (17.5% of national employment) (BDL, 2024). The Polish plastics industry, incorporating both production and recycling, is a pivotal sector. Despite the absence of prominent multinational corporations, the Silesian Voivodeship assumes a pivotal function as a regional nexus for the processing and recycling of synthetic plastics, thereby catering to the evolving market demands and addressing pressing environmental concerns. At the stage of diagnosis, following a review of the literature and consultation with experts, the following specific technologies were identified as having potential for development in the Silesian Voivodship: technologies for the production of rubber products, technologies for the production of plastic products, technologies for the production of composites, and polymer recycling technologies.

Ceramic materials are a diverse group of substances with non-metallic and inorganic character and unique physicochemical properties (González-Angulo et al., 2023). The importance of ceramic materials is particularly evident in the context of modern technologies and their extensive use in the aerospace, energy, electronics and medical industries (Chung et al., 2023). Poland is the third largest producer of ceramic tiles in Europe, after Spain and Italy. Polish applied ceramics, including porcelain, enjoy a worldwide reputation. The Silesian Voivodeship is distinguished by its wealth of ceramic raw materials, including dolomite mines, and a dynamically developing glass industry. Poland is the fifth largest producer of glass in Europe, and the Silesian Voivodeship is its main base. Glass, thanks to its optical and mechanical properties, is used in the construction and packaging industries. Its growing role is also due to new EU regulations which oblige producers to recyclability of packaging by 2030. The region is home to more than 2,000 companies in the ceramics and glass sector, accounting for 10% of the country's businesses. Employment exceeds 22,000 people (15% nationally), confirming the importance of the Silesian Voivodeship as a key centre for ceramic technologies in Poland (BDL, 2024). At the diagnosis stage, based on desk research and discussions with experts, the following specific technologies were identified in the group of ceramic product technologies with potential for development in the Silesian Voivodeship: technologies for the production and processing of glass, technologies for the production of refractory products, technologies for the production of ceramic building products, technologies for the production of porcelain and ceramic products, technologies for the production of optical fibres, and technologies for the production of composites.

4.2 Technology Assessment in the Area of Production and Materials Processing

The detailed analyses carried out in stages 1-5 of the research process were summarised in a synthetic technology assessment using four key criteria: effectiveness, market age, scope of application and impact on the technology landscape. The results of this analysis were compiled and presented in the form of a technology assessment table, which is a synthetic compilation of expert knowledge and data from R&D and market analysis. Table 1 classifies individual technologies according to four relevant dimensions:

- Effectiveness, i.e. an indication of whether the technology has a baseline, key function or is experimental,
- Market age, enabling an assessment of the maturity and potential growth dynamics of a given technology (from the introduction phase, through growth, maturity and into the decline phase),
- Technology application, referring to the area of application: material, (operation or product) technologies,
- Impact on the technology landscape, i.e. allocation to categories such as niche, critical, disruptive and deep tech.

Such a methodological approach, in line with the assumptions of regional foresight and the adopted research process, makes it possible to effectively identify the most promising technologies in the context of industrial transformation of the Silesian Voivodeship. At the same time, it enables the detection of technologies of decreasing importance or limited impact, which may require modernisation or withdrawal from strategic priorities.

Table 1: Technology assessment in the area of production and materials processing

	Effectiveness			**Market age**				**Application**			**Impact on the technological landscape**			
Technology group/ Technologies	base technology	key technology	experimental technology	introduction phase	growth and popularity phase	maturity phase	decline phase	material technology	technology of operation	product technology	niche technology	critical technology	disruptive technology	deep tech
Technology group - metallic materials														
steelmaking technologies	x					x			x			x		
steel processing technologies		x				x			x			x		
foundry technologies		x				x			x		x			
technologies for the production of non-ferrous metals and alloys		x				x		x				x		
non-ferrous metals processing technologies		x				x			x				x	
hydrometallurgical process technologies		x				x			x			x		
technologies for metal structures and other fabricated metal products		x				x			x		x			
metalworking and metal coating technologies		x				x			x			x		
metal composite manufacturing technologies		x			x			x					x	
recycling technologies for metallic wastes		x			x				x			x		
Technology group - polymer materials														
rubber product manufacturing technologies		x				x				x	x			
production technologies for plastic products		x				x				x		x		
polymer matrix composite manufacturing technologies		x			x			x					x	
polymer recycling technologies		x			x				x			x		
Technology group - ceramic material														
glass production and processing technologies		x				x		x				x		

	Effectiveness			**Market age**				**Application**			**Impact on the technological landscape**			
Technology group/ Technologies	base technology	key technology	experimental technology	introduction phase	growth and popularity phase	maturity phase	decline phase	material technology	technology of operation	product technology	niche technology	critical technology	disruptive technology	deep tech
production technologies for refractory products	x						x		x		x			
production technologies for ceramic building products		x				x				x		x		
porcelain and ceramic product manufacturing technologies		x				x				x		x		
fibre optic manufacturing technologies		x			x				x				x	
ceramic composite manufacturing technologies		x			x			x					x	

Source: Own work.

