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Decoding Progress: Assessing R&D Institutes Performance in the Contemporary Landscape

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Abstract - In the dynamic landscape of research and development (R&D) institutes, performance measurement is a multifaceted challenge. This paper undertakes an exploration of the current state of R&D institutes, delving into their methodologies, achievements, and adaptability within the contemporary research ecosystem. Drawing insights from diverse perspectives, the study employs a comprehensive approach to assess the complicated factors influencing R&D institutes' performance. The focus extends beyond traditional metrics, including new criteria that capture the institutes' responsiveness to evolving research trends, interdisciplinary collaborations, and societal impact. Through this examination, the paper seeks to unravel the nuanced dynamics of progress within R&D institutes and contribute to the ongoing discourse on optimizing their efficacy in the ever-evolving scientific landscape.

Keywords R&D institutes, performance assessment, research and development, research ecosystem, scientific landscape, research efficiency

I. INTRODUCTION

In the domain of research and development (R&D), where innovation serves as the compass guiding societal advancement, the evaluation of R&D institutes performance emerges as a pivotal undertaking. This paper embarks on a comprehensive exploration of the multifaceted dimensions that define and shape the success of R&D institutes in the present era.

As we stand at the intersection of technological breakthroughs, collaborative networks, and evolving global challenges, understanding the nuances of R&D institutes performance becomes imperative. This paper endeavours to unravel the complexities inherent in the contemporary landscape, aiming to provide a nuanced framework for assessing the effectiveness of R&D institutes.

This paper begins with an examination of the frameworks that support the assessment of performance, delving into the various metrics employed in gauging the impact and contributions of R&D activities. We will explore the comparative landscape of R&D institutes, scrutinizing their innovative capacities, collaborative dynamics, and the critical role played by human capital and expertise in driving research excellence.

Furthermore, the paper delves into the subtleties of funding and resource allocation, recognizing them as foundational elements that influence the trajectory of R&D institutes success. In the context of rapid technological evolution, we analyse the impact of emerging trends on the performance of R&D institutes and present case studies that show exemplary models of research excellence.

By synthesizing insights collected from various perspectives, we aim to provide a holistic understanding of the contemporary challenges and opportunities faced by R&D institutes, charting a course for the future.

Through this paper we aim to untangle the complex tapestry of R&D institute performance, fostering a topic that transcends disciplines and borders. As we embark on this intellectual exploration, we aspire to contribute meaningfully to the ongoing discourse surrounding the vital role of R&D in shaping the future trajectory of our societies.

II. DATA-DRIVEN INSIGHTS: ANALYTICS FOR R&D PERFORMANCE ASSESSMENT IN ROMANIA

Every year, the state authority for research and development in Romania (currently Ministry of Research, Innovation and Digitization) issues a report regarding the activity and performance of the national research & development institutes of Romania.

The report includes [3]:

a. Analysis of the key indicators quantifying the results achieved by the national research and development institutes mentioned in section 1.3. following research and development activities;

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b. Analysis of the main economic and financial indicators recorded by the national research and development institutes;

c. Analysis regarding the structure of the research and development human resources based on distribution by scientific degrees and age groups;

d. Analysis regarding the structure and utilization level of the research infrastructure facilities;

e. Analysis concerning the visibility and prestige of the national research and development institutes.

According to the report for the year 2022, regarding the activity and performance of the 43 research institutes under the coordination of the Ministry of Research, Innovation and Digitization we can highlight some observations.

The report emphasizes the continuous growth in scientific and technological performance achieved through the development of ongoing research projects and the exploration of new research themes won in national and international project competitions. The activities of the institutes align with the INCD's Strategic Institutional Development Plan, in harmony with national strategies for research, development, and innovation. Notably, efforts were made to attract European and international funds amid reduced national budgets and delays in project evaluations.

Rigorous directions were followed, including improving internal control systems, maintaining quality management certification, expanding laboratory test authorizations, increasing services to the private sector, and efficient cash flow management.

Efforts were directed towards fostering a positive research culture, acknowledging the role of leadership in setting values and the influence of younger researchers in shaping the institute's direction. Emphasis was placed on physical structures and regular events promoting team building and cohesion.

