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Integrated policymaking in the area of RDI

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1. Introduction

1.1. Purpose

This report is being prepared under the DG REFORM call for tender REFORM/2021/OP/0006 Lot 1 "Integrated policymaking in the area of RDI" project under Deliverable 2 – Methodological Handbook (for creating horizontal and sectoral industrial strategies including implementation roadmap/action plan). This handbook provides a detailed methodology for mapping Slovak Research, Development, and Innovation (RDI) value chains to guide industrial strategies.

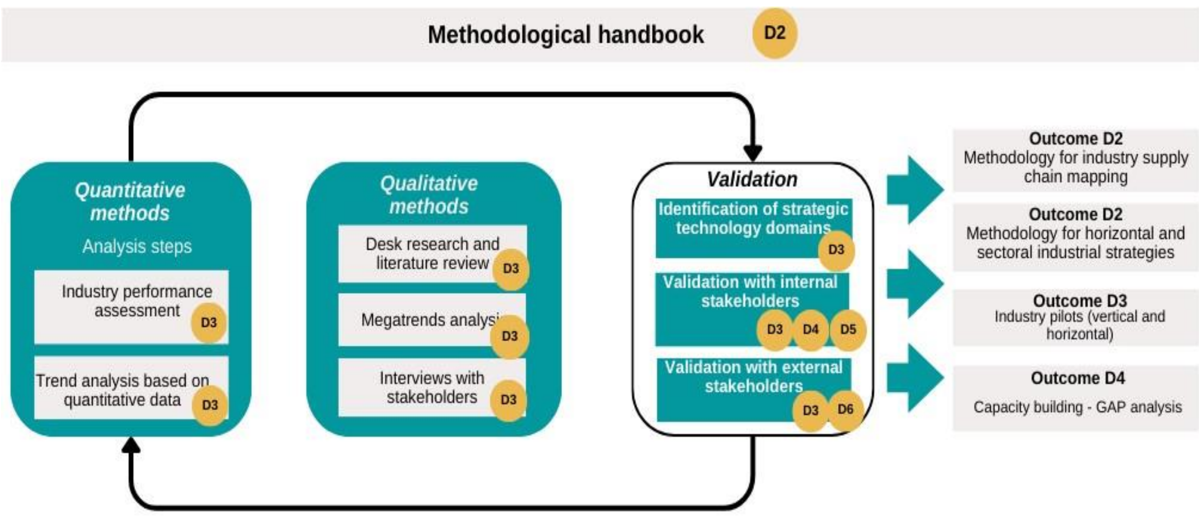
Policymakers need comprehensive information on the current state, strategic options, drivers, risks, and challenges influencing industrial investment decisions and their macro-level impacts. This handbook aims to support the assessment and monitoring of RDI, technologies, and markets, ensuring that strategic industrial efforts are well-informed and effectively directed.

1.2. Scope and methodological framework of value chain mapping

The methodology for creating roadmaps with horizontal and vertical industrial strategies employs a mixed methods approach that integrates qualitative and quantitative techniques to develop a comprehensive understanding of Slovakia's industrial landscape. This approach emphasises leveraging expert insights and empirical data to identify strategic pathways and areas for growth and innovation within the country's industries. Below, we present an overview of the handbook's methodological framework (

Figure 1), explaining how each integral part of the research project connects to the deliverables. This section also provides a detailed description of each step in the methodological framework and a list of indicators and data sources that can be used.

FIGURE 1. OVERVIEW OF THE PROJECT'S METHODOLOGICAL FRAMEWORK AND LINKS TO DELIVERABLES OF VALUE CHAIN MAPPING



Source: Created by the project team.

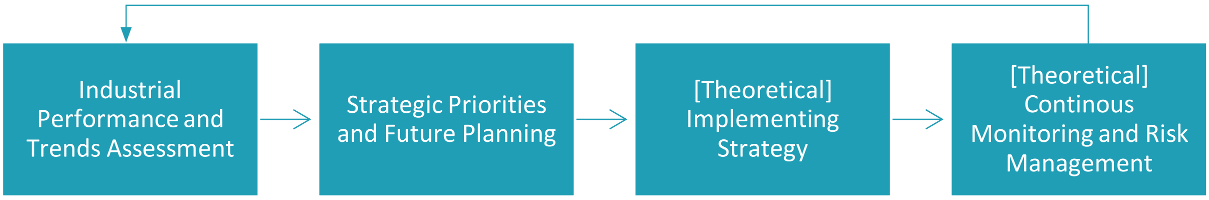
1.2.1. Utilisation of data analysis in broader strategic activities

In a landscape defined by regional and global competition, coupled with pressing global challenges, developing comparative knowledge and measurement capacity related to research and development and innovation (R&D&I) investments in industrial technologies is essential. Market competitiveness demands continuous technological advancement, with potentially disruptive technologies evolving from niche innovations to widely adopted norms. Maintaining and improving market positioning while fostering a socially inclusive, resilient, and autonomous industry requires a **strategic, data-driven approach** that integrates both qualitative and quantitative insights[1].

Industrial strategy or Foresight studies enable anticipation of disruptive events and technologies. Such studies provide a structured framework for identifying long-term challenges and opportunities, helping policymakers prioritise R&D investments and shape innovation strategies. Research suggests a strong correlation between well-executed foresight studies and improved national innovation performance[2]. The iterative process of *industrial performance assessment*, which combines **global trends with quantitative approaches**, allows governments to detect early signals of change. Advanced technologies, such as AI and digital tools, enhance the ability to filter and analyse vast amounts of data, turning insights into actionable decisions. This combination of foresight and data-driven insights aligns with modern policymaking, making the process more agile, responsive, and effective in addressing the continuous influx of data on technological and market developments[3].

Analytical insights derived from technological foresight are also critical for **strategic roadmapping**, which guides R&D investments and ensures alignment with market demands. Effective roadmapping relies on a strong knowledge base to support informed decision-making and align processes with ongoing technological advancements. Roadmapping, being a cyclical process, begins with identifying key technology areas, aligning them with market needs, and prioritising investments (Figure 2). As new challenges or opportunities arise, the process restarts, making it essential for governments to adopt a systematic approach that streamlines data, ensures continuous adaptation, and fosters long-term innovation[4].

FIGURE 2. INDUSTRIAL STRATEGY ROADMAPPING*



Source: Created by the project team based on Cho, Yoon and Kim (2016)[5].
**Stages that are outside of the scope of this project are marked as [Theoretical]*

[1] European Commission. (2020). A new ERA for research and innovation (COM(2020) 628 final). EUR-Lex. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2020%3A628%3AFIN

[2] Meissner, D. (2012). Results and impact of national Foresight studies. *Futures*, *44*(10), 905-913.

[3] Monteiro, B., & Dal Borgo, R. (2023). Supporting decision making with strategic foresight: An emerging framework for proactive and prospective governments.

[4] Cho, Y., Yoon, S. P., & Kim, K. S. (2016). An industrial technology roadmap for supporting public R&D planning. *Technological Forecasting and Social Change*, *107*, 1-12.

[5] Cho, Y., Yoon, S. P., & Kim, K. S. (2016). An industrial technology roadmap for supporting public R&D planning. *Technological Forecasting and Social Change*, *107*, 1-12.

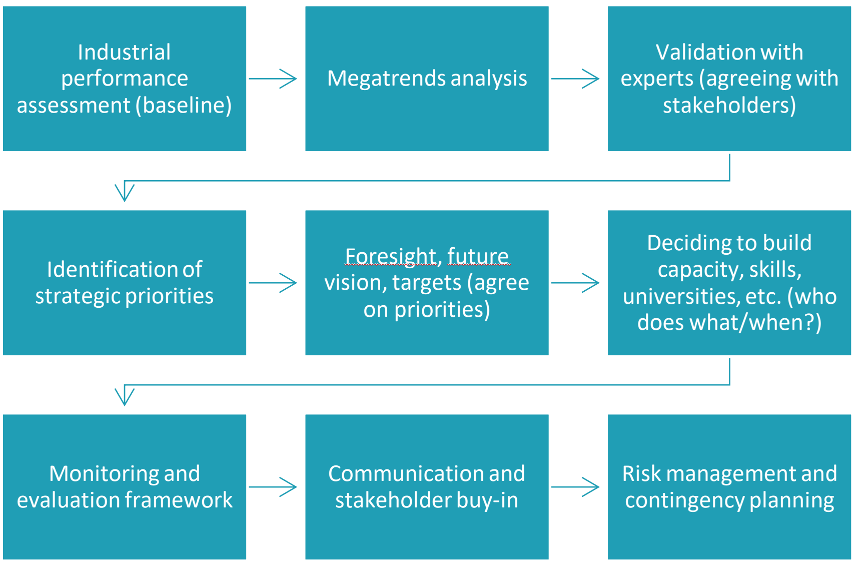
For this project, the team relied on Milda.ai to gather data for analysis, leading to observations and insights about the industrial automation and robotisation ecosystem and cutting-edge technology companies in Slovakia's automotive and robotisation sectors. This approach demonstrates how digital tools can streamline data access, extraction, and formatting, providing a foundational understanding of the current landscape and supporting informed recommendations. By leveraging advanced analytics and AI-driven platforms, the process becomes more efficient—reducing the time required for data collection—and enhances the accuracy and depth of insights.

The quantitative data collected is crucial for supporting **qualitative expert input**. Experts can use this data to refine their qualitative narratives, ground their observations in factual evidence, and identify gaps or emerging trends. This synergy between data-driven insights and expert qualitative analysis ensures that findings are comprehensive and actionable. Furthermore, expert data validation enriches the analysis, providing nuanced interpretations and contextual relevance that purely quantitative methods may overlook. Ultimately, best practices for government agencies involve adopting processes that enable easy access to current data for monitoring trends and anticipating future developments. Establishing a robust data infrastructure supports continuous adaptation, allowing policymakers to update strategies dynamically as new data emerges. Fostering such a responsive approach is essential for effectively navigating global competition, staying ahead of technological disruptions, and maintaining a resilient, future-ready industrial ecosystem.

1.2.2. Methodological framework

Figure 3 presents a step-by-step methodology for creating industrial strategies, including roadmaps. Each step is outlined below in more detail and corresponds to the chapters of the handbook. We provide detailed guidelines on completing each stage: industrial performance assessment (baseline), megatrends analysis, validation with experts, identification of strategic priorities, industrial foresight, capacity-building, monitoring and evaluation framework, communication and stakeholder buy-in, risk management, and contingency planning.

FIGURE 3. METHODOLOGY FOR CREATING INDUSTRIAL STRATEGIES, INCLUDING ROADMAPS



Source: prepared by the project team.

1. **Industrial Performance Assessment:** Evaluating the current state and strategic positioning of Slovakia's industries using the quantitative approach outlined in Chapter 2.
2. **Megatrends Analysis:** A systematic assessment of transformative global trends impacting Slovakia's industries over extended periods, including technological advancements, demographic shifts, and environmental changes. This analysis is based on desk research and literature review and is outlined in Chapter 3.
3. **Validation with Experts:** Engaging internal stakeholders, such as VAIA experts involved in industrial strategies, Steering Committee members, and selected experts from key institutions, to validate findings. The approach is detailed in Chapter 4.
4. **Strategic Framework:** Developing a structured long-term strategy for Slovakia's industrial sector, including creating a future vision, selecting strategic priorities, and setting objectives. This approach is detailed in Chapter 5.
5. **Capacity-Building:** Enhancing national industrial capabilities through workforce training, technological upgrades, and institutional strengthening, as detailed in Chapter 6.
6. **Communication and Stakeholder Buy-In:** Creating and implementing an effective communication plan to engage stakeholders, including government entities, academic institutions, and industry experts, through training sessions, workshops, and conferences, as detailed in Chapter 7.
7. **Monitoring and Evaluation Framework:** Establishing a system to continuously track the implementation of the industrial strategy, measure its impact, and use data-driven insights for necessary adjustments, as outlined in Chapter 8.
8. **Risk Management and Contingency Planning:** Identifying potential risks and uncertainties that could impact the strategy and developing plans to mitigate these risks, ensuring resilience and adaptability to unforeseen changes, as discussed in Chapter 9.
9. **Conclusion: Bridging Methodology with Practical Implementation:** Chapter 10 emphasises the need for additional elements to make the handbook more actionable and effectively guide Slovakia's industrial strategy.

1.2.3. List of indicators and data sources

In this section, we overview the main features of the methodology for mapping value chains in Slovakia and the Visegrád region (see Table 1). Below, we provide an overview of indicators and international and local Slovak databases that can be used for value chain mapping.

TABLE 1. THE MAIN FEATURES OF THE METHODOLOGY FOR MAPPING VALUE CHAINS IN SLOVAKIA & THE VISEGRÁD REGION

FEATURE	SHORT DESCRIPTION
Units of analysis	The main units are 1) companies; and 2) researchers: • Companies are categorised by country, industry/ecosystem, and technology. • Researchers are affiliated with specific organisations and publish research related to technologies of interest to Slovak authorities. Companies and researchers are linked via technologies, mapping both the demand and supply of R&I capacity in prioritised technologies in Slovakia.
	Selection criteria for companies and researchers
Selection criteria for companies	Companies are selected from Orbis if they have at least EUR 1 million in turnover or total assets or at least ten employees. Technote (4.5 million companies) and Dealroom (2.5 million companies) are fully integrated.
Selection criteria for researchers	Researchers are selected if they published at least three publications in the last five years (as per OpenAlex data) and indicate recent publication activity (at least one publication since 2019) and technological relevance (at least five related publications).

Analysis levels	Country (i.e., Slovakia, Slovakia in the world; Slovakia versus other countries in Visegrád region), Region (NUTS-2 and NUTS-3 levels), Industry (Nace 2-digit and Nace 4-digit levels), Technology (see below for details)
Geographic scope	Slovakia and the Visegrád countries
Ecosystems and industries covered	60 industries in total at Nace 2-digit level
Data sources	Orbis, Technote, Dealroom, PATSTAT, OpenAlex, as well as several Slovak databases (see below for more details) and companies' websites
Technologies	Industrial automation and robotisation technologies, cutting-edge automotive technologies
Key indicators for strategic positioning of Slovakia and identification of priorities	Estimated size and TRL level of technology: • Number of companies active in a particular technology • Number of start-ups active in a particular technology • Top-5 industries (% share of companies) Positioning in the region: • Slovak share of companies in the Visegrád region • Slovak share of innovation leaders in the Visegrád region • Slovak rank by absolute numbers • Slovak rank with numbers adjusted for population Systemic strength: • Slovak share of industrial automation companies • Slovak share of companies involved in R&D Researching capacity: • Number of research organisations in a particular technology • Number of researchers with publications related to a particular technology • Number of publications related to a particular technology
Value chain positioning data	Companies are mapped to 14 activities: consulting and project management, R&D*, critical raw materials, design and engineering, distribution and sales, logistics, transport and storage, machinery hardware and components, maintenance and repair, manufacturing and assembly, mining and extraction, operators and providers of management services, raw and processed materials, recycling and waste management, and software and IT solutions.

Source: Created by the project team.
** Companies were flagged as involved in R&D if they were applying for patents, were affiliated with the R&D industry, or explicitly stated their involvement in R&D through keywords.*

The data sources available include databases that provide comprehensive R&D indicators on national statistics, industries, companies, patents, funding, investments, researchers, and research organisations. The table below presents a mix of national and international databases, which can either be used independently or merged to complement each other (see

Table 2).