The technologies assigned to the metallic materials group revolve around the manufacturing and processing of ferrous and non-ferrous metals, casting, recycling and the production of composites. The majority of these technologies have been classified as key technologies, as well as technologies in the market maturity phase. These are well-established industrial solutions that form the basis of the region's industrial activity. In particular, technologies such as steel processing and production or non-ferrous metal processing have also been labelled as critical technologies, highlighting their strategic importance for the further industrial development of the province. At the same time, it should be noted that none of the technologies in this group were labelled as deep tech, which may suggest the need for greater emphasis on innovation and development of technologies beyond standard industrial processes. Foundry technology was also categorised as a niche technology, indicating its limited but specialised potential in specific industries. This can be both an opportunity and a threat - indicating the potential for a high degree of specialisation, but at the same time the risk of limited scalability. Non-ferrous metal processing technology and metal composite manufacturing technology were identified as breakthrough technologies.

In the polymer plastics group, technologies with growing market potential were noted, particularly in the context of the development of biocomposites, green materials and recycling technologies. All technologies were flagged as critical technologies, of which 2 are in the growth and popularity phase (polymer matrix composite technologies and polymer recycling technologies). It is particularly noteworthy that polymer recycling has been classified as a critical technology, reflecting current priorities related to the closed loop economy and the regulatory requirements of the European Union. However, as with metallic materials, the absence of classification as deep tech may suggest a moderate level of R&D in this area. These technologies require further support in terms of product and process innovation, especially in the context of implementing new green material solutions. The production of polymer matrix composites was identified as a breakthrough technology.

Technologies in the ceramics group, including, among others, the production of glass, refractory products, porcelain and fibre optics, show a high degree of specialisation and technological sophistication. They include both critical technologies (glass production and processing, ceramic building products production, porcelain and ceramic products production) and breakthrough technologies (fibre optics production, ceramic composites production), which testifies to their significant impact on shaping modern economic sectors such as optoelectronics, energy and intelligent building materials. In particular, the production of ceramic building products and the production of porcelain and ceramic products (critical technologies) have been classified as technologies with high potential for impact on the technological landscape, while being strongly rooted in the region (maturity phase). Refractory technologies have a clear tendency to be classified as niche, confirming their potential in specialised sectors with a high barrier to entry but limited competition.

The research carried out also made it possible to identify key challenges, which are becoming necessary to build scenarios. Five key challenges requiring systemic action were identified in the perspective of the long-term development of the Silesian manufacturing and materials processing sector. The first is the green revolution, aimed at decarbonising production processes and increasing environmental efficiency. In this respect, the intensification of low-carbon steel production, the use of hydrogen in steel production and the generation and storage of electricity and hydrogen, as well as the construction of financing systems for the development of green hydrogen technology in production, are of key importance. The second challenge is to achieve climate neutrality, which involves the need to support advanced copper processing, glass packaging production and plastics recycling. There is also a need for actions oriented towards improving the logistics of metal scrap recycling and supporting the development of polymer fuel cell technology. The third priority is the reduction of energy and material intensity, which should be implemented through the development of highly specialised processing technologies, especially in the areas of steel and copper. It is also advisable to undertake cooperation between enterprises in energy clusters and other solutions to reduce energy costs. The fourth challenge is automation and digitisation, which focuses on the development of competences for automation and digitisation of processes. This requires, first and foremost, aiming to reduce the digital and technological gap between large companies and SMEs, promoting automation as a driver of innovation, and creating preferential conditions for companies using automated and digital systems. Lastly, and crucial from the point of view of international competitiveness, is the challenge of locating and understanding the global market. Its implementation is based primarily on the internationalisation of companies in the field of technology, the development of international scientific and industrial cooperation networks, the intensification of the use of global resources and instruments of the digital economy, and the promotion of a new image of cooperation between science and business in international terms.