Despite financial constraints and unpredictability, INCDs focused on valorising research outcomes, resulting in a slight increase in patented inventions and a decrease in technological services. The private sector's increased participation in supporting research activities led to enhanced collaboration, fostering interdisciplinarity in project proposals. Strategic human resource management aimed at maintaining an optimal organizational structure, adapting to modern research directions, and addressing specific social and economic needs.

The report highlights challenges related to financial stability, including the impact of COVID-19, and the need for prudent economic and budgetary policies. Noteworthy performance indicators include the increased number of patents, copyrights, and researchers involved in national and international projects. In addition, tThe report acknowledges the need for modern, efficient management, organizational innovation, competitiveness, and technology transfer to ensure the sustained success of INCDs in the face of economic, political, and financial uncertainties.

Regarding managerial performance, it has been highlighted that National Research and Development Institutes (INCDs) with a coherent strategic planning, considering the primary objectives and directions in research, integrated at both national and European levels of research, development and innovation, and aligned with the local socio-economic environment, have achieved effective management.

Research in Romania faces significant challenges, characterized by low performance, insufficient funding from both public and private sources, and a limited global impact. [1] The European Commission's evaluation (2022) highlighted recurring issues, including governance fragmentation, a focus on fundamental research, and underutilization of private potential, contributing to a non-coherent research sector [1].

In 2022, Romania occupied the 49th place among the 132 economies included in The Global Innovation Index 2022. The Global Innovation Index (GII) report is made by the World Intellectual Property Organization, "Cornell" American University and the French School of Management "INSEAD" and is published annually from 2007 (WIPO,2022) [1].

The poor performance of the Romanian research system is determined by the low level of RDI spending, underfunding, the fragmentation of RDI in the public sector and its insufficient orientation towards the needs of the industrial sector, the excessive priority given by some institutes to fundamental research, insufficient number of researchers [1]. Romanian public research institutes exhibit low collaboration rates with industries and struggle to commercialize R&D results.

At the European level, according to the European Innovation Scoreboard 2021, Romania is an emerging innovator and occupies the last position in the EU in terms of innovation performance [1].

III. GLOBAL PERSPECTIVES

The significance of research and development (R&D) in fostering productivity, growth, and competitive advantage within firms has been widely recognized. However, many European countries have experienced economic stagnation or setbacks due to inadequate investments in R&D. Evaluating the economic value generated by R&D achievements and the strategic infrastructure is crucial in assessing the role of R&D in creating economic value.

Efficient performance evaluation models are essential for enhancing productivity and fostering growth across various organizational levels, including personnel, teams, projects, departments, and the entire organization. However, evaluating and comparing R&D activities pose challenges due to their complex nature, characterized by risk, uncertainty, long-term development, and diverse output parameters.

The Triple Helix (TH) theory demonstrates the existence of nonlinear interactions in the innovation process in which actors from 3 helices are involved: universities/academia and research institutes form the first helix that conducts fundamental research; the

industries represent the second helix, producing commercial goods and services, and the government as the third helix, regulates the market [2].

The synergy among universities and research institutes, industry, state, and civil society is known as the Quadruple Helix (QH). QH is an improvement of the TH perspective, to which it adds the fourth dimension: civil society, media, and culture-based public [2]. Studies emphasize the importance of knowledge dissemination and its societal impact. Findings indicate that international cooperation positively impacts the research performance of public research institutes in terms of publications and citations, though technological transfer beyond national borders remains limited.

Scientific knowledge requires the collective effort of the scientific community to advance [4].

Collaboration within the scientific community is important and has a major role in advancing scientific knowledge and generating economic value. There are various aspects of this type of collaboration, including interdisciplinary cooperation, trust-building, and the exchange of ideas across different fields and geographical areas.

Public research institutes are identified as crucial players in knowledge dissemination and technological development, funded primarily by public funds and tasked with meeting societal needs. The literature suggests that research institutes can enhance their research outputs by forming close links with other organizations and engaging in interdisciplinary teams, both internally and externally. Collaboration with external partners, such as industries and universities, is shown to positively impact researchers' productivity and the overall scientific performance of research institutes.

Studies provide evidence that collaboration and internationalization of public research institutes activities have a positive effect on their scientific performance, both quantitatively and qualitatively.