TABLE 2. LIST OF DATABASES FOR EVIDENCE COLLECTION

DATABASE NAME	SHORT DESCRIPTION AND MAIN INDICATORS
Eurostat	The European Union's statistical office, Eurostat, offers comprehensive data on various aspects of R&D and innovation, including economic indicators, R&D expenditure, innovation statistics, and more.
OECD	The online platform of the Organisation for Economic Co-operation and Development (OECD) offers a wide range of statistics. Data types: R&D expenditure, innovation indicators, economic data, and more.
European Innovation Scoreboard	The European Innovation Scoreboard provides a comparative analysis of innovation performance in EU countries. Data types: innovation drivers, firm activities, outputs, and economic effects.
Community Innovation Survey	The Community Innovation Survey provides statistical information on innovation activities in enterprises. Data types: types of innovation, innovation expenditure, and impacts.

ORBIS	Bureau van Dijk (BvD) - Orbis is a comprehensive database offering financial and ownership information on millions of public and private companies worldwide, including Europe. It provides financial statements, ownership structures, M&A deals, and risk assessment tools.
OpenAlex	OpenAlex is an open and centralised database of academic publications. It is a useful tool for automating article data collection for processes like meta-analysis or literature reviews.
Scopus	Scopus is a comprehensive database of information on scientific publications. Data types: research publications, citations, journals, authors, and institutional information.
PATSTAT	PATSTAT contains bibliographical data on over 100 million patent documents from leading industrialised and developing countries. It also includes the legal event data from more than 40 patent authorities contained in the EPO worldwide legal event data.
EPO	The European Patent Office (EPO) provides data on patent applications, grants, technology fields, and patent statistics.
Dealroom	Dealroom is a global database that tracks innovative companies and identifies growth opportunities. It provides data on startups, growth companies, and tech ecosystems in Europe and around the globe.
Crunchbase	Crunchbase is an online platform providing in-depth information on companies, startups, investors, and industry trends worldwide.
Technote	Technote is a large company and product database. It predicts companies' technologies/CPC codes based on website text data. This makes it possible to identify companies in technologies even if those companies do not patent them.
CORDIS	Community Research and Development Information Service (CORDIS) is the European Commission's primary public repository and portal for disseminating information on all EU-funded research projects and their results. Data types: R&I project-specific information, including participants, objectives, results, and funding.
CREPC	The Central Register of Evidence of Publication Activity (CREPC) has data available on science fields and publication types (books, articles, patents, etc.).
SKCRIS	The Slovak Current Research Information System (SKCRIS) – is a national register of researchers, research organisations, projects, and publications.
Registeruzsk	Registeruzsk is a Slovak national register for firms' financial statements.

Source: Created by the project team.

The methodologies and sources mentioned above are general recommendations for research implementation. However, not all of them have been applied within the scope of the horizontal and vertical pilot projects. During the inception phase, we reviewed and evaluated the scope and coverage of Slovak local databases, which led us to make the following decisions:

- After evaluating the data coverage, we used the ORBIS database, as the Slovak company register contained fewer companies (370,000 companies compared to 1.2 million in ORBIS). Also, Slovak databases lacked website information, which is essential for Milda.ai's web scraping.
- OpenAlex was selected for further use because it provides uniform data on research institutions, researchers, and publications in a single platform. In contrast, CREPČ contained fewer publications, with many missing DOI (53,000 publications vs. 250,000 in OpenAlex).

1.2.4. Company data collection with Milda.ai

Milda.ai tool

Our study used Milda.ai[6], an advanced AI-driven sales research tool for data extraction. Milda.ai is designed to automatically pre-qualify companies by assessing their alignment with product-market fit and momentum. The platform uses proprietary datasets for innovation forecasting and trend analysis

[6] https://milda.ai/solutions

by monitoring technologies, industries, key events, and market players. This approach enables users to identify emerging trends and make informed strategic decisions.

Milda.ai offers extensive coverage, encompassing companies across 198 countries and 35 languages, providing detailed and current information on over 6 million active companies.

Core features:

- **"Ask Anything" search:** the platform's key feature is its AI-powered search engine, which allows users to locate companies based on specific niche keywords or areas. Users can customise their search with advanced operators or exact matches or use direct database queries with precise filters.
- **Company assessment:** Milda.ai evaluates companies for their fit with products and markets, ensuring that only relevant companies are featured in search results. To assess their momentum and relevance, it monitors company activities and growth indicators, including new product launches, investments, and business contracts. Each company is assigned a Milda *Relevance Score*[7] and *Momentum Score*[8], supported by textual information.
- **Data collection and updates:** Milda.ai integrates a wide range of data sources and provides continuous real-time updates to maintain the accuracy and relevance of its database. The platform's database includes:
  - **Company dossier:** information such as country, locations, website and social media, industry, value chain, age, headcount, turnover, momentum score, keywords, trademarks, emails, and ISO standards.
  - **Product information:** insights into over 60 million products, offering additional details on product-market fit and competitive positioning.
  - **News and events:** aggregates data from over 200,000 news sources, analysing over 5 million news items in real-time across 20 languages. Categories include contracts, financials, funding, hiring, intellectual property, etc.
  - **Event monitoring:** real-time tracking of 5 million events, including investments, financial disclosures, and licensing agreements.
  - **Patent data:** detailed information on 45 million patents, providing insights into intellectual property and technological advancements. This data is tailored to user search keywords to assess technological value.
  - **Decision makers:** contact details for decision-makers in over 70% of the companies in the database, facilitating direct outreach and enhancing lead generation efficiency.

By leveraging these comprehensive data sources and real-time updates, Milda.ai delivers accurate, relevant, and up-to-date information essential for strategic decision-making.

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[7] The Relevance Score measures how integral a specific technology is to a company's core activities, indicating the level of specialisation and engagement in that technology. The score is categorised into three main ranges:

- 80-100%: the company highly specialises in the technology. Most of its core products and services directly relate to the technology keyword.
- 50-79%: the company is active in the technology, offering relevant products and services. However, the technology is not the company's primary focus.
- 0-49%: the company has some involvement in the technology. While it may offer some related products or services, the technology is not a significant part of its overall operations.

[8] The Momentum Score is a comprehensive metric that evaluates a company's recent activity, growth trend, and industry standing. Companies are ranked into categories such as top 1% (indicating very strong momentum and growth), top 5%, top 10%, top 25%, and top 50%.

Data collection on companies:

We relied on Milda.ai B2B solution's value chain mapping and market research capabilities to gather comprehensive company data. Milda.ai provided access to a vast database with key company facts, product details, events, and related companies. Key features used include:

- **Detailed lists:** Milda.ai enabled us to create and manage company lists categorised by technologies and countries, which is crucial for our Visegrád benchmarking analysis.
- **Data enrichment and export:** the platform's tools ensured our research was based on accurate, up-to-date information, enhancing the quality of our market analysis.

Milda.ai sourced data from multiple databases, including Orbis, Dealroom, LinkedIn, Technote, and local Slovak databases such as Start-up and the Slovak company registers. This comprehensive data covered:

1. **Products and services:** information from company websites.
2. **Key events:** details on significant events like partnerships, investments, and new contracts.
3. **Patent data:** sourced from the PATSTAT database.
4. **Industries:** information on specific industries involved, supporting sectoral analysis.
5. **Value chain positioning:** classification across 14 activities: consulting and project management, R&D[9], critical raw materials, design and engineering, distribution and sales, logistics, transport and storage, machinery hardware and components, maintenance and repair, manufacturing and assembly, mining and extraction, operators and providers of management services, raw and processed materials, recycling and waste management, and software and IT solutions.

Data source integration and prioritisation in Milda.ai:

This section outlines how Milda.ai integrates and prioritises data from various sources to ensure that company profiles and associated insights are accurate and relevant to user queries. By leveraging advanced technologies such as Large Language Models (LLMs) and Natural Language Processing (NLP), Milda.ai aggregates data from diverse inputs, creating structured and comprehensive company profiles.

Data aggregation and source attribution

Table 3 below provides a detailed overview of the key data variables and their corresponding sources used by Milda.ai. It demonstrates how Milda.ai utilises multiple data sources to ensure accuracy, consistency, and reliability in the data collection process. The use of advanced methods such as LLMs and NLP techniques enables the system to validate and refine information, offering valuable insights into companies' profiles, activities, and products:

[9] Companies were flagged as involved in R&D if they were applying for patents, were affiliated with the R&D industry, or explicitly stated their involvement in R&D through keywords.

TABLE 3. OVERVIEW OF DATA VARIABLES AND SOURCE ATTRIBUTION IN MILDA.AI

VARIABLE	SOURCE
Company name	Derived from the company's social media accounts (e.g., LinkedIn, Facebook, Twitter). If unavailable, the name is captured from the landing page. The most frequently used variant is selected if multiple name versions exist.
Key activities	Generated by an LLM using specific information about the company's products and services obtained from its website.
Description	Generated by an LLM using detailed information about the company's products and services from its website.
Company website	The company's URL.
Country	Derived using a combination of the company's URL (e.g., a .sk domain suggests a Slovak company), LinkedIn data (if available), and website information. Predicted by LLMs and validated via NLP techniques.
Locations	Derived from information provided on the company's website.
Patents	A number of patents owned by the company contain specific technology keywords in their abstracts. Based on PATSTAT data, an algorithm matches companies to PSN IDs using name, country, address, website, and other data points.
Link to Milda	URL link to the company's profile on Milda.
Industries (All)	All industries in which the company is active are assigned based on LinkedIn data (if available) and website information predicted by LLMs.
Main industry	The company's primary industry, as predicted by Milda's LLMs.
Age	Derived from the company's LinkedIn data and website information (LLMs).
Headcount	Based on the company's LinkedIn data and website information (LLMs).
Turnover	Based on information provided on the company's website (LLMs).
SDGs	Indicates the UN Sustainable Development Goals (SDGs) the company contributes to, based on an algorithm developed by OSDG (www.osdg.ai).
Total number of products	The total number of products advertised on the company's website that contain the technology keywords entered by the user in their descriptions.
Value chain positions	Indicates whether the company is active in one of the 14 value chain positions assigned by Milda. The assignment is based on information provided on the company's website, predicted by LLMs and validated via NLP techniques.

Source: Created by the project team.

1.2.5. Company data collection without Milda.ai

The following methods can be employed to gather comprehensive company data without using the Milda.ai tool. Each approach involves different resource requirements, including team composition and financial investment:

1. Utilise multiple data sources and compile datasets:

- **Company registers:** access national company registers, such as the Slovak Company Register, which provides detailed information on company size, industry, and key personnel.
- **Business databases**: explore databases such as Orbis, Dealroom, Crunchbase or Technote for comprehensive company profiles and market data. Technical expertise is needed to navigate and extract relevant data efficiently, in addition to subscriptions to these databases.
- **Professional networks:** use LinkedIn to gather information on company activities, employee roles, and industry connections. While LinkedIn itself is a free platform, access to LinkedIn's advanced features and data might require a premium subscription.
- **AI and search tools:** leverage tools like Google, Perplexity, Copilot, and ChatGPT to identify companies, particularly at early stages, and highlight prominent market players.

These tools are especially useful for gathering insights quickly, enhancing the efficiency of company identification and industry analysis.

Team requirements: this approach generally requires a team of data analysts and researchers skilled in data extraction, data management, and analysis. Depending on the project's scale, a team of 3-5 members might be necessary.

2. Develop data aggregation tools:

Web scraping tools: develop or implement web scraping tools to extract and format data from company websites. This includes information on products, services, and key events. Developing custom scraping tools requires programming expertise and ongoing maintenance. Additional investment for this approach includes costs for software development, potential cloud infrastructure for data storage, and ongoing maintenance.

Team requirements: building and managing web scraping tools typically require a team of software developers or data engineers with programming and data extraction expertise. Depending on the complexity of the scraping requirements, a smaller team of 2-3 developers may be sufficient.

The table below provides a systematised evaluation of how research with and without Milda.ai compares in terms of resources required, as well as the advantages and disadvantages of each (Table 4):

TABLE 4. COMPARISON OF COMPANY DATA COLLECTION WITH AND WITHOUT MILDA.AI

ASPECT	WITH MILDA.AI (AI-DRIVEN)	WITHOUT MILDA.AI (MANUAL)
Efficiency	**Advantage:** Fast, real-time updates, highly efficient for large-scale research.	**Advantage:** Fully customisable to specific research needs.
	Disadvantage: In some instances, it may still require manual checking by an expert.	**Disadvantage:** Time-intensive, requires manual and continuous updates.
Data accuracy	**Advantage:** Real-time data, automatic updates, relies on a wide range of reliable databases.	**Advantage:** Manual verification allows for greater control over the accuracy of specific data.
	Disadvantage: Relies on AI predictions when specific data is unavailable, potentially introducing inaccuracies.	**Disadvantage:** Potential for outdated or incomplete data if not frequently managed.
Team requirements	**Advantage:** Minimal team needed (1-2 people), less reliance on technical expertise.	**Disadvantage:** Requires a larger team (3-5 people), leading to higher staffing costs.
Technological expertise	**Advantage:** No programming skills required; user-friendly interface.	**Disadvantage:** Requires technical expertise and the development of custom tools.
Data export & analysis	**Advantage:** Built-in tools for easy exporting and managing lists.	**Disadvantage:** Manual processes are more time-consuming and prone to errors during integration.

Source: Created by the project team.

1.2.6. Researchers' data collection

This section outlines the methodology for identifying Slovak researchers working on cutting-edge technologies. The process was carried out using OpenAlex's Application Programming Interface (API), which allows for efficient interaction with OpenAlex's extensive dataset of scholarly works.

1) Institution identification in Slovakia

The first step involved identifying all research institutions in Slovakia. Using OpenAlex's API, we filtered for institutions based in Slovakia (country code: SK). This returned a list of institution IDs, which are unique identifiers used by OpenAlex to track each organisation.

2) Extracting author information

Using the institution IDs, we queried OpenAlex to identify all authors affiliated with Slovak institutions. We ensured that only authors with their most recent institutional affiliation in Slovakia were included by applying the "last_known_institution" filter. This returned a list of author IDs linked to their affiliated institutions. Retrieving Publications for Each Author

For each author identified, their associated publications were retrieved by querying OpenAlex using their author ID. The API returned all works attributed to each author, including publication titles, abstracts, and publication IDs. Only publications from 2019 onwards were considered, ensuring that the authors were engaged in recent research activities.

3) Keyword search within abstracts

After gathering the publication data, we identified publications related to technologies in the automotive and robotisation sectors. This was done using the related keywords prepared for company search with Milda.ai (see 2.1.2). Industry scoping: Data-validated approach). Using the OpenAlex API, we matched predetermined keywords with the terminology used in publication abstracts, identifying relevant academic research.

4) Data compilation and output

Once relevant publications were identified, all the data – including author names, institutional affiliations, publication counts, and the detected keywords – was compiled into a structured format. The output was saved as an Excel sheet, listing authors, institutions, publications, and the corresponding keywords within the abstracts.