The research conducted is important for the development of regional policy. Smart specialization strategies (S3) have empowered regions to identify and cultivate their unique technological and industrial strengths, fostering competitive advantage in a rapidly evolving global economy. However, in an era of disruption (BANI world), merely recognizing these strengths is no longer enough. This is where technological foresight becomes critical—by anticipating future trends, challenges, and opportunities, regions can proactively align their innovation ecosystems with long-term economic and societal needs. Integrating foresight into S3 enables: strategic prioritization of high-impact technologies and sectors, Resilience-building against future shocks, enhanced collaboration between industries, academia, and policymakers, sustainable transitions in line with digital and green agendas. Regions that effectively combine smart specialization with foresight not only strengthen their innovation capacity but also position themselves as leaders in tomorrow's economy. This goal is also shared by the Silesian Voivodeship, which, since the beginning of the regional policy-making process, has been a leader in Poland in developing and implementing innovation strategies and technology development programs.

5. Conclusion

In the BANI world, regional policy post-smart specialization focuses on harnessing a region's unique strengths to spur innovation, economic growth, and competitiveness. Building on smart specialization strategies (S3), it emphasizes interregional collaboration, strengthens innovation ecosystems, and tackles the challenges posed by the green and digital transitions. Going beyond mere identification of competitive advantages, this evolved approach actively fosters innovation, cooperation, and sustainable development—both within and across regions. Ultimately, it aims to enhance Europe's economic resilience and global competitiveness. The research presents synthetic conclusions from the first stage of technological foresight conducted in the Silesian Voivodeship, focusing on a single area: the production and processing of materials. The article emphasizes three critical technology groups: metallic, polymeric, and ceramic materials. The assessment of these groups enabled the formulation of future recommendations and identified challenges necessary for building future scenarios. Recommendations include investing in high-performance materials, additive manufacturing, green technologies, and recycling, while fostering collaboration among industry, academia, and authorities to accelerate innovation. Promoting interdisciplinary knowledge-sharing will support technology adoption. To date, comparable research has been conducted across ten key technological areas in the region. Current efforts are focused on developing comprehensive regional scenarios, establishing Delphi groups for expert analysis and the formulation of strategic insights. This proven methodology holds significant transfer potential, with several other Polish provinces already considering its adoption for their own strategic planning processes. A long-term, strategic approach that integrates technological foresight with supportive policies is essential to maintaining competitiveness and addressing regional challenges through coordinated, forward-looking efforts. Importantly, the key is not merely defining goals and roadmaps but, above all, initiating decision-making processes, supporting leaders, and encouraging participation in joint ventures.

While the presented conclusions may require further elaboration, the project reports already completed serve as a critical foundation for the region's technological advancement. This research delivers value not only to regional policymakers but also to industry leaders and academic institutions. The article's authors bring more than just project expertise—they have years of collaborative experience with regional authorities and actively contribute to strengthening the innovation ecosystem. Their ongoing work developing a Materials Production and Processing Observatory further demonstrates their deep engagement in shaping the region's technological future.

The main recommendation for regional stakeholders involved in regional development is to continue to analyze specific technological areas both the diagnosis of the current state and foresight activities to develop scenarios for future technology development. So far, the results of the assessment of technologies used in enterprises indicate the effectiveness of the involvement of experts from enterprises - users of technologies and academics analyzing and indicating technological trends of a global nature. This principle has so far proven itself in the creation of a regional knowledge management system in the Silesian Voivodeship, and can also be applied in other regions.

A key limitation of the article was the need for a very synthetic presentation of the research results. In addition, effective foresight requires the involvement of various stakeholder groups and reaching out to experts, which was a major challenge. The experts themselves also stressed that foresight is based on current data and knowledge, which means that it may not consider the emergence of new, unexpected changes.

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References

Akpinar, M., Can, O., & Mermercioglu, M. (2015). Determinants of competitiveness in European regions: A test of the emerald model. IJTIS, 4(3/4), 114-130. https://api.semanticscholar.org/CorpusID:156708245.

Amini, H., Jabalameli, M.S. & Ramesht, M.H. (2021). Development of regional foresight studies between 2000 and 2019: an overview and co-citation analysis. Eur J Futures Res 9, 1. https://doi.org/10.1186/s40309-021-00170-7.

BDL Bank Danych Lokalnych GUS, 2024. https://bdl.stat.gov.pl.