Interactions with universities facilitate participation in new projects and provide opportunities for training and networking, positively impacting the research performance of public research institutes.

Collaboration with industries brings financial resources, technology transfer opportunities, and economic benefits, although it faces challenges such as intellectual property regulations and role conflicts.

Government involvement through funding and policy support enhances the quality of public research institutes' research and ensures continuous financing.

Interaction with civil society promotes social inclusiveness and evaluation of scientific knowledge based on public interest, leading to more efficient integration of technology producers and users.

The scientific performance of public research institutes is evaluated using bibliometric and technometric methods, which involve quantifying the number of articles published in ISI indexed journals (ISI_no), granted patents (PG_no), and citations in ISI indexed journals (ISI_cit_no) [2]. These methods are widely utilized due to their accessibility, accuracy, comparability, and ease of analysis through statistical models, despite some limitations in providing a comprehensive picture of R&D productivity.

ISI_no reflects the scientific contribution of a public research institute and its ability to generate and disseminate knowledge within the scientific community. It serves as a proxy for measuring scientific accomplishment and is influenced by factors such as career advancement imperatives and the pressure to publish.

PG_no assesses a public research institute's engagement in innovation and technology transfer activities, representing a convergence of novelty production, legislative control, and wealth generation. Patents are crucial drivers of productivity and growth, particularly in the context of academic capitalism. Furthermore, scientific performance is not solely measured quantitatively but also qualitatively.

ISI_cit_no serves as a proxy for the quality of published articles, reflecting scientific reputation and impact within the academic community. Factors such as funding, authorship, affiliation, and prior citations influence citation metrics.

Overall, these metrics provide valuable insights into the scientific and technological contributions of public research institutes and their impact on research advancement and innovation.

To test the hypothesis of the impact of collaboration and internationalization on the research performance of public research institutes, besides the dependent variables described before (ISI_no, PG_no and ISI_cit_no) several independent variables are included in the model [2]:

- *Number of memberships in research networks (RsNet)*: This variable represents the public research institute's participation in international research networks and databases, which facilitate the emergence of new ideas, stimulate research projects, and provide access to additional resources, ultimately enhancing R&D productivity.
- *Number of papers presented at international conferences (No_conf):* Conference participation serves as a channel for knowledge transfer and contributes to the development of social capital, positively impacting R&D performance.
- *Number of memberships in associations, clusters, technical and scientific boards, and committees (M_Assc_no):* This variable reflects the public research institute's networking activities, which are essential for collaboration and knowledge exchange.
- *Number of partnership projects/contracts (PartPr):* This indicator measures collaboration by tracking the number of research projects and contracts, which is crucial for attracting public and private research funding.

- *International partners (expressed as a weight in total partners - WIP):* This variable signifies the importance of international connections in enhancing research quality and stimulating new projects, particularly for researchers in developing countries.

To test the hypothesis, these independent variables were grouped into the four dimensions of the Quadruple Helix (QH) model: interaction with universities, industries, government, and civil society.

Interaction with universities is represented by the number of teaching assignments in universities (TA) and the presence of academic representatives in the public research institute's Board of Directors, reflecting collaboration in training and research activities.

Interaction with the private sector is illustrated by the existence of industry representatives in the Board of Directors and the number of granted patents (PG_no), indicating collaboration for technology transfer and innovation.

Interaction with the government sector is represented by the weight of public partners in total partners (WPP) and the presence of governmental representatives in the Board of Directors, highlighting partnerships to improve competencies and attract funding.

Interaction with civil society is captured through variables such as press coverage (PC) and the number of memberships in associations, clusters, technical and scientific boards, and committees (M_Assc_no), reflecting the public research institute's engagement with the public and non-profit organizations for knowledge exchange and dissemination.

Various studies have explored the performance evaluation of Research and Development (R&D) organizations, employing different models and methodologies. While some studies have utilized the Data Envelopment Analysis (DEA) approach, a few have adopted a DEA-ANP hybrid combining DEA with Analytic Network Process (ANP) model for assessing efficiency.

There are studies that aim to address the gap by introducing new criteria, such as researchers' satisfaction and customers' satisfaction, to provide a more comprehensive assessment of R&D organizations' performance [5].