5) Additional data filtering

We further refined the dataset at the researcher data analysis stage (see 2.2. Methodology for researchers' analysis). Researchers were selected if they met the following criteria:

- Demonstrated recent publication activity (at least one publication since 2019)
- Had technological relevance, indicated by at least five related publications

Additionally, we focused on researchers from applied sciences universities in Slovakia, such as the Technical University of Košice, Slovak University of Technology in Bratislava, and the University of Žilina. This approach ensured a robust dataset of active researchers with relevant, recent publications, enhancing the relevance and specificity of our research.

1.2.7. Resolving data conflicts

When conflicting data arises, especially when choosing data sources manually, the lack of clear guidance can lead to inefficiencies or inaccuracies in analysis and subsequent decision-making. Establishing a structured protocol for resolving data conflicts is essential to address this. This protocol should prioritise data based on key factors such as recency, source reputation, and reliability. Here's a proposed framework for resolving data conflicts (Table 5):

TABLE 5. FRAMEWORK FOR RESOLVING DATA CONFLICTS

FACTOR	PRIORITY LEVEL	RATIONALE	ACTION
Recency of Data	High	More recent data reflects current trends in Slovak RDI and is critical for aligning industrial strategies with up-to-date technological advancements and market conditions.	Prioritise data with the latest timestamps, ensuring alignment with Slovakia's most current state of RDI.
Source Reputation	High	Data from established national and international sources such as Eurostat, OECD, or OpenAlex is essential for ensuring credibility in strategy development.	Assign higher priority to data from authoritative and widely recognised sources, particularly those aligned with RDI goals.
Data Validation	High	Verified data, especially across multiple reputable sources, enhances the reliability of inputs used for RDI strategy formulation.	Cross-check data across Slovak and international databases to ensure consistency and credibility in decision-making.
Contextual Relevance	Medium to High	Data must directly relate to Slovakia's industrial landscape, RDI priorities, and the Visegrád region to provide actionable insights.	Assess the data's relevance regarding its specific application to Slovak industries and the project's strategic needs.
Consistency Over Time	Medium	Data consistency over multiple reporting periods provides insights into long-term trends essential for strategic foresight in Slovak industries.	Prioritise data that remains consistent over time, especially for evaluating long-term industrial trends and growth areas.
Geographical Relevance	Medium to High	Data must be geographically relevant to Slovakia and the Visegrád region to inform regional benchmarking and strategy comparisons.	Prioritise data specific to Slovakia and the Visegrád countries to inform regional industrial positioning.
User-generated or Crowdsourced Data	Low to Medium	While user-generated data can offer insights into emerging trends, it requires rigorous verification before being integrated into industrial strategy processes.	Treat as secondary, using it only when corroborated by national or international databases relevant to RDI in Slovakia.

Source: Created by the project team.

2. Industrial performance assessment (baseline)

This chapter outlines the methodology for assessing industrial performance. It covers the approaches used in the horizontal pilot on the Slovak industrial automation and robotisation ecosystem and the sectoral pilots on cutting-edge automotive and robotisation technology companies.

It details two industry assessment approaches (Section 2.1): the Data-Driven Approach, which provides a broad overview of the Slovak industrial automation and robotisation ecosystem, and the Data-Validated Approach, which identifies and analyses companies in advanced technologies to offer targeted insights into Slovakia's performance in future technologies.

The chapter also covers the researchers' analysis, focusing on identifying researchers and their R&D contributions in priority areas, i.e. cutting-edge technologies (Section 2.2.).

Additionally, it reviews approaches to data analysis, assessment, and categorisation, including the theoretical basis for network analysis (Section 2.3). It further describes the two approaches – qualitative and quantitative – to data assessment and visualisation used in the pilots to evaluate Slovakia's positioning regarding academic and commercial performance across technologies (Section 2.5).

2.1. Methodology for industry performance assessment

Below are two approaches used in our study for scoping industries, identifying relevant stakeholders, and categorising companies:

1. **The data-driven approach** delivers a broad overview of the Slovak industrial automation and robotisation sectors, providing a comprehensive understanding of the broader ecosystem and insights across industries.
2. **The data-validated approach** identifies and analyses companies engaged in advanced automotive and robotisation technologies, offering targeted insights into specific innovations. It is suitable for testing hypotheses about national performance in particular sectors and/or technologies.

Table 6 compares the two approaches in more detail:

TABLE 6. COMPARISON OF DATA-DRIVEN AND DATA-VALIDATED APPROACHES FOR INDUSTRY SCOPING

	DATA-DRIVEN APPROACH	DATA-VALIDATED APPROACH
Objective:	Understand the broader ecosystem	Identify and analyse companies engaged in cutting-edge technologies
Approach:	Gather and analyse a comprehensive dataset of Slovak companies within specific industrial ecosystems (e.g., all Slovak automotive companies or all Slovak industrial automation companies) using metrics such as industrial affiliation, activities, size, and age.	Start by validating experts' assumptions about advanced technology companies through data analysis. Then, select technologies of interest to test whether they are represented in national commercial and academic activities.

Application (within this project):	Horizontal pilot: Extensive report on the state of the Slovak industrial automation and robotisation ecosystem	Vertical Pilots: Vertical cutting-edge automotive and robotisation pilot reports
Outcome:	Describe the ecosystem and company categories with growth and value-added potential.	Identify and describe companies focused on innovative technologies.

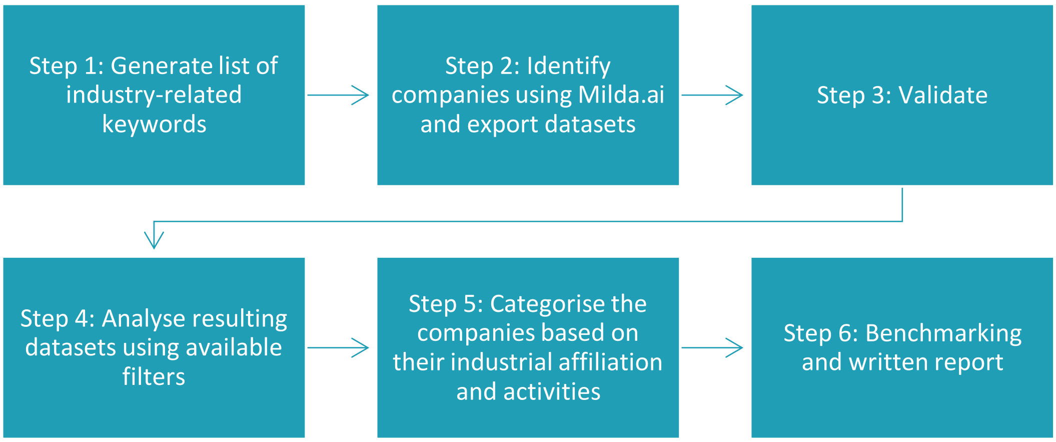
Source: Created by the project team.

2.1.1. Industry scoping: Data-driven approach

For the extensive report on Slovakia's industrial automation and robotisation ecosystem, we aimed to cover all relevant companies to describe the ecosystem comprehensively. We also sought insights from the overall data, such as prevailing company types and their industrial focuses and activities. We started with an extensive list of 2,463 companies. Then, we analysed all available data from Milda.ai, identifying companies of interest and categorising them into high-value-added groups (e.g., industrial automation, manufacturing and R&D, software development and R&D). Additionally, the report included a benchmarking element comparing Slovak performance with the rest of the Visegrád group, including across the high-value-added clusters (see an overview of the process in

Figure 4).

FIGURE 4. DATA-DRIVEN APPROACH TO INDUSTRY SCOPING



Source: prepared by the project team.

1. **Keyword compilation:** After selecting industrial automation and robotisation as our industry of focus, we compiled a list of relevant industry-related keywords (for the methodology of keyword list compilation, see Annex A).
2. **Company identification:** Using these keywords, we identified 2,463 Slovak companies via the Milda.ai tool. We also identified companies in the other Visegrád countries: Poland (7,805), Czechia (4,119), and Hungary (1,871).
3. **Validation:** The project management team reviewed the initial analysis of Slovak companies' data, using its contextual knowledge to assess the relevance and accuracy of the findings. This included confirming the significance of key ecosystem players and ensuring the data accurately reflected the industry landscape.
4. **Data analysis:** The exported datasets were analysed using various filters, focusing on company size, age, industry, and activities. This analysis was essential for understanding and positioning the companies' roles within the value chain. Additionally, a network

analysis was conducted to establish Slovak industrial interconnectivity (for more details, consult Section 2.3).

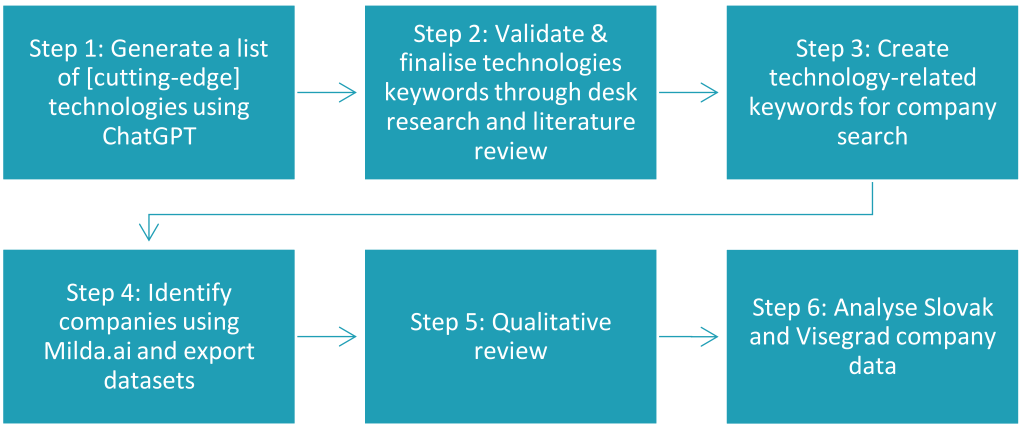
5. **Categorisation:** We applied activity filters to categorise companies into three main high-value-added industry clusters: industrial automation, manufacturing and R&D, and software development and R&D.
6. **Further data analysis:** The data was further examined to refine insights and ensure comprehensive coverage of the industry sectors. A benchmarking element was also introduced to evaluate Slovakia's performance relative to the other Visegrád countries. The same analytical steps were applied to the company data from the Visegrád countries as were used for Slovakia.

2.1.2. Industry scoping: Data-validated approach

For vertical pilots, our goal was to identify companies engaged in cutting-edge technologies within their respective industries: automotive and robotisation for the vertical pilots. We compiled a list of cutting-edge technologies specific to the robotisation and automotive sectors. Using these lists, we identified 165 companies specialising in robotisation and 108 in automotive cutting-edge technologies. We then analysed Slovak performance across these technologies. Additionally, both pilots included a benchmarking element, comparing Slovak performance with the rest of the Visegrád group (see an overview of the process in

Figure 5).

FIGURE 5. DATA-VALIDATED APPROACH TO INDUSTRY SCOPING



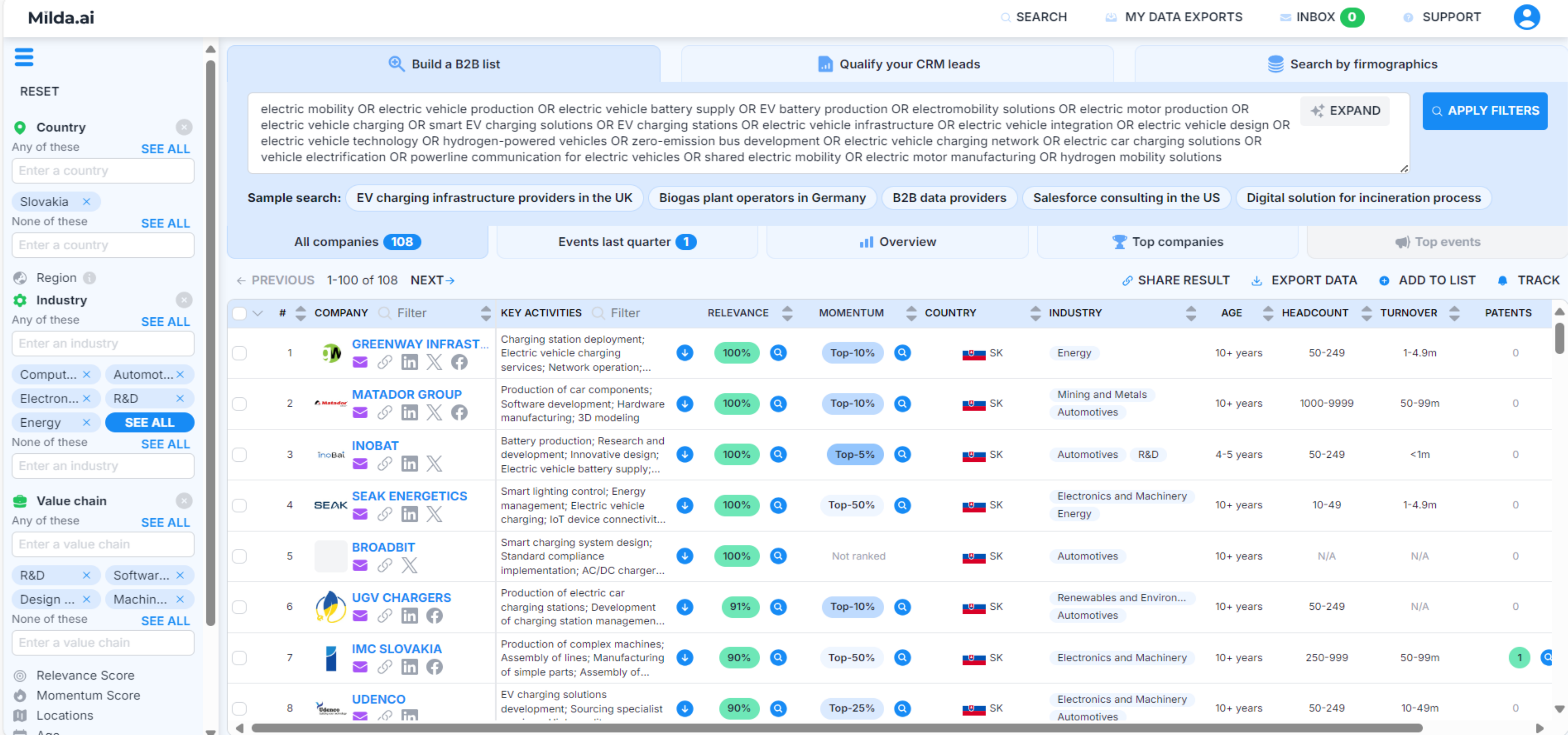
Source: prepared by the project team.

1. **Technology list generation:** We compiled two lists of keywords related to cutting-edge technologies in the automotive and robotisation sectors (for the methodology of keyword list compilation, see Annex A).
2. **Validation and literature review:** We validated and finalised the technology lists through desk research and a literature review, including academic papers, industry reports, and market analyses, to identify prevailing technologies. This approach enabled us to identify companies within the context of current trends in consumer markets and the broader industry.
3. **Keyword development:** We created technology-related keywords to find relevant companies in Slovakia, ensuring they were comprehensive and unambiguous.