Cascio, J. (2020). Facing the Age of Chaos. Medium. https://medium.com/@cascio/facing-the-age-of-chaos-b00687b1f51d.

Chung, J.-K.; Im, J.-S.; Park, M.-S., (2023). Development of Photo-Polymerization-Type 3D Printer for High-Viscosity Ceramic Resin Using CNN-Based Surface Defect Detection. Materials, 16, 4734. https://doi.org/10.3390/ma16134734.

Cuhls, K., Dönitz, E., Erdmann, L., Gransche, B., Kimpeler, S., Schirrmeister, E. & Warnke, P. (2024). Foresight: Fifty Years to Think Your Futures. In: Edler, J., Walz, R. (eds) Systems and Innovation Research in Transition. Sustainability and Innovation. Springer, Cham. https://doi.org/10.1007/978-3-031-66100-6_4.

García-Rojas, E., Leo, P., Tapiador, J., Martos, C., & Orcajo, G., (2024). URJC-1: Stable and Efficient Catalyst for O-Arylation Cross-Coupling. Nanomaterials, 14(13), 1103. https://doi.org/10.3390/nano14131103.

Gavigan, P. J. & Scapolo, F. (2001). Foresight and the long-term view for regional development. The IPTS Report, 56, 19-29.

González-Angulo, E.; Fernández-Estevan, L.; Casas-Terrón, J.; Senent-Vicente, G.; Fons-Badal, C.; García-Sala Bonmatí, F.; Agustín-Panadero, R.; Román-Rodríguez, J.L., (2023). Microtensile Bond Strength of CAD-CAM Restorative Dental Material Blocks to Resin Cement: An In Vitro Study. Materials, 16, 4796. https://doi.org/10.3390/ma16134796.

High Level Expert Group for the European Commission: Thinking, debating and shaping the future: Foresight for Europe. Final report, April 2002. Available online at: ftp://ftp.cordis.lu/pub/rtd2002/docs/report_hleg_20426final.pdf.

Industrial Policy of Poland (2021). Ministry of Economic Development and Technology, Warsaw.

Jasiński, L., (2007). Myślenie perspektywiczne. Uwarunkowania badania przyszłości typu foresight, 2007, Instytut Nauk Ekonomicznych Polskiej Akademii Nauk, Warszawa.

Li, N., Chen, K., & Kou, M. (2017). Technology foresight in China: Academic studies, governmental practices and policy applications. Technol. Forecast. Soc. Change., 119, 246-255. https://doi:10.1016/j.techfore.2016.08.010.

Lozano Platonoff, A. (2009). Zarządzanie dynamiczne. Nowe podejście do zarządzania przedsiębiorstwem. Difin, Warszawa.
Marinković, M., Al-Tabbaa, O., Khan, Z., & Wu, J. (2022). Corporate foresight: A systematic literature review and future research trajectories. J. Bus. Res., 144, 289-311. https://doi.org/10.1016/j.jbusres.2022.01.097.
Martin, B.R. (1995). Foresight in science and technology. Tech Anal Strat Manag 7:139–168.
Martin, B.R., & Johnston, R. (1999). Technology foresight for wiring up the national innovation system: experiences in Britain, Australia, and New Zealand. Technol. Forecast. Soc. Change., 60(1), 37-54. https://doi:10.1016/S0040-1625(98)00022-5.
Materials management in 2023 (2024). Statistics Poland, Statistical Office in Rzeszów. Available online at: https://stat.gov.pl/en/topics/industry-construction-fixed-assets/industry/materials-management-in-2023,6,18.html.
Menaria, N. (2024). Comparative Analysis of VUCA and BANI Frameworks. Int. J. Multidiscip. Res., 6(2). https://doi.org/10.36948/ijfmr.2024.v06i02.15715.
Porter, M.E. (1990). Competitive advantage of nations. Harvard Business Review, 68(2), 73–91. https://hbr.org/1990/03/the-competitive-advantage-of-nations.
Sawlan, Z., Scavino, M., & Tempone, R., (2024). Modeling Metallic Fatigue Data Using the Birnbaum–Saunders Distribution. Metals, 14(5), 508. https://doi.org/10.3390/met14050508.
Wiener, M., Gattringer, R., & Strehl, F. (2020). Collaborative open foresight - A new approach for inspiring discontinuous and sustainability-oriented innovations. Technol. Forecast. Soc. Change, 155, 119370. https://doi:10.1016/j.techfore.2018.07.008.