Moreover, recent research has shown that factors like gender diversity can influence R&D efficiency, emphasizing the importance of considering various dimensions in performance evaluations. By incorporating a wider range of criteria and methodologies, one study aims to provide a more accurate and practical evaluation of R&D organizations' efficiency, contributing to the advancement of performance evaluation models in this field.

A total of 6 input indicators and 7 output indicators were considered in the model, with 17 organizations - Decision Making Units (DMUs) included in the study. Each period under examination spans one year.

The input indicators of the model are as follows: budget (I1), tax rate (I2), researchers' work experience (I3), education level of researchers (I4), dedicated time for researcher training and updating (I5) and degree of researchers' satisfaction with their job (I6).

The output indicators of the model are as follows: Hirsch indicator (O1), publications (O2), patents (O3), project operationalization rate (O4), total income (O5), degree of satisfaction of client (O6) and increase/decrease rate of client (O7).

While the DEA method categorizes DMUs into "efficient" and "inefficient" classes, the DEA-ANP method offers a more precise and practical calculation of efficiency values.

The study introduces novel indicators such as "researchers' work experience", "degree of satisfaction of researchers with their jobs in the organization", "project operationalization rate" and "client satisfaction" and suggests focusing on enhancing specific indicators as the ones listed above to improve overall efficiency in R&D organizations.

Scientists working at research institutes understand that they are part of a larger ecosystem beyond their own labs. The culture, standards, social cohesion, and funding of the institute are crucial for its success. Institutes worldwide focus on creating environments propitious to generating and utilizing new scientific ideas. Education plays a significant role, as scientists continuously learn from each other through various means like emulation, discussion, collaboration, and competition.

Most research institutes prioritize freeing scientists' time for research, offering little teaching but providing internal funding. They often promote interdisciplinarity and collaboration. Notably, research institutes have made significant contributions to groundbreaking discoveries. Success is measured by scientific contributions, publication output, grant funding, and staff satisfaction. Creating a positive research culture involves leadership setting values, while younger researchers influence direction and contribute energy. Physical structures and social events also play a role. Research culture impacts creativity and discovery, thus institutions focus on nurturing it. Crafting a successful research environment requires collaboration, support, and inclusivity, recognizing contributions from all members.

The success of a research institute is influenced by various factors, forming a "golden triangle" comprising core facilities, supportive administration, and research group [6]. While there's no one-size-fits-all formula for an ideal institute, every aspect contributes to nurturing the next generation of scientists and their discoveries.

To maximize success within the golden triangle, research institutes should focus on several key concepts [6]:

Effective Feedback Mechanisms: Institutes should establish internal and external feedback mechanisms to continually evolve and optimize their organization and scientific endeavors.

Supportive Administration: An efficient and communicative administration with a deep understanding of research culture is essential to enable scientists to focus on their research.

Promoting Plug and Play Research: Institutes should invest in state-of-the-art facilities and operational infrastructure to facilitate research activities efficiently and effectively.

Building a Holistic Research Environment: Creating a supportive research culture that empowers scientists to develop and realize their potential is crucial for maximizing success.

Recruitment is a critical aspect of research institutes, impacting both scientific endeavors and organizational culture. Institutes may employ different recruitment strategies, from internally driven processes to external assessments, each with its benefits and risks. Once hired, fair remuneration, additional perks, and dual hiring options can enhance recruitment outcomes.

The institute's size, group size, and focus on technology are key considerations in recruitment and organization. Additionally, managing interdisciplinarity within an institute is essential for fostering collaboration while avoiding fragmentation.

Technology transfer and training are crucial for advancing discoveries and nurturing talent within institutes. Technology transfer systems manage intellectual property and promote entrepreneurial activities. Training programs equip researchers with essential skills. Mentorship plays a vital role in career development and addressing research misconduct.

Building an inclusive environment that values diversity fosters creativity and innovation. Instituting policies for equality, diversity, and inclusion at all levels is essential, with high-level support and dedicated funding. Diverse perspectives enrich the research culture and contribute to scientific excellence. It's crucial to acknowledge and address mental health and well-being among institute staff to maintain a positive research culture.