4. **Company identification:** We employed a multi-step approach to filter out only the most relevant companies. Mainly, we relied on keywords to create queries in Milda.ai, targeting technologies of interest. Apart from keywords, we also applied filters, including country filters, industry filters, and value chain positions (key operational activities). These filters helped narrow the search to companies operating in Slovakia in specific industries and parts of the value chain relevant to each technology. For each technology, the selected industries and value chain positions varied, ensuring that our search criteria were tailored to the unique characteristics of each field (providing an example of technology-related keywords and a link to the Milda.ai search, which pre-selected filters).
    - In cases where Milda.ai did not adequately return the desired list of companies, we:
        - Expanded our search by consulting online resources and seeking recommendations from VAIA.
            - Identified companies we knew fit our profile and analysed the keywords associated with their products and activities to refine our search criteria further.
            - The search resulted in 108 automotive and 165 robotisation Slovak companies. Using the same keywords as in Slovakia's case, we identified companies in the other Visegrád countries for both pilots.
5. **Qualitative review:** To ensure the quality and relevance of the data, researchers qualitatively reviewed company lists, checking if companies fit the searched profile and if there are no missing companies, that desk research, literature review and experts input pre-identified.
6. **Data analysis:**
    - We analysed company datasets using technology, allowing us to evaluate the extent of Slovak commercial involvement in each. All companies were analysed by age, industry, size, turnover and value chain positions (key operational activities).
    - We also added a benchmarking element, comparing Slovak companies with other countries in the Visegrád region (Poland, Czechia, and Hungary). This allowed for a more objective assessment, as the metrics were population-adjusted. Additionally, a Network Analysis was conducted to establish industrial interconnectivity (for more details, consult Section 2.3).

An example of a Milda.ai search with selected filters and keywords is provided below (Figure 6):

FIGURE 6. EXAMPLE OF KEYWORDS AND MILDA.AI SEARCH LINK FOR ELECTRIC MOBILITY AND BATTERY TECHNOLOGY



Source: prepared by the project team.

2.1.3. Lessons learnt during implementation of vertical and horizontal pilots

Company identification and categorisation:

- To ensure comprehensive coverage, the identification and categorisation of companies were improved through qualitative revisions of technology lists. This process was essential for accurately capturing the ecosystems of both sectors.
  - For robotics, particular attention was given to manufacturers, integrators, sub-component suppliers, and service providers developing their own hardware and software solutions. This was done manually, checking companies' operational activities.
  - The automotive report similarly focused on firms engaged in design, research and development, production, and creation of new mobility solutions, including IT hubs and software developers. This was done using Value chain positioning flags available on Milda.ai.
  - By adopting a data-driven approach for the horizontal pilot, we identified three key value-added clusters. These clusters outlined the most innovative companies and their roles, offering a detailed and precise overview of the broader industrial landscape for:
    - Manufacturing and Software/IT companies
    - Software/IT and R&D companies
    - Manufacturing and R&D companies
- Filters were applied to exclude unrelated industries and companies, such as those in health and wellness (for robotics) or car rentals and insurance services (for automotive), ensuring the focus remained on technological innovators.
- Relevance scores from Milda.ai were utilised to maintain a high standard, considering only companies with scores of 80-100% and 50-79%.

Iterative and agile methodology:

- Our initial focus on industrial automation technologies as digital manufacturing technologies proved too restrictive. Expanding to a holistic analysis of the entire industrial automation and robotisation ecosystem allowed us to capture a comprehensive landscape view and include all critical companies contributing to sector development.
- An iterative approach proved essential when working with data based on assumptions about technological presence. Regular reviews of technology lists and feedback from national experts are necessary for timely updates and refinement of search strategies.
  - Internal and external validation showed that the initial company lists included related companies but were not directly relevant to the project's objectives. This led to further refinement of company profiles, improvement of queries, and adjustments to technology and company lists.
  - Following feedback and qualitative revision, some technologies with limited company presence were adjusted. Certain technologies were removed, while others were added. In the robotisation report, quantum, nano, swarm, and soft robotics were excluded. In the automotive report, V2X communications, AVs, AR dashboards, ADAS, advanced sensors and perception systems, lightweight materials, and HFC were removed. At the same time, Smart Mobility Solutions, Intelligent Transportation Systems, and Digitally Controlled Micro-Precision Manufacturing were added.
- An agile and creative approach was needed to compare diverse technologies, as not all innovations can be evaluated on a like-for-like basis. Adjustments in quantitative analysis and data contextualisation were essential to account for differences.

  - For example, some technologies naturally have a stronger commercial presence but limited research involvement. For instance, in the automotive pilot, in the Smart Mobility Solutions category, limited academic presence was expected and should not be seen negatively.
- Allowing buffer time for evaluating compiled datasets was identified as a critical step for manual and qualitative data quality and validity assessment.

Efficient use of digital tools:

- Utilising Milda.ai facilitated efficient preliminary company scraping and streamlined data extraction. While a qualitative approach remains important, digital tools should be leveraged to initiate and expedite the research process and access data that would otherwise be collected inefficiently.
- The horizontal analysis of Industrial automation and robotisation aimed to strengthen our understanding of the status quo rather than uncover new insights. It validated existing expert knowledge and confirmed alignment with industry perceptions. Additionally, it facilitated a clear, network-based visualisation of the ecosystem, highlighting key sectors and connections.

The role of benchmarking approach: Benchmarking against Visegrád countries provided context rather than precise rankings or definitive market positioning. Given the variations in the economic sizes of countries and the extent of technology specificity, this comparative framework aimed to offer insights and provide a clearer understanding of Slovakia's performance. Nevertheless, acknowledging the limitations of full coverage, the results should be interpreted with caution.

Integration of subsidiary companies: Both reports integrated subsidiary companies into the general lists. Nevertheless, not all subsidiaries have their respective websites with Slovak domains. In this case, desk research and VAIA's input were crucial for including relevant and important companies in the lists manually

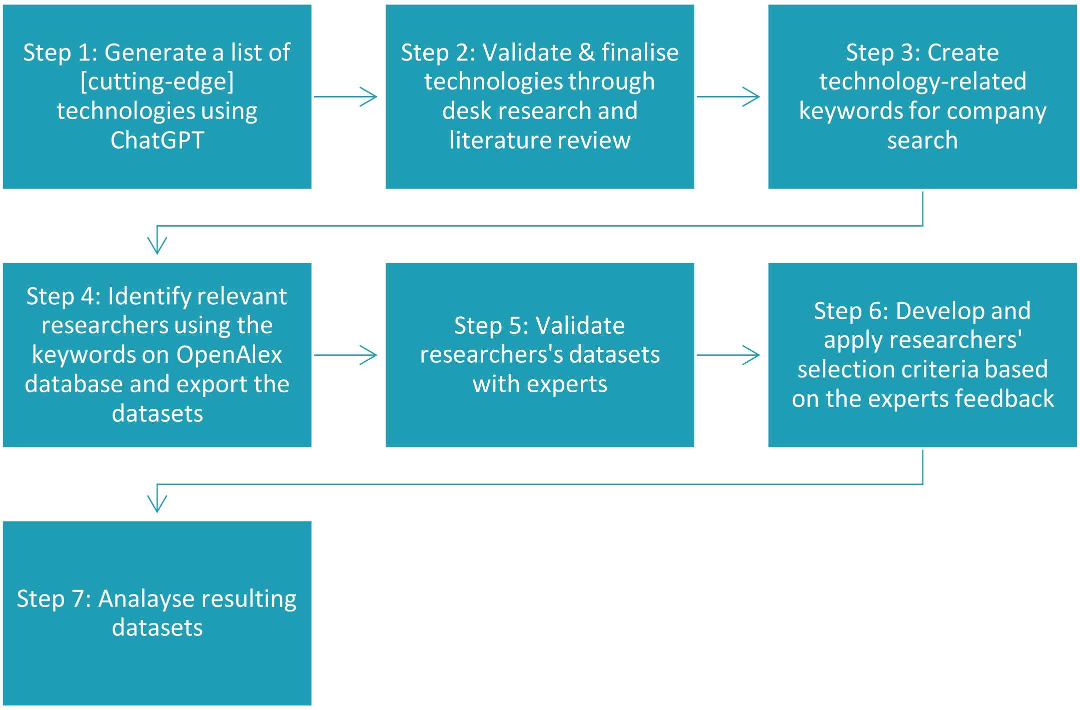
2.2. Methodology for researchers' analysis

As part of vertical pilots, we assessed the involvement of academia in researching cutting-edge technologies in robotisation and automotive industries. The sample for automotive analysis included 244 unique researchers affiliated with 15 research and educational facilities, whereas the sample for robotisation analysis – 148 researchers from 18 research institutions[10,11]. Our goal was to identify researchers and their R&D contributions to pinpoint areas where strong research capabilities and numerous companies could present valuable collaboration and investment opportunities within the Slovak ecosystem (see an overview of the process in Figure 7).

[10] The initial available sample spanning automation, robotisation and automotives included 3,198 researchers across 126 institutions. However, several filters have been applied, namely 1) researchers with their last known institution in Slovakia (ensures focus on national research capabilities), 2) researchers with at least one publication since 2019 (assumed to be active researchers), and 3) researchers with at least five term-related publications (to help identify researchers focusing on applied research). Moreover, some technologies have been removed from the analysis after a round of external validation.

[11] Some researchers might be responsible for technologies within both automotive and robotization pilot reports. Nevertheless, for each of the reports separate the numbers reflect unique researchers.

FIGURE 7. OVERVIEW OF RESEARCHERS' ANALYSIS



Source: prepared by the project team.

1-3. ***Follow the initial steps from the Data-validated approach to industry scoping: Follow the first three steps from the*** *data-validated approach to industry scoping. Use the same keywords for both analyses to ensure consistency. This allows for the creation of cutting-edge technology lists and keywords once for both analyses.*

4. **Data gathering:** We used cutting-edge technology-related keywords to identify relevant companies to gather data on researchers from the OpenAlex database (see 1.2.5. Researchers' Data Collection).
5. **Preliminary analysis and expert feedback:** We exported the datasets and conducted a preliminary analysis of researchers by technology and institution. We then shared the resulting datasets with VAIA for expert feedback.
6. **Refine criteria based on feedback:** After receiving feedback that some authors might not be relevant or active, we made the requirements more stringent and representative of active, impactful researchers. The updated criteria included:
    - **Recent publication activity:** Researchers must have published at least one article within the last five years (2019 onwards).
    - **Technological relevance:** Researchers must have at least five publications related to the specified technological terms.
    - Additionally, we focused on applied sciences universities in Slovakia: the Technical University of Košice, the Slovak University of Technology in Bratislava, and the University of Žilina.
7. **Final analysis:** Once we were satisfied with the resulting datasets, we analysed them using three main indicators: counts of publications and authors by technology, publication-to-author ratio coefficients by technology, and the number of researchers by technology across institutions.

2.3. Network analysis

Milda.ai uses AI to identify a company's main industry and establish other industrial affiliations. Cases of companies with more than one industrial affiliation might reveal the type of ecosystem that industrial automation and robotisation companies constitute. Using this data for Network Analysis (NA) can show how these companies interconnect and influence each other. This insight can be valuable for understanding the dynamics and opportunities within the sector.

In the horizontal pilot, we applied NA to investigate industrial connections, focusing on companies with affiliations in more than one industry. We utilised four centrality measures to understand the roles and importance of different industries within the network: degree centrality, closeness centrality, betweenness centrality, and eigenvector centrality. Below, we provide adapted definitions of these centrality measures tailored to an industrial context:

- **Degree centrality** measures the number of direct connections (edges) an industry (node) has in the network. Industries with a high degree of centrality are directly connected to many other industries, indicating greater possibilities for accessing or delivering resources and opportunities. These industries are more central and influential due to their extensive direct connections.
- **Closeness centrality** measures how close an industry is to all other industries in the network. Industries with high closeness centrality can communicate[12] quickly and easily with others, implying efficient access to resources and information. A low closeness centrality score means an industry does not have to "travel"[13] far along network paths to reach other industries, requiring minimal steps or connections for interaction and influence.
- **Betweenness centrality** measures how often an industry lies on the shortest path between two other industries. Industries with high betweenness centrality act as gatekeepers of resources, frequently serving as intermediaries in the network. These industries control the flow of information and resources, playing a crucial role in connecting otherwise distant parts of the network.
- **Eigenvector centrality** measures a node's importance by considering both its direct connections and the importance of its neighbours. This indicator highlights influential industries within the network due to their strong connections with other central nodes, making them pivotal in facilitating key interactions and resource flows across the network.

In the network, each ***node*** represents an industry, while each ***edge*** represents a connection between two industries. A connection (edge) between industries (nodes) signifies that at least one company operates in both industries, indicating a potential for resource sharing, collaboration, or influence between these industries.

Below, we provide two examples from the extensive report on the state of industrial automation and robotisation in Slovakia: Table 7 presents precise centrality indicators across industries, and Figure 8 illustrates the ecosystem.

[12] "Communication" means the transfer of information or resources between nodes (industries). Efficient communication implies fewer steps and less time taken to connect different industries, which is highly relevant for industries aiming to optimise their resource distribution and collaborative efforts.

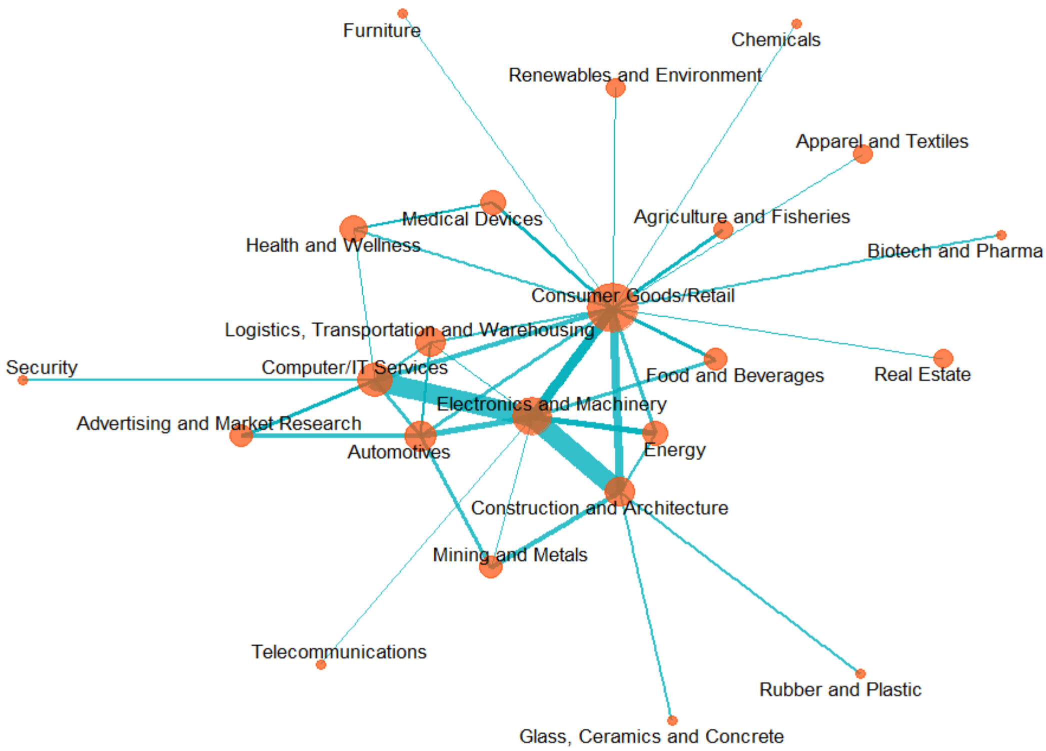
[13] In Network Analysis, "travelling" refers to the number of edges one must traverse to move from one node to another. In our industrial context, it means the number of intermediary industries a resource, information, or influence must pass through to reach its destination.

TABLE 7. NETWORK ANALYSIS: CENTRALITY MEASURES*

Industry	Degree	Betweenness	Closeness	Eigenvector
Consumer Goods/Retail	43	0.07	0.398	0.779
Electronics and Machinery	36	0.08	0.516	1.000
Mining and Metals	28	0.16	0.550	0.179
Construction and Architecture	26	0.06	0.434	0.597
Computer/IT Services	24	0.01	0.393	0.588
Food and Beverages	22	0.04	0.471	0.245
Logistics, Transportation and Warehousing	22	0.03	0.452	0.211
Automotives	20	0.12	0.493	0.319
Real Estate	20	0.12	0.532	0.078
Renewables and Environment	19	0.04	0.500	0.109
Energy	18	0.03	0.452	0.380
Packaging and Delivery	18	0.02	0.465	0.105
Security	18	0.12	0.508	0.074
Chemicals	17	0.05	0.493	0.057
Forestry and Wood	16	0.02	0.478	0.081
Health and Wellness	16	0.03	0.500	0.129
Advertising and Market Research	15	0.00	0.402	0.224
Medical Devices	15	0.07	0.500	0.176
Biotech and Pharma	13	0.01	0.440	0.106
Rubber and Plastic	13	0.08	0.471	0.081
Agriculture and Fisheries	12	0.00	0.407	0.207

*Source: produced by the study team. * The table presents industries with a degree centrality greater than 10. ** Industries with the 1st, 2nd, and 3rd highest measures in each centrality category are colour-coded as follows: Dark green for the 1st highest measure, Green for the 2nd highest measure, and Light green for the 3rd highest measure.*

FIGURE 8. NETWORK ANALYSIS: INDUSTRY INTERCONNECTION MAPPING



Source: produced by the study team.

2.4. Categorisation and visualisation

We used a categorisation system to evaluate Slovak performance in the vertical pilots for each cutting-edge technology. Technologies were divided into three groups:

- **LEAD**: High numbers of both companies and researchers.
- **GROW**: High numbers in either companies or researchers, but not both.
- **LAG**: Low numbers in both companies and researchers.

LEAD sectors should be supported as areas of Slovak excellence. **GROW** sectors are strategic opportunities for enhancing Slovakia's role through targeted actions. **LAG** sectors need significant policy and investment interventions.
Given the lack of industry standards for the optimal number of researchers and companies, evaluations should be considered critically and complemented with qualitative insights.
For our pilots, we used two different approaches for data assessment and visualisation. Both approaches employ LEAD-GROW-LAG categories but apply different methods:

1) "Traffic light system" – qualitative – relies on the researcher's expertise and judgement;
2) Scatter plot – quantitative – relies on the R programming.

1) "Traffic light system"

For the vertical pilot on robotisation, we employed the so-called "traffic light system" method for categorising cutting-edge technologies by national performance and visualisation. The assessment focuses on the presence and strength of companies and researchers within each technology. The method uses colour-coded categories to indicate the level of development and potential for each technology based on two key indicators: commercial presence and academic research activity, measured by the number of companies and researchers, respectively.

Criteria and colour-coding:

- **Indicators:**
  - Commercial presence: the number of companies involved in a specific technology.
  - Academic research activity: the number of researchers engaged in related research.
- **Colour codes:**
  - Green: a favourable indicator (strong presence).
  - Yellow: a moderate indicator or an opportunity.
  - Red: an unfavourable indicator (weak presence).
- **Classification categories:**
  - LEAD (green-green): both commercial presence and academic research activity are strong.
  - GROW (yellow-yellow or mixed red-green): indicators are either uniformly moderate or mixed. Represents sectors with growth potential.
  - LAG (red-red): both indicators are weak, indicating a deficiency in both industry engagement and research activity, suggesting an area where significant improvement is needed.

TABLE 8. SLOVAK POSITIONING IN THE CUTTING-EDGE ROBOTISATION TECHNOLOGIES

Cutting-edge technology	Rank in Visegrád region	Rank in Visegrád region (population adjusted)	No of Slovak companies	No of Slovak researchers	Positioning
Robotic Process Automation	4th place	2nd place	61	14	Grow
Humanoid Robotics	4th place	2nd place	4	65	Grow
Medical Robotics	2nd place	**1st place**	8	25	Lag
Aerial Drones	4th place	**1st place**	60	57	**Lead**
Collaborative Robots (Cobots)	4th place	**1st place**	35	70	Grow
Agricultural Robotics	2nd place	**1st place**	32	7	Grow

Source: prepared by the project team.

2) ***Scatter plot***

We employed a quantitative methodology for the vertical pilot on cutting-edge automotive technologies. Using the R programme, we created scatter plots divided into quadrants, representing the categories of LEAD-GROW-GROW-LAG in cutting-edge technology performance in terms of companies' and researchers' counts (see

Figure 9 for an example). The methodological steps were as follows:

- **Scatter plot visualisation:** we created scatter plots using the R programming language, specifically the ggplot2 package.
- **Dividing values:** the x and y axes were set at the custom values[14] of Slovak companies and researchers, respectively. This categorisation placed technologies into four quadrants based on relative involvement:
    - Top-left (GROW): low number of companies, high number of researchers.
    - Bottom-right (GROW): high number of companies, low number of researchers.
    - Bottom-left (LAG): low number of both companies and researchers.
    - Top-right (LEAD): high number of both companies and researchers.

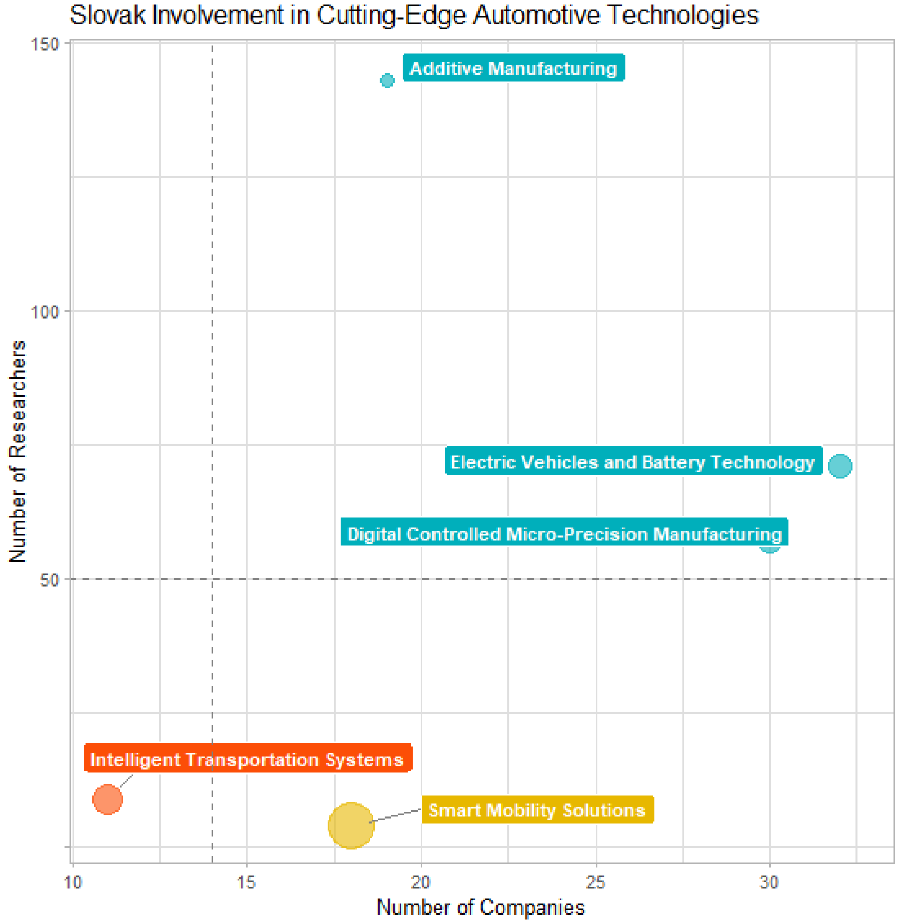
  Based on these dividing values, each technology was assigned to a quadrant. This categorisation helps identify areas of strength and potential growth or lag in commercial and research involvement.
- **Bubble size indicators:**
    - Larger bubbles: represent sectors with a higher concentration of companies relative to researchers, suggesting a more commercially driven area.
    - Smaller bubbles: indicate a stronger focus on research and development, with fewer companies involved.

  This visualisation method facilitates the evaluation of niche technologies, which might naturally fall into the GROW or LAG quadrants due to their smaller scale. The relative

[14] Given the significant variability across different technologies, initial scatterplots did not effectively represent the data patterns. To improve clarity and comparability, the x and y axes were set to custom values close to the median. This adjustment helped standardise the scale and highlight relative positioning without skewing the visual interpretation, providing a more balanced and informative view of the data.

positioning and bubble sizes provide insights into these technologies' balanced or imbalanced contributions to industry and research.

FIGURE 9. SLOVAK POSITIONING IN THE CUTTING-EDGE AUTOMOTIVE TECHNOLOGIES



Source: prepared by the project team.

3. Megatrends analysis

Megatrends analysis involves systematically assessing and evaluating large-scale, transformative forces that significantly impact societies, economies, industries, and individuals over extended periods, often spanning decades. These megatrends are overarching, pervasive, and have far-reaching consequences, shaping various aspects of human life and the business environment. Recognising the dynamic nature of the business landscape, this methodology aims to identify emerging trends where Slovak companies can add value and strategically position themselves for future opportunities.

For vertical pilots, we relied on the 'Better Regulation Toolbox' (EC, 2023), which outlines the inclusion and objectives of strategic foresight for impact assessment and evaluation (TOOL #20)[15]. An important aspect of this foresight is megatrends—long-term global driving forces with significant impacts over the coming decades. We used the 14 key megatrends officially identified by the European Commission (see Table 9). However, megatrends analysis is a creative and qualitative process, so selecting applicable megatrends can vary and rely on specialised literature, expert input or both.

TABLE 9. OVERVIEW OF MEGATRENDS IN THE COMMISSION'S MEGATRENDS HUB

Continuing urbanisation By 2100, the urban population could reach 9 billion. Cities are increasingly functioning autonomously, setting new social and economic standards.	**Growing consumption** By 2030, the consumer class is expected to reach 5 billion people. This means 2 billion more people with increased purchasing power than today.	**Diversifying inequalities** The absolute number of people living in extreme poverty has been declining. The gaps between the wealthiest and poorest of the population are widening	**Increasing demographic imbalances** The world population may reach 8.5 billion by 2030, with rapid growth in many developing economies while shrinking in many developed countries.
Diversification of education and learning New generations and hyperconnectivity are rapidly changing both educational needs and modes of delivery.	**Shifting health challenges** Science and better living standards reduced infectious diseases. Unhealthy lifestyles, pollution, and other anthropogenic causes turn into health burdens.	**Accelerating technological change and hyperconnectivity** Technologies are changing the nature and speed of new scientific discoveries and are transforming systems of production, management, and governance.	**Changing nature of work** New generations entering the workforce and older generations working longer are changing employment, career models, and organisational structures.
Expanding influence of East and South The shift of economic power from the established Western economies and Japan towards the emerging economies in the East and South is set to continue.	**Increasing significance of migration** The social and political significance of migration has increased. Migration flows and dynamics have become more mixed in an interconnected world.	**Increasing influence of new governing systems** Non-state actors, global conscientiousness, social media and internationalisation of decision-making are forming new multi-layered governing systems.	**Changing security paradigm** The diversification of threats and actors is generating new challenges for the defence and security communities and society.
Aggravating resource scarcity Demand for water, food, energy, land, and minerals is rising substantially, making natural resources	**Climate change and environmental degradation** Continued unabated anthropogenic pollution		

[15] https://commission.europa.eu/law/law-making-process/planning-and-proposing-law/better-regulation/better-regulation-guidelines-and-toolbox_en

increasingly scarce and more expensive.	and greenhouse gas emissions will further

Source: created by project team based on the Commission's Megatrend Hub[16]

For this project, we followed the process below to identify and integrate megatrends' insights into the analysis:

- **Identification of megatrends:** to identify forces affecting the robotisation and automotive sectors globally and on a regional/national scale, we reviewed literature and conducted desk research.
- **Classification and prioritisation:** after gathering information on ongoing and expected future trends, we attributed each insight to the megatrends in the EC classification. This step was important for a better understanding and for forming a system of interconnected forces that affect the robotisation and automotive industries. At the same time, trends were prioritised based on relevance, certainty, and potential to influence each sector.
  When researching, we focused on technological advancements, socio-economic shifts, environmental changes, and geopolitical influences. We considered these aspects when reviewing the literature.

Below is an example of mapping megatrends to cutting-edge technologies from the automotive pilot (Table 10):

TABLE 10. CUTTING-EDGE AUTOMOTIVE TECHNOLOGIES MAPPING TO MEGATRENDS

TECHNOLOGY	ASSOCIATED MEGATRENDS	DEVELOPMENT DESCRIPTION
Electric Vehicles & Battery Technology	Climate change, Scarcity of resources, Growing consumption	The rise in EVs and advancements in battery technology is driven by the need to reduce emissions and meet growing consumer demand for sustainable transport solutions.
Digital Controlled Micro-Precision Manufacturing	Rapid technology development, Consumer demand, Globalisation	This technology allows for highly accurate, automated production processes, meeting the demands of mass customisation, precision, and efficiency in global supply chains.
Additive Manufacturing (3D Printing)	Scarcity of resources, Rapid technology development, Growing consumption	Additive manufacturing enables resource-efficient production methods, reducing material waste and allowing for on-demand, localised production to meet growing consumer needs.
Smart Mobility Solutions	Urbanisation, Consumer demand, Climate change	Focused on individual and commercial mobility, this includes shared, electric, and autonomous vehicles and app-based solutions that provide seamless and sustainable transport options for consumers.
Intelligent Transportation Systems (ITS)	Urbanisation, Rapid technological development, Ageing society	A broader infrastructure-based ecosystem that integrates communication technologies, IoT, and data analytics to manage traffic flow, enhance safety, and optimise transport networks at the city or regional level.

Source: prepared by the project team.

[16] https://knowledge4policy.ec.europa.eu/foresight/tool/megatrends-hub_en#explore

4. Validation with experts

Validation with experts in the context of industrial strategy development refers to the inclusive process of involving various entities, including government bodies, industry representatives, academic institutions, NGOs, and community groups, in the planning, decision-making, and implementation phases. This engagement is vital as it ensures that the strategies formulated align with the stakeholders' diverse needs, perspectives, and aspirations.

To ensure the accuracy and relevance of our findings, we employed both internal and external validation with experts' processes:

- **Internal validation:** continuous communication with VAIA included regular check-ins throughout the project, covering industry and technology selection, company searches, and confirmation of company lists pre- and post-analysis. Feedback from report reviews and workshops informed improvements, with explanations and adjustments based on VAIA and other stakeholders' input. Monthly progress reports and project management meetings further supported regular check-ins.
- **External validation:** experts and stakeholders from governmental agencies, academia, and industry should validate the analytical outputs. These experts are needed to provide feedback during deliverable presentations in workshops. They should assess key deliverables, such as technology and company lists, discuss the findings, and offer input to the study team through VAIA. Additionally, focus groups with high-level industry experts can be arranged.