Table 1 Key ingredients for a successful research institute. [6]

Organizational component	Key ingredients
Funding review process	• Individual principal investigator-based review or collective (e.g., departmental) reviews depending on the institute • Review process designed to promote collaboration and interdisciplinarity • A carefully appointed scientific advisory board • A transparent and clear process
Administration and corporate services	• Proactive service mindset, customer-friendly • Fast turnaround and agility • Transparency in performance • Buy in to the institute's vision • Clear two-way communication channels
Core facilities	• Proactive and transparent user data distribution • Rapid training • Equipment shared across the institute • Fair governance • Commitment to career pathways, acknowledgement in papers
Technology transfer and innovation teams	• Management of intellectual property, external partnerships, and patents • Legal and business counsel • Promotion of entrepreneurship in researchers
Training	• Train scientists at all levels across the institute • Research methods and cutting edge techniques • Holistic skills: communication, research management, leadership, etc.
Faculty recruitment	• Transparency • Internal or external recruitment processes (and measures that counterbalance any potential negative consequences) • Attractive packages • Long-term versus short-term considerations • Distribution of experience
Institute culture	• Transparency in operations and management/governance, recruitment, packages, salary, space, and platform access • Promote collaboration and creativity by fostering an open research culture (e.g., open seminars with unpublished work, retreats, funding mechanisms that promote collaboration) • Provide training at all levels: scientific as well as communication and leadership • Enable people to call out bad behavior (e.g., bullying, scientific fraud), with clear escalation routes and consequences, even for highest levels of management • Culture of allowing mistakes • Build diversity in the workforce at all levels based on merit • Supporting needs of diverse groups (parents, religious groups, individuals with disabilities, etc.) in order to build truly inclusive environment • Senior leadership buy-in to demonstrate commitment from the top

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In addition to the challenges already mentioned - including funding constraints and the impact of global events such as the COVID-19 pandemic - research institutes also face other challenges in today's rapidly evolving landscape, such as climate change and the integration of artificial intelligence (AI) [6].

The climate crisis presents both operational and psychological challenges for institutes, requiring them to implement policies to reduce carbon emissions and address the psychological effects of climate change on staff. Additionally, the increasing integration of AI into research processes offers opportunities for transformative insights but requires careful consideration and involvement of all staff in decision-making.

Despite efforts such as the Europe 2020 strategy, many European Union members have not met R&D targets. The Multiannual Financial Framework for 2021–2027 [7] places a strong focus on innovation. The measurement of R&D achievements is crucial, with data envelopment analysis (DEA) being a common approach, although criticisms exist regarding traditional indicators. Sustainable development requires innovation, and objective measurement of R&D achievements is essential for decision-makers and policymakers. Economic efficiency in terms of maximizing outputs with minimal inputs is a key focus [8].

For nine EU countries (Austria, Bulgaria, Cyprus, Denmark, Germany, Latvia, Luxembourg, Malta, and the Netherlands), both the score of pure technical efficiency and that of scale efficiency are maximum for all three intervals analyzed (2011-2012, 2013-2014, 2015-2016) [9].

There are countries that excel both in terms of transforming human and financial resources into intermediate output but also in terms of transferring these results to the economic sector (Germany, Italy, Malta and Portugal) [9].

IV. EXAMINING THE IMPACT OF THE FRAUNHOFER GESELLSCHAFT (FHG)

The German science system is globally recognized for its excellence, producing cutting-edge knowledge, fostering its application, and contributing to various societal and economic goals.

Universities and research institutions are expected to promote interdisciplinary collaboration, internationalization, and diversity. Political and societal demands for accountability have led to a focus on demonstrating the impact of research beyond mere output.

Fraunhofer-Gesellschaft (FhG) is committed to delivering impacts across these dimensions.

The Fraunhofer Gesellschaft, established in 1949, is a prominent public non-profit organization dedicated to advancing applied research in Germany. Initially formed to aid in the post-WWII reconstruction of the industrial sector, it serves as a bridge between basic research and industrial applications. Over the years, it has grown significantly, evolving from nine institutes with a modest budget in 1959 to becoming the largest non-profit organization for applied sciences globally.

With 72 centers and an annual budget of €2.3 billion, the Fraunhofer Society promotes innovation and technology transfer, bridging academia and industry.