A training **workshop** for internal VAIA stakeholders is *envisioned* to disseminate information and engage participants in understanding and evaluating the actionable steps derived from the analyses (D3 and D4). This workshop aims to ensure that all internal stakeholders are well-informed and actively involved in applying the findings.

A **conference** *(envisioned)* will be hosted for both VAIA and external stakeholders to share best practices and lessons learned and raise awareness of the project outcomes. This final conference will include all partners directly involved in implementing the pilots and gap analysis, providing a platform for discussing the project's impact and future directions.

5. Strategic framework: Vision, priorities, and goal setting

This chapter presents a structured approach to developing a long-term strategic framework for Slovakia's industrial strategy. The process begins with **Industrial Foresight**, incorporating **Visioning**—creating a desirable future outlook for Slovakia's industry. Visioning establishes a foundation by defining broad aspirations aligning with national and EU priorities, ensuring Slovakia's industry remains competitive, sustainable, and innovative.

Following the visioning process, **strategic priorities** are identified to guide policy direction. These priorities encompass key domains where policy interventions can enhance resilience, competitiveness, and sustainable growth. By selecting these strategic areas, policymakers can focus on domains requiring immediate action or demonstrating strong potential for positive impact. Additionally, the framework ensures that planned interventions align with Slovakia's strengths and European objectives, including the Green and Digital transition.

Finally, the chapter outlines establishing **general and specific objectives** linked to measurable indicators that monitor progress across key areas, including technology presence, market share, competitiveness, innovation networks, and investment dynamics. These objectives serve as practical, actionable targets that directly support the realisation of the vision established for Slovakia's industrial strategy. By focusing on specific, pre-selected domains, these objectives ensure that policy interventions are both strategically aligned and capable of driving meaningful outcomes.

5.1. Industrial foresight

Industrial foresight is a strategic approach that anticipates future developments, trends, and potential disruptions across technology, policy, and market dynamics. It supports decision-making by assessing uncertainties and envisioning possible future scenarios. Through collecting, synthesising, and analysing data from diverse sources, foresight activities enable policymakers to make informed choices, fostering proactive strategies that align with long-term goals and drive sustainable growth. European foresight frameworks outline a best-practice structure for these activities[17]. In this project, industrial foresight incorporates visioning to provide a foundational framework for guiding strategic priorities and actionable pathways in Slovakia's industrial strategy.

Scenario development is essential for exploring strategic options and understanding potential policy impacts. This includes **Vision formulation (Visioning)**—defining a desirable future state for industry that aligns with national capabilities and EU priorities, ensuring relevance to policy objectives. Visioning involves experts from scientific, industrial, policy, and public domains collaboratively developing desirable future states. This process is vital in industrial strategy roadmapping as it integrates a comprehensive understanding of current industry landscapes with aspirations for a sustainable and competitive future. **Backcasting** complements Visioning by establishing pathways, policies, and measures needed to achieve these future states.

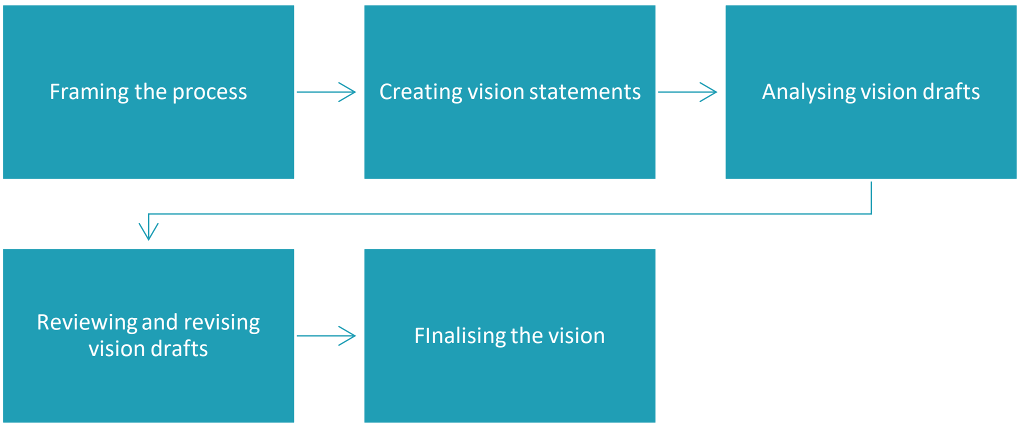
Visioning aims to develop a shared vision for the industry's future, guiding the creation of a roadmap for achieving this vision. Visioning can be categorised as follows:

[17] https://commission.europa.eu/strategy-and-policy/strategic-foresight_en

- **Quantitative and qualitative**: Visioning includes quantitative objectives (e.g., increasing the share of Slovak companies in key technologies) and qualitative aspirations (e.g., advancing sustainable practices in robotics and the automotive sector).
- **Focus on individual, systemic, and global impact**: Visioning assesses impacts from local industry advancements to sector-wide and global trends, ensuring alignment with national and EU priorities in R&D&I.
- **Temporal scale**: Visioning and Backcasting range from immediate (e.g., 5-year targets for technology adoption) to long-term goals (e.g., 30-50 years for full-scale industrial automation and sustainable robotics integration).

For industrial foresight to be effective, it must be a continuous and systematic process, engaging stakeholders across sectors to maintain relevance and adaptability in response to change. Engaging stakeholders enriches the process, incorporating diverse perspectives and expertise. Finally, the resulting visions and scenarios must be clearly communicated to all relevant parties to foster shared understanding and alignment across industries, governments, and communities, promoting sustained, forward-looking collaboration. Below, the phases of visioning are detailed (Figure 10):

FIGURE 10. PHASES OF VISIONING & BACKCASTING



Source: Prepared by the project team, synthesising information from the EC's Strategic Foresight page[18] *and the step-by-step process outlined in Iwaniec & Wiek's (2014) empirical study*[19].

1. **Framing the process**: Define the visioning scope, focusing on sector-specific and cross-sectoral themes aligned with Slovakia's R&D&I strategy. Set parameters (temporal, spatial, and thematic) and engage a multidisciplinary team.
2. **Creating vision statements**: Develop vision statements addressing questions like, "*What is the ideal future state for Slovakia's automotive sector by 2050?"* Rank statements by relevance to strategic priorities, such as competitiveness and sustainability.
3. **Drafting and mapping vision**: Analyse and map vision elements, identifying interconnections and gaps. Draft a preliminary vision map to visualise the interconnected elements in the proposed future state.

[18] European Commission. (n.d.). *Strategic foresight*. European Commission. Retrieved, from https://commission.europa.eu/strategy-and-policy/strategic-foresight_en

[19] Iwaniec, D., & Wiek, A. (2014). Advancing Sustainability Visioning Practice in Planning—The General Plan Update in Phoenix, Arizona. *Planning Practice & Research*, *29*(5), 543–568. https://doi.org/10.1080/02697459.2014.977004

4. **Reviewing and refining vision drafts**: Facilitate workshops to review and adjust vision drafts, gathering stakeholder input to ensure alignment and inclusive involvement of all interested and affected parties.
5. **Finalising the vision**: Integrate and compile a unified vision map, produce a comprehensive report summarising the vision with supporting data, and align it with EU and national strategies. Embed the vision within Slovakia's R&D&I framework to guide policy initiatives.

5.2. Identification of strategic priorities

Identifying strategic priorities translates the high-level aspirations from the visioning phase into more specific focus areas. Building on this foundation, strategic priorities bridge the aspirational vision and the practical interventions needed to realise it. These priorities encompass key domains where policy interventions can significantly enhance resilience, drive sustainable growth, and strengthen Slovakia's global position. By focusing on these strategic areas, policymakers can ensure that each intervention aligns directly with the desired future state established in the vision.

The process for identifying strategic priorities involves selecting key domains through a combination of industrial performance assessments and expert insights tailored to R&D&I policy. By examining the comprehensive industry landscape, policymakers can decide which domains offer the most significant potential, factoring in technological advancements, market needs, and societal benefits.

Each identified priority is further evaluated against a set of indicators, enabling policymakers to determine which domains merit immediate intervention and resource allocation and which may be set aside or assigned limited resources for the time being. Below, we provide an example of the Strategic Priority Evaluation Matrix with indicators that can be used (Table 11). Each indicator requires quantitative and qualitative inputs, data analysis, and expert insights across relevant domains. Additionally, this intelligence must be assessed in terms of alignment with European priorities, examining the coherence between national and European objectives.

TABLE 11. STRATEGIC PRIORITY EVALUATION MATRIX FOR R&I DOMAINS

INDICATOR TYPE	QUANTITATIVE INPUTS	QUALITATIVE INPUTS	EUROPEAN PRIORITY ALIGNMENT	OVERALL ASSESSMENT
Market dynamics	- Market size - Growth rate - Revenue potential - GDP Contribution potential	- Insights from governmental agencies - Insights from industry agencies - Insights from academia	- Supports EU industrial strategy - Relevant to Green Deal	High/Moderate/Low
Innovation capacity	- R&D investment - Patent filings - Innovation spending		- Contributes to EU tech and digital goals - Aligned with innovation policies	High/Moderate/Low
Employment impact	- Job growth rate - Employment in high-skill roles		- Contributes to EU employment targets - Aligned with social inclusion	High/Moderate/Low
Sustainability impact	- Emissions reduction - Renewable energy use		- Aligned with EU Green Deal - Supports EU's carbon neutrality goals	High/Moderate/Low

Scalability	- Export market potential - Adaptability across EU	- Supports EU integration goals - Relevant to cross-border trade	High/Moderate/Low

Source: Prepared by the project team based on a synthesis of information from the European Commission (2012) Guide to Research and Innovation Strategies for Smart Specialisation (RIS3), particularly Step 4, "Identification of Priorities," and Step 5, "Definition of Coherent Policy Mix, Roadmaps, and Action Plan."[20]

5.3. Identification of strategic objectives

Creating specific objectives is essential to translate strategic priorities into practical, measurable targets. These objectives break down each priority into actionable steps, focusing on defined outcomes that directly contribute to the broader industrial vision. Specific objectives clarify success within each priority domain, provide benchmarks for tracking progress, and align policy efforts with tangible, results-driven metrics.

A set of indicators is applied to evaluate each objective's effectiveness. These indicators offer a clear, measurable way to track progress and determine the impact of initiatives over time. Table 12 provides an example of how strategic priorities, specific objectives, and corresponding indicators interconnect. Similar matrices support policymakers in understanding the effectiveness of their initiatives and adapting them as necessary based on measurable outcomes.

TABLE 12. EXAMPLES OF LINKS BETWEEN STRATEGIC PRIORITIES, OBJECTIVES AND INDICATORS

GENERAL PRIORITIES	SPECIFIC OBJECTIVES	INDICATORS
Enhance Slovakia's position in key technologies	Increase the number of Slovak enterprises in priority technology sectors	Number of companies and start-ups active in prioritised technologies
	Attract greater capital investment for Slovak start-ups in high-tech domains	Capital raised by Slovak start-ups since 2018
	Strengthen leadership in top industries for technology adoption	Top-5 industries by share of Slovak companies in specific technologies
	Increase market share of Slovak technology exports	Export volume of Slovak products in key technology areas
Increase technology adoption and market share in Visegrád/EU	Increase adoption rates of innovative technologies among Slovak firms in Visegrád	Percentage of Slovak companies adopting specific technologies in Visegrád/EU
	Position Slovak firms as innovation leaders within the Visegrád/EU region	Share of Slovak firms identified as innovation leaders within Visegrád/EU
	Increase visibility in regional technology collaborations	Number of joint projects or patents within Visegrád/EU networks
Boost Slovak firms' competitiveness and growth	Increase the number of large, high-growth Slovak enterprises	Slovak share of large companies within Visegrád/EU
	Support the development of high-growth sectors	Number of fast-growing companies in priority sectors
	Enhance access to funding for start-ups in priority sectors	Slovak share of highly funded start-ups in Visegrád/EU
	Improve scale-up success rates for Slovak start-ups	Percentage of start-ups successfully scaling operations in target markets
	Increase Slovakia's participation in EU R&I collaborations	Number of EU R&I collaborations involving Slovak organisations

[20] European Commission. (2012). *Guide on research and innovation strategies for smart specialisation (RIS3 guide)*. Publications Office of the European Union., from https://s3platform.jrc.ec.europa.eu/en/w/guide-on-research-and-innovation-strategies-for-smart-specialisation-ris3-guide-

Expand Slovak innovation and collaboration networks	Foster collaboration in key industries involving Slovak entities	Top-5 industries for EU collaboration involving Slovak firms
	Strengthen public-private partnerships in innovation	Number of active public-private partnerships in R&I initiatives
Enhance investment dynamics and R&D commitment	Increase average investment levels in Slovak firms	Median total investment per Slovak enterprise
	Strengthen commitments to R&D investments	Median R&D investment per Slovak firm
	Expand start-up funding avenues within the EU	Total capital raised by Slovak start-ups within EU networks
	Increase domestic and foreign R&D investments	Annual growth rate of R&D investments from both domestic and foreign sources
Strengthen research output and industry-research collaborations	Increase the number of research institutions in key technological fields	Number of research organisations focused on priority technologies
	Expand research affiliations in strategic technology areas	Number of researchers affiliated with targeted technologies
	Boost publication output in priority technology domains	Publications and patents by technology area
	Enhance collaboration between industry and academia	Number of collaborative projects between researchers and firms
	Improve the quality of research outputs	Number of high-impact publications in priority areas

Source: Prepared by the project team based on the EC's Better Regulation Guidelines Toolbox, Tool #43, Section 2.2, "Indicators."[21]

5.4. Overview of resources useful for Industrial foresight

Below, we provide a list of resources that can be helpful when planning for and implementing the strategic framework, focusing on creating a vision, establishing priorities, and setting goals for industrial policy implementation:

1) European Commission. (2022). *ERA industrial technology roadmaps*. European Commission, from https://research-and-innovation.ec.europa.eu/research-area/industrial-research-and-innovation/era-industrial-technology-roadmaps_en
2) European Commission. (2023). *2023 Strategic foresight report: Sustainability and wellbeing at the heart of Europe's open strategic autonomy*. European Commission, from https://commission.europa.eu/strategy-and-policy/strategic-foresight/2023-strategic-foresight-report_en
3) European Commission. (2023). *Better regulation toolbox: Chapter 3 - Tool 20: Strategic foresight for impact assessments and evaluations*. European Commission. https://commission.europa.eu/law/law-making-process/planning-and-proposing-law/better-regulation/better-regulation-guidelines-and-toolbox/better-regulation-toolbox_en
4) European Commission. (n.d.). *Strategic foresight*, from https://commission.europa.eu/strategy-and-policy/strategic-foresight_en.
5) European Commission. (n.d.). *The Scenario Exploration System (SES)*. Knowledge for policy, from https://knowledge4policy.ec.europa.eu/foresight/tool/scenario-exploration-system-ses_en

21 https://commission.europa.eu/law/law-making-process/planning-and-proposing-law/better-regulation/better-regulation-guidelines-and-toolbox/better-regulation-toolbox_en

6) Foray, D., et al. (2012). *Guide on research and innovation strategies for smart specialisation (RIS3 guide)*. Smart Specialisation Platform. European Commission, from https://s3platform.jrc.ec.europa.eu/en/w/guide-on-research-and-innovation-strategies-for-smart-specialisation-ris3-guide-

6. Capacity-building

As part of Deliverable 4 of the project, we conducted a Gap Analysis Report on the administrative capacities for implementing industrial strategies, examining the **AS-IS** (current state) versus the **TO-BE** (desired state) situation. This analysis aims to provide a comprehensive understanding of the administrative capacity within public institutions in Slovakia, particularly focusing on their ability to design and implement effective industrial strategies. The underlying principle of this work is that the quality of governance within these institutions directly impacts the effectiveness of public investments, which in turn influences economic growth.