Existing research mainly focuses on economy-wide treatments and pre-existing datasets, such as financial incentives and intellectual property protection's effects on R&D and patenting. However, there's a gap in knowledge regarding the impact of policies involving public sector participation in innovation and their effects on variables like productivity and employment. Unlike traditional innovation policies, FhG's aim is to provide technological solutions to specific company problems, rather than solely focusing on patent development.

Studies indicate a strong causal effect of contracting with FhG on turnover and productivity growth. Furthermore, the impact of FhG seems to be heterogeneous in characteristics of the participating firm as well as the project.[10].

An overview of the FhG interactions with firms from 1997 to 2014 [10] shows that approximately 6,500 projects were initiated per year, with a peak of 8,800 in 2009. The average project duration is one year and eight months, yielding around €37,000 in FhG revenue. A significant portion (26.55%) of projects report no registered revenue. Most firms collaborate with FhG once (42%), while 31% engage in more than three projects, and 90% of projects involve less than €100,000 in revenue.

According to the studies, the long-term effects significantly surpass the short-term impacts, with firms experiencing substantial increases in turnover and value added per employee over the 15-year period.

Econometric models reveal that increased collaboration with FhG correlates with higher turnover and productivity growth for companies. Interactions aimed at developing new technologies have a more substantial impact than those focused solely on implementing existing ones. Moreover, FhG's economic impact extends beyond direct effects, influencing macroeconomic productivity [12].

Recent analyses, using refined methodologies and additional data sources, further corroborate the substantial economic benefits of research organizations like FhG, highlighting their pivotal role in driving innovation and economic growth.

According to *A microeconomic perspective on the impact of the Fraunhofer-Gesellschaft* from 2022 [12], scientific institutions like the Fraunhofer-Gesellschaft play a crucial role in political, strategic, and economic decision-making, with stakeholders seeking to understand and evaluate the impact of investments. FhG has proactively assessed its economic and technological influence, its role in training young scientists, and its contribution to emerging technologies. Since 2016, FhG has commissioned

studies to delve deeper into its impact, focusing on economic effects and collaborations with industry, particularly small and medium-sized enterprises. The organization's mission emphasizes collaboration with industry to drive innovation for societal and economic benefit, positioning itself as a key player in the innovation system. There's a growing societal and political expectation for research institutions to address societal challenges, a goal Fraunhofer actively incorporates into its operations.

This study from 2022 Fraunhofer ISI report aims to assess the impact of collaborating with Fraunhofer Institutes and other German public research organizations (PROs) on companies' economic and innovation performance. Descriptive statistics, correlation analyses, and multivariate models were employed to analyze the relationship between research institution collaborations and company success.

Several databases were used:

1. BvD Orbis;[3]
2. The German Manufacturing Survey (GMS);[4]
3. Funding Catalog (Förderkatalog);[5]
4. Fraunhofer's contract data (SIGMA);[6]
5. Patent data and additional financial indicators[7]

Matching procedures like *matching using Levenshtein distance algorithm*[8], *Time-window consideration*[9], *Matching with patent data*[10] and *Matching with financial data from Amadeus*[11] were involved in the study aiming to link information from various datasets, ensuring accurate analysis of cooperation between companies and research organizations.

According to the results of the study, the number of projects and the annual budget of contract research with industry have generally increased between 2010 and 2019. Despite the growth in the number of employees at Fraunhofer Institutes during this period, the compound average annual growth rate for projects, budget, and employees remains positive. The average size of each project has slightly increased in nominal terms but decreased in real terms. However, the average industry project budget per employee has remained relatively stable over time. These trends indicate that the share of national industry contracts in FhG's total budget has increased, and FhG has effectively maintained the average budget of these contracts while growing in terms of employment, demonstrating success in fulfilling its mission of conducting research with and for industry [12].

The structure of contracted projects reveals that over two thirds (68%) of the companies involved are small and medium-sized enterprises (SMEs), with an additional 20% falling within the broader definition of the German "Mittelstand" (mid-tier business) with less than 5,000 employees. Large enterprises, with over 5,000 employees, make up only 5% of the companies. This distribution underscores FhG's mission of collaborating primarily with SMEs and Mittelstand. Although large enterprises represent a small percentage of the companies, their collaboration projects have a significantly higher average budget [12].