6.1. AS-IS analysis

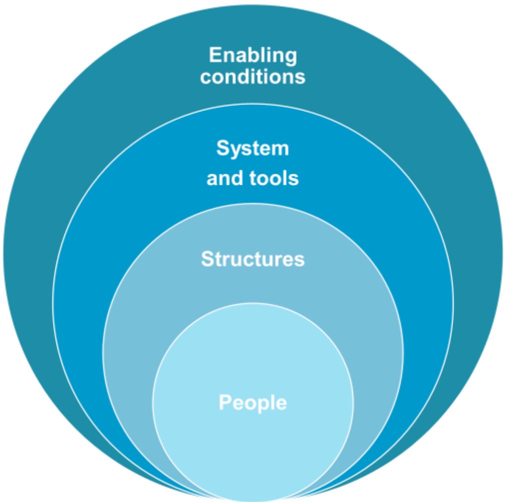
6.1.1. Scope of the AS-IS analysis

The AS-IS analysis centres around four main factors of administrative capacity (the key chapters of the report correspond to these key areas):

- **Human resources**: Includes staff roles, management, turnover, skills, competencies, and training needs related to industrial strategy.
- **Structures**: Examines institutional setup, alignment with political priorities, stakeholder involvement, and flexibility in communication and information exchange.
- **Systems and tools**: Focuses on methods, data sources, external expertise, ICT systems, knowledge management, and monitoring and evaluation frameworks.
- **Enabling conditions**: Considers legal and regulatory frameworks, funding sources, and transparency.

These factors collectively form the analytical framework for assessing gaps in administrative capacities, providing a structured basis for understanding the current capabilities and identifying areas for improvement. This framework was adapted from the **OECD's Administrative Capacity Building Roadmaps** and tailored to Slovakia's context by the project team (Figure 11).

FIGURE 11. SCOPE OF THE AS-IS ANALYSIS



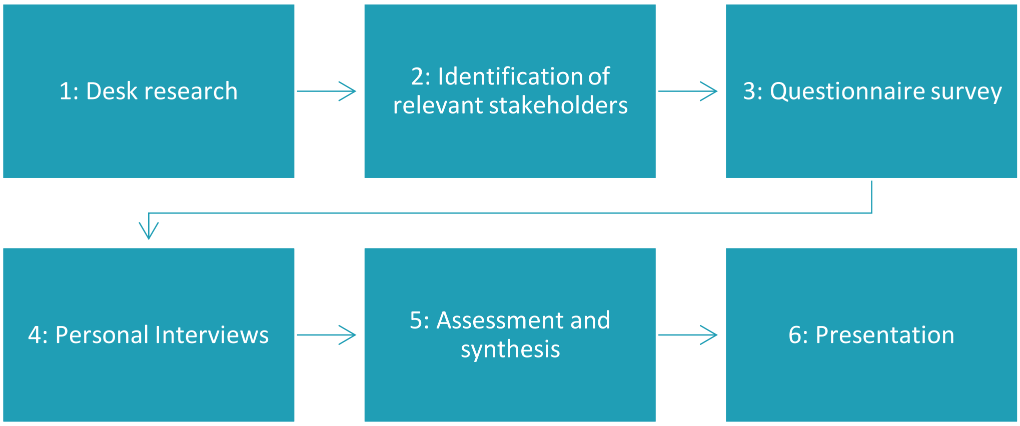
Source: OECD (2021), Administrative capacity building roadmaps, adopted by the project team

6.1.2. Methodological framework

To perform AS-IS analysis, the team relied on a step-by-step methodology, which enabled a systematic approach to gathering and interpreting data on administrative capacities relevant to Slovakia's industrial strategies, specifically within the framework of the **Smart Specialisation Strategy (RIS3)** and Domain 1, "Innovative Industry for the 21st Century."

The methodological steps are as follows (Figure 12):

FIGURE 12. METHODOLOGY FOR ELABORATION OF THE AS-IS ANALYSIS



Source: prepared by the project team.

1. **Desk research**: We began by collecting and reviewing documentation on institutions involved in designing and implementing industrial strategies in Slovakia. This initial step provided a foundational understanding of the organisational landscape.
2. **Identification of relevant stakeholders**: Relevant organisational units responsible for industrial strategy were selected to participate in the analysis. This selection ensured that the data collected was comprehensive and representative of the administrative capacities across key institutions.
3. **Questionnaire survey**: To gather information on administrative capacities, we developed a questionnaire focusing on the main factors (human resources, structures, systems and tools, and enabling conditions). The questionnaires were distributed electronically, ensuring broad coverage and accessibility. A sample of the questionnaire is provided in Annex 1.
4. **Personal interviews**: Following the survey, we conducted personal interviews to fill information gaps and clarify responses from the questionnaire. These interviews offered an opportunity to delve deeper into specific issues and collect qualitative insights.
5. **Assessment and synthesis**: The expert team assessed, synthesised and interpreted the data. For each factor, a SWOT analysis was conducted to identify strengths, weaknesses, opportunities, and threats within Slovakia's administrative capacities.
6. **Presentation of findings**: Preliminary findings from the AS-IS analysis were presented to stakeholders in a workshop held in September 2024. This discussion facilitated feedback, allowing stakeholders to validate the findings and contribute additional perspectives.

It is worth noting that the AS-IS analysis did not include a comparative element with other countries, as no relevant data on administrative capacities for industrial strategies was available for such a comparison.

List of respondents

The institutions and organisational units involved in the questionnaire survey and personal interviews were as follows:

- Department of Research and Innovation Policies, VAIA
- Department of Priorities, VAIA
- Department of Innovations, Ministry of Economy of the Slovak Republic
- Department of Industrial Policy, Ministry of Economy of the Slovak Republic
- Institute of Economic Analyses, Ministry of Economy of the Slovak Republic
- Department of Implementation of State Research and Development Policy, Ministry of Education, Research, Development and Youth of the Slovak Republic
- Slovak Innovation and Energy Agency

6.2. TO-BE Analysis

Based on the **'AS-IS** analysis, the next step involves defining the **'TO-BE'** state – a vision for Slovakia's future innovation ecosystem – and identifying the actions required to achieve it. This involves proposing solutions and structured actions to address the issues identified in the state-of-play analysis. The roadmap should make clear the links between current challenges, proposed actions, and desired outcomes.

Defining the 'TO-BE' State

The **'TO-BE'** state should clearly articulate a vision of a more effective, resilient, and competitive innovation ecosystem. This includes setting specific goals and objectives aligned with Slovakia's strategic priorities in innovation, such as increasing R&D investments, enhancing industry-academia collaboration, and improving regulatory frameworks to foster innovation. The priorities for the enhancement of administrative capacities are to be suggested along 4 main elements: human resources, structures/tools and external factors.

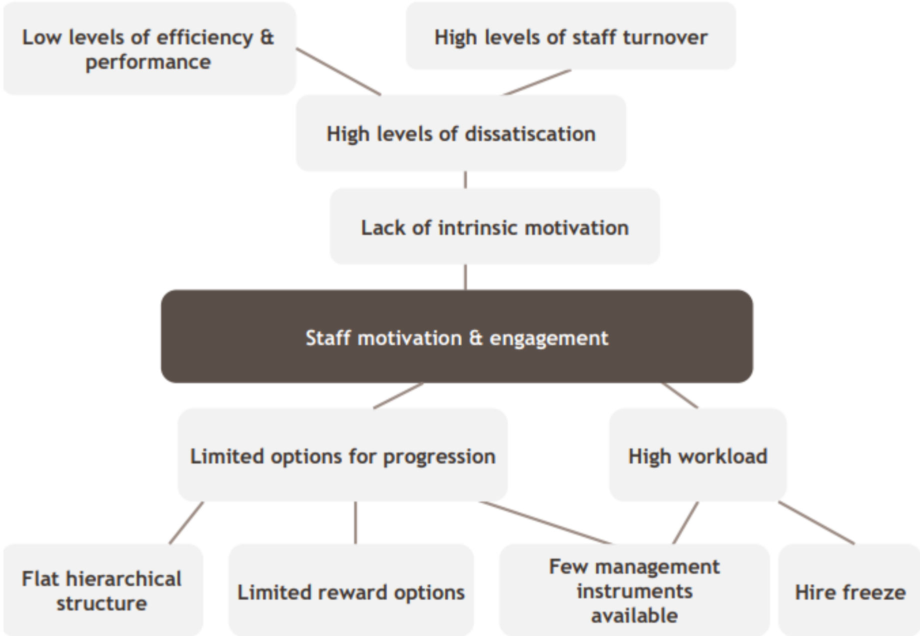
Identifying actions

To reach the **'TO BE'** state, the roadmap should outline actions that:

- **Address identified problems**: Actions should target the gaps and challenges identified in the AS-IS analysis, ensuring each issue has a corresponding solution.
- **Link to expected results**: Each action should contribute to a broader change process, showing how the proposed measures will lead to desired outcomes.

A **problem tree analysis** can illustrate the connections between problems, causes, and effects (Figure 13). The key issue forms the "trunk," with causes as the "roots" and effects as the "branches." It is mainly useful because it encourages discussion, debate and revision of causes, effects, and arguments. It can also draw attention to missing information and highlight known and unknown aspects before designing solutions.

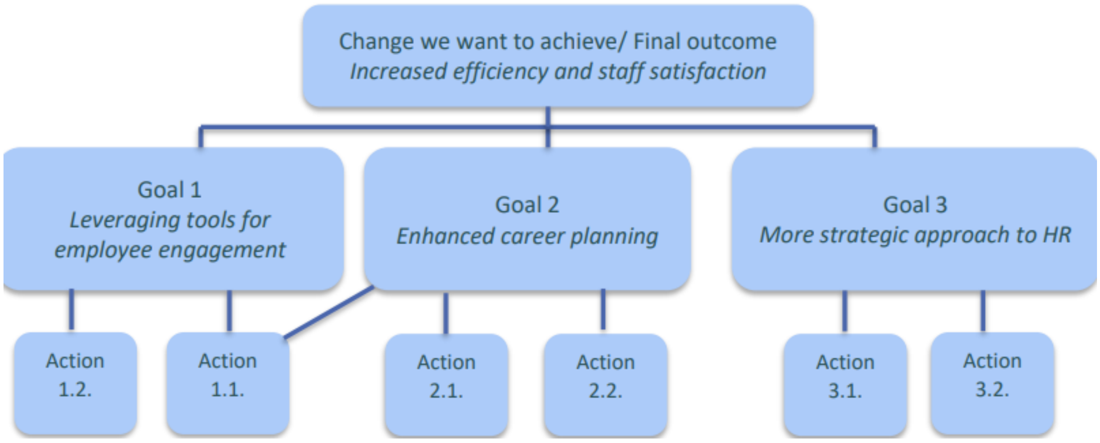
FIGURE 13. EXAMPLE OF A PROBLEM TREE ANALYSING STAFF MOTIVATION AND ENGAGEMENT



Source: *EC (2020). Roadmap toolkit: Enhancing administrative capacity for better EU investment*[22]

After the tree is established, the problems are reformulated positively in an objectives tree, which maps objectives to actionable steps to address the issues (Figure 14). Establishing a cause-effect chain is crucial for constructing a 'theory of change,' which serves as a pathway to realising desired outcomes (like intervention logic).

FIGURE 14. EXAMPLE OF AN OBJECTIVES TREE: GOALS AND ACTIONS FOR INCREASED EFFICIENCY AND STAFF SATISFACTION



Source: *EC (2020). Roadmap toolkit: Enhancing administrative capacity for better EU investment*[23]

[22] European Commission. (2020). *Roadmap toolkit: Enhancing administrative capacity for better EU investment*. Publications Office of the European Union. https://ec.europa.eu/regional_policy/sources/policy/how/improving-investment/roadmap_toolkit.pdf

[23] European Commission. (2020). *Roadmap toolkit: Enhancing administrative capacity for better EU investment*. Publications Office of the European Union. https://ec.europa.eu/regional_policy/sources/policy/how/improving-investment/roadmap_toolkit.pdf

6.3. Overview of EC toolkits for capacity building strategies

Various capacity-building resources are available to strengthen administrative functions and ensure long-term sustainability in delivering industrial strategies to support the effective implementation of the TO-BE interventions. The following European Commission toolkits offer comprehensive guidance and instruments that can be applied to the specific context of Slovakia's administrative capacity needs (Table 13).

TABLE 13. OVERVIEW OF EC RESOURCES ON CAPACITY BUILDING FOR ADMINISTRATIVE DEVELOPMENT

TOOLKIT NAME	DESCRIPTION	KEY ASPECTS COVERED
Roadmap toolkit: Enhancing administrative capacity for Better EU Investment[24]	The Roadmap Toolkit provides in-depth guidance on improving administrative capacities to ensure efficient and effective investment management. It addresses critical areas for capacity building, including improving governance structures, refining decision-making processes, and enhancing accountability. Institutions can apply these principles to strengthen internal capacities, reduce inefficiencies, and increase overall impact.	- Strategic planning for investment processes - Structuring efficient administrative functions - Tools for transparent and accountable decision-making
EC (2010). EuropeAid. Tools and methods Series. Reference document N. 6 Toolkit for Capacity Development[25]	This toolkit offers a structured approach to assessing and building institutional capacities at various levels. It focuses on actors, roles, processes, and sectoral and institutional development results. The toolkit includes specific tools and methodologies for conducting gap analyses, setting development goals, and tracking progress.	- Capacity assessment instruments for sectoral and institutional development - Tools for clarifying roles and responsibilities - Methods for process improvement and result-oriented capacity tracking

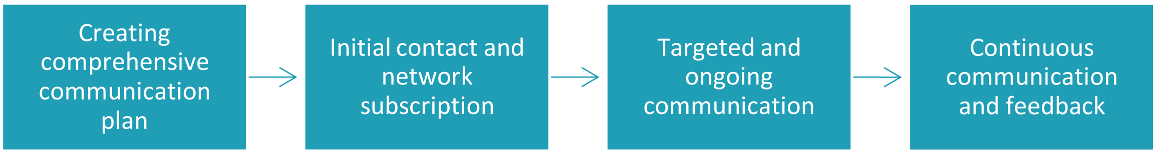
Source: prepared by the project team.