Publicly funded joint projects with industry play a crucial role in knowledge and technology transfer, often involving multiple industry partners and sometimes other research institutions. These projects typically focus on pre-competitive research, addressing medium- to long-term challenges for industry. For FhG, these projects serve as a bridge between basic research outcomes and potential industrial applications, aligning with its mission.

Overall, cooperation with the FhG in R&D projects is associated with innovation-driven, globally oriented firms with a focus on modernization and technological advancement in manufacturing [12].

V. DISCUSSIONS AND CONCLUSIONS

Despite facing challenges such as financial constraints R&D institutes of Romania have shown continuous growth in scientific and technological performance. Efforts to attract European and international funds, enhance collaboration with the private sector, and foster a positive research culture have been notable. However, there are persistent challenges including low funding, governance

[3] This database contains information on 2.4 million companies in Germany, including location, sector, and ownership structures. It covers all sizes of firms from micro to large companies and forms the basis for large-scale analyses, primarily for recent years; [12]

[4] This survey captures techno-organizational innovations in manufacturing at the level of individual manufacturing sites, providing data on performance increases. It covers the entire manufacturing sector in Germany and is conducted every three years, with data from 2012, 2015, and 2018 being used in this report; [12]

[5] This catalog lists collaborative research projects between companies and PROs, including universities. It contains information on nearly 270,000 projects, with approximately 120,000 being joint research projects, starting from 1968 and being particularly comprehensive from 2000 onwards; [12]

[6] This internal FhG database provides information on contracted research projects from firms, covering the period from 2010 to 2018. It allows the separation of contract research from joint research projects; [12]

[7] Patent filings, including transnational patents and filings to the German Patent and Trademark Office, are matched to the datasets. Additionally, financial indicators such as EBIT and Return on Equity are sourced from Bureau van Dijk's Amadeus database to provide further information beyond what is available in SIGMA or the Funding Catalog. [12]

[8] Company names from SIGMA and the funding catalog were matched with those in the Fraunhofer GMS and BvD Orbis datasets using a string-matching algorithm based on Levenshtein distance. This measures the similarity between two text strings, enabling identification of matches even with variations in spelling or formatting. A similarity threshold of 0.89 was set to optimize precision and recall. [12]

[9] To avoid bias, a time-window of three years (five years for the Orbis dataset) was applied to ensure that cooperation instances occurring several years ago do not influence the results.

[10] Similar matching procedures were applied to merge companies from the GMS and Orbis datasets with the EPO Worldwide Patent Statistical Database (PATSTAT), focusing on the share of manufacturers filing for patents during specific time frames.

[11] For firms surveyed in the GMS, VAT numbers were used to search for financial indicators in the Amadeus database. For firms without VAT numbers, a string-matching algorithm on company names was applied. This two-step process enabled the assignment of a BvD-ID to a significant proportion of surveyed firms, though the coverage of financial information varied across waves and datasets.

fragmentation, and a focus on fundamental research, contributing to Romania's limited global impact in research and innovation.

The country's position in international innovation rankings remains relatively low, reflecting the need for significant improvements in R&D spending, collaboration with industries, and commercialization of research outcomes.

Moving forward, addressing these challenges through coherent strategic planning, increased funding, and a stronger focus on applied research aligned with industrial needs will be crucial for enhancing Romania's research and innovation landscape and fostering sustainable economic growth.

Research institutes play a pivotal role in advancing scientific knowledge and innovation. Creating a positive research culture, promoting interdisciplinary collaboration, and providing state-of-the-art facilities are crucial for nurturing talent and maximizing success. Effective recruitment strategies, technology transfer mechanisms, and training programs further support research endeavors and talent development.

The global perspective on research and development (R&D) underscores its crucial role in fostering productivity, growth, and competitive advantage within organizations. International collaboration and knowledge dissemination play vital roles in enhancing R&D performance, as evidenced by increased publications, patents, and project operationalization rates. Also, the Triple Helix and Quadruple Helix models highlight the interconnectedness of academia, industry, government, and civil society in driving innovation and economic development.

Statement regarding the ethics of using AI software

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