[24] https://ec.europa.eu/regional_policy/en/information/publications/guides/2020/roadmaps-for-administrative-capacity-building-practical-toolkit
[25] https://capacity4dev.europa.eu/library/reference-document-nr-6-toolkit-capacity-development-2010_en

7. Communication and stakeholder buy-in

Effective communication and engagement are essential for a successful industrial policy roadmap. The roadmap gains broader support, relevance, and responsiveness to industry needs by involving stakeholders early and aligning with national and EU priorities. Engaging diverse stakeholders builds trust, encourages collaboration, and secures long-term commitment, ensuring the roadmap's strategic value and impact. Key phases of stakeholder engagement and communication are detailed below:

FIGURE 15. KEY PHASES OF STAKEHOLDER ENGAGEMENT AND COMMUNICATION



Source: prepared by the project team.

1. **Comprehensive communication plan:** Develop a structured communication plan to share strategies and foster stakeholder buy-in effectively. This plan will ensure clarity, adaptability, and responsiveness throughout roadmapping.

2. **Initial contact and network subscription**
   - **Invitation to network:** Reach out to stakeholders via the project website, social media, newsletters, and direct emails, inviting them to join a dedicated Industrial Policy Platform.
   - **Standardised outreach materials:** Provide a consistent invitation letter with a registration link and key project details. A survey may be included to gather information on stakeholder interests and expectations.
   - **Informed consent:** Ensure data privacy by including an informed consent form detailing data use, storage, and contributions aligned with ethical standards.

3. **Targeted and ongoing engagement**
   - **Stakeholder analysis and clustering:** Conduct a detailed analysis of group stakeholders based on sector, expertise, and policy role, tailoring messaging to each cluster.
   - **Customised messaging:** Tailor communication for each group, adapting channels to their engagement level (e.g., newsletters for updates, workshops for active contributors).
   - **Multiplier network:** Identify key stakeholders who can amplify the roadmap's reach, building collaborative relationships with industry bodies and associations.
   - **Stakeholder database management:** Regularly update a centralised stakeholder database, designating team members for management and monitoring engagement trends.

4. **Continuous communication and feedback**
   - **Regular updates:** Share roadmap progress and milestones through newsletters, social media, and the project website.
   - **Feedback loops:** Gather feedback via surveys, focus groups, and forums to meet stakeholders' evolving needs.

- **Capacity building:** Provide resources and training to help stakeholders understand and contribute meaningfully to the roadmap.
- This approach fosters sustained engagement, support, and alignment with national and EU priorities, enhancing the roadmap's effectiveness and stakeholder buy-in.

8. Monitoring and evaluation framework

Grounded in continuous data collection, the monitoring and evaluation framework is a critical structure for tracking progress, measuring performance, assessing the effectiveness of implemented strategies, and policy accountability and transparency. Tool #43 in the European Commission's Better Regulation Toolbox[26] outlines the principles and components of an effective monitoring system, emphasising timely data collection, contextual indicators, and alignment with initiative objectives to ensure a comprehensive assessment of outcomes.

Setting up a monitoring system requires clear arrangements for data collection, processing, and reuse:

- **Defining monitoring parameters**: Parameters must be set to monitor relevant aspects of the industrial strategy, including inputs (e.g., research funding allocated), outputs (e.g., number of technology assessments conducted), results (e.g., new patents filed or technology adoption rates), and long-term impacts (e.g., growth in strategic industrial sectors). These parameters should align with the initiative's objectives, such as advancing innovation in specific technologies or sectors.
- **Use of indicators**: Quantitative and qualitative indicators are key parts of the monitoring system, which measure aspects of policy or programme progress. Defining indicators should include the exact description of the object that is being measured.
    - Indicators must follow RACER criteria—Relevant, Accepted, Credible, Easy to monitor, and Robust:
        - **Relevant –** indicators should be directly linked to the specific objectives they are measuring, capturing critical information that aligns with policy or strategic priorities,
        - **Accepted –** indicators should be well-defined and shared by stakeholders involved in implementing and affected by it. Acceptance fosters trust, accountability, and cooperation among stakeholders and establishes the credibility of the criteria.
        - **Credible –** refers to the reliability and validity of the indicator and the data it generates. Additionally, the indicator should be unambiguous, making it easily accessible to non-experts.
        - **Easy to monitor –** indicators should be straightforward to measure, track, and report. The ease of monitoring depends on administrative needs and capacities and may include aspects like cost and administrative burden.
        - **Robust** against manipulation – indicators should accurately reflect genuine progress toward the goal, avoiding adjustments that meet targets superficially.
    - Beyond the RACER criteria, several additional factors strengthen the effectiveness of indicators. **Attributable** indicators ensure a clear causal link between the changes measured and the initiative. **Data availability** and **quality** are vital for reliability. **Timeliness** ensures indicators capture the initiative's effects within a relevant timeframe, while **baseline** and **target values** provide context, showing progress against initial conditions and set objectives. **Metadata** helps define the measurement units, data sources, and collection frequency, facilitating data sharing

[26] https://commission.europa.eu/law/law-making-process/planning-and-proposing-law/better-regulation/better-regulation-guidelines-and-toolbox_en

and reuse. Finally, all indicators must respect the **data protection legal framework** to ensure compliance with data privacy laws and safeguard sensitive information.

- **Contextual indicators**: Contextual factors, such as global economic shifts or technological disruptions, should be integrated into monitoring to capture the broader environment in which the industrial strategy operates. This can include tracking technological advancements across industries and shifts in international regulatory standards.

The initiative's monitoring relies on evaluating the achievement of objectives and related indicators, as outlined in Chapter 5, specifically during the identification of strategic objectives stage, where each aim is matched with concrete indicators (see Table 12). For complex concepts like innovation, composite indicators or Key Performance Indicators (KPIs) that combine multiple measures can be useful. These KPIs are suitable for assessing the broad context rather than specific aspects of the initiative's progress. It is useful to summarise the system of indicators in a tabular form (

Table 14):

TABLE 14. MONITORING AND EVALUATION FRAMEWORK TEMPLATE FOR KPIS

Strategic objective	Indicator	Definition	Unit of measurement	Data source	Data quality rating	Frequency of measurement	Baseline	Target

Source: Prepared by the project team based on the EC's Better Regulation Guidelines Toolbox, Tool #43, Section 2.2, "Indicators."[27]

Finally, the monitoring and evaluation approach should be adaptive and flexible, allowing adjustments to emerging challenges and internal and external changes. Continuous data collection and periodic reassessment of indicators ensure alignment with evolving objectives and context. This flexibility upholds accountability and supports informed decision-making, providing the framework remains relevant throughout the initiative's lifecycle.

[27] https://commission.europa.eu/law/law-making-process/planning-and-proposing-law/better-regulation/better-regulation-guidelines-and-toolbox/better-regulation-toolbox_en

9. Risk management and contingency planning

Risk management and **contingency planning** are essential to anticipate, manage, and mitigate potential disruptions. Effective risk management ensures that the roadmap remains aligned with strategic goals despite challenges, while contingency planning provides alternative pathways to maintain progress. This chapter outlines key steps in risk identification, mitigation strategies, and contingency planning, focusing on a proactive approach to sustaining momentum and achieving intended outcomes. General risk assessment and management guidelines are available in the European Commission's *Better Regulation Guidelines Toolbox*, Tool #14[28].

1. **Risk identification:** Identifying risks early in the process is crucial to preventing disruptions and ensuring preparedness. Common risk areas in policy roadmapping include (Table 15):

TABLE 15. EXAMPLE OF RISKS IN INDUSTRIAL STRATEGY ROADMAPPING

INTERNAL/EXTERNAL	RISK GROUP	DESCRIPTION	POTENTIAL RISKS
External	**Strategic risks**	Risks due to misalignment with policy changes or regulatory updates that impact project direction.	• Changes in EU or Slovak funding frameworks affecting project scope. • Regulatory shifts or new policies impacting R&D&I alignment. • Advances in competing technologies.
Internal	**Operational risks**	Risks arising from resource limitations that could delay or impact project milestones and outcomes.	• Insufficient funding for critical stages. • Limited human resources or technical expertise in selected technologies. • Bottlenecks in resource allocation impacting timelines.
Internal/external	**Stakeholder risks**	Risks associated with low stakeholder engagement or support critical for successful project outcomes.	• Low buy-in from industry or government bodies reducing impact. • Limited collaboration with key stakeholders, leading to misalignment. • Insufficient communication, reducing engagement.
External	**Market and economic risks**	Risks tied to market fluctuations or economic changes that impact project feasibility or strategic relevance.	• Global economic downturns reducing investment opportunities. • Shifts in industry demand affecting project priorities. • Market unpredictability in the automation sector.

[28] https://commission.europa.eu/law/law-making-process/planning-and-proposing-law/better-regulation/better-regulation-guidelines-and-toolbox/better-regulation-toolbox_en

Internal/external	**Technological risks**	Risks due to rapid advancements or challenges in adopting new technologies relevant to the project's focus areas.	• Difficulty in adopting or integrating advanced technologies (e.g., robotics, automation). • Technological obsolescence impacting project relevance. • Lag in technical support for new systems.
External	**Environmental and external risks**	Risks from external events or environmental factors that could disrupt timelines or resource availability.	• Natural disasters or pandemics impacting project timelines. • Political instability affecting stakeholder support. • External shocks (e.g., supply chain disruptions) reducing resource availability.

Source: Created by the project team based on EC's Risk management in the Commission: Implementation guide (2018-2019)[29]

A comprehensive **risk assessment** should be conducted by reviewing each project phase to identify potential issues. Risk assessment matrices are helpful tools for evaluating the likelihood and impact of identified risks, enabling prioritisation and resource allocation (Table 16).

TABLE 16. EXAMPLE OF A RISK IMPACT AND LIKELIHOOD ASSESSMENT MATRIX

RISK CATEGORY	DESCRIPTION	LIKELIHOOD	IMPACT	MITIGATION STRATEGY
Strategic risks	Misalignment with evolving EU or national policy priorities or funding changes.	Medium	High	Conduct regular policy reviews; engage policymakers for alignment.
Operational risks	Resource constraints, such as insufficient funding, staff, or expertise.	High	High	Secure additional funding sources; consider cross-training staff.
Stakeholder risks	Low engagement from key stakeholders, reducing project support.	Medium	Medium	Improve communication strategies; hold regular stakeholder forums.
Market and economic risks	Economic downturns or shifts in industry demand impacting project relevance.	Low	High	Adjust project scope as needed; explore alternative market needs.
Technological risks	Rapid tech advancements or difficulties in adopting new technologies.	High	Medium	Invest in tech training; collaborate with technology partners.
Environmental and external risks	Unforeseen external events (e.g., political shifts, natural disasters) affecting project timelines.	Low	High	Develop crisis response plans; establish remote work protocols.

Source: Created by the project team based on EC's Risk management in the Commission: Implementation guide (2018-2019)[30]

2. **Risk mitigation strategies:** After identifying risks, implementing mitigation strategies is essential to minimise their potential impact. Some key mitigation approaches include:
    - **Strategic flexibility**: Regularly monitor changes in national and EU policies to ensure alignment with evolving priorities. Establish adaptable frameworks within the roadmap, allowing for adjustments as new regulations or policies emerge.

[29] European Commission. (n.d.). *Risk management in the Commission: Implementation guide (2018-2019)*. Retrieved [date accessed], from https://wikis.ec.europa.eu/pages/viewpage.action?pageId=50108960

[30] European Commission. (n.d.). *Risk management in the Commission: Implementation guide (2018-2019)*. Retrieved [date accessed], from https://wikis.ec.europa.eu/pages/viewpage.action?pageId=50108960

- **Resource planning**: Allocate resources efficiently to prevent shortages. Establish a reserve budget for unexpected costs and develop partnerships with academic, public, and private institutions to access additional expertise when needed.
- **Stakeholder engagement and communication**: Maintain ongoing communication with stakeholders, providing regular updates and gathering feedback. This builds trust and secures ongoing support, especially from critical partners whose input or participation is essential to the roadmap's success.
- **Market analysis and forecasting**: Conduct regular market analyses to understand economic trends and adapt the roadmap to align with shifting industry demands. Scenario planning can help prepare for various economic conditions.
- **Technology readiness and adoption**: Invest in staff training and capacity building to stay current with technological advancements. Collaboration with tech experts and academic institutions can help the project stay on the cutting edge, minimising risks related to technology adoption.
- **Crisis response protocols**: Develop crisis protocols for external risks, including clear communication plans, resource reallocation processes, and alternative work arrangements to address disruptions like natural disasters or political instability.

3. **Contingency planning:** Contingency planning prepares the roadmap for smooth continuation, even when risks materialise. This process involves creating alternative action plans to sustain progress toward goals and ensure the roadmap's resilience. Key components of contingency planning include:
   - **Developing contingency scenarios**: Based on identified risks, create scenarios that address potential disruptions. For example, if resource limitations are identified, outline specific partnerships or funding sources that could provide supplementary support.
   - **Prioritisation of critical pathways**: Identify the roadmap's most critical components and focus contingency plans on these areas to protect the project's core goals. This includes essential technologies, key milestones, and high-impact deliverables.
   - **Decision-making frameworks**: Establish clear decision-making processes to facilitate quick responses when risks occur. This includes designating a risk management team and defining roles and responsibilities for implementing contingency measures.
   - **Regular review and testing of plans**: Schedule regular reviews of contingency plans to ensure they remain relevant and updated. Conduct periodic testing or simulations of contingency scenarios to refine responses and improve readiness.

4. **Monitoring and evaluation:** Effective risk management and contingency planning are continuous processes requiring regular monitoring. Establish key performance indicators (KPIs) to track risk levels and monitor the success of mitigation strategies. Regular evaluation sessions with project stakeholders and risk management teams enable timely adjustments and ensure that plans stay aligned with project goals (this element falls under the monitoring and evaluation framework, see Chapter 8. Monitoring and evaluation framework).

10. Conclusion: Bridging methodology with practical implementation

The **Methodological Handbook for Industrial policy roadmapping** serves as a comprehensive guide focused on frameworks and methodologies for developing an industrial strategy. However, it does not fully encompass certain elements typically essential for implementing a roadmap in practice. These elements would add clarity and actionable detail if the roadmap were to be operationalised:

1) **Clear milestones and timelines:** The handbook outlines methodologies but lacks specific milestones and phased timelines. An implementation roadmap should include a structured schedule to track progress and ensure timely achievements.
2) **Detailed action plans for each priority:** While the handbook provides a general approach to setting strategic priorities, a real-life roadmap would require more detailed action steps. This includes specifying responsibilities, necessary resources, and concrete projects for each priority area.
3) **Budget and resource allocation:** An actionable roadmap requires outlining budget allocations and funding sources to ensure financial feasibility and clarity in resource distribution.
4) **Stakeholder roles and responsibilities:** The handbook includes strategies for stakeholder engagement but does not explicitly define roles and responsibilities. A practical roadmap would assign clear duties to each stakeholder group, enhancing accountability and coordination.
5) **Performance metrics with specific targets:** While the monitoring framework provides indicators, an implementation roadmap would include specific target values for these metrics, offering measurable benchmarks for success.
6) **Scenario planning and adaptive pathways:** Although risk management and foresight are discussed, a fully developed roadmap would include adaptive pathways for responding to scenarios such as technological advancements or economic shifts, guiding decision-makers through alternate strategies.

These elements would enhance the handbook by bridging methodological precision with actionable steps, timelines, and responsibilities necessary for real-world implementation. This integration would provide a clearer and more practical pathway for achieving Slovakia's RDI goals.

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