The Role of Industrial Clusters in Enhancing Innovation: An Analysis of the Biotechnology Experience in Germany

BENSAADI Djamel[1♦], BOUGABA Ouerdia [2]

[1] University of Bordj Bou Arreridj, LEZINRUL, (Algeria), djamel.bensaadi@univ-bba.dz
ORCID: https://orcid.org/0009-0007-6711-3121

[2] University of Bordj Bou Arreridj, LEZINRUL, (Algeria), ouerdia.bougaba@univ-bba.dz
ORCID: https://orcid.org/0009-0009-3707-6256

Received: 26/03/**2025** **Accepted: 28/06/2025** **Published:20/07/2025**

Abstract:

This study aims to examine the role of industrial clusters in fostering innovation, with a focus on the biotechnology sector in Germany. Using a descriptive approach for literature review and an analytical approach to assess the impact of clusters on research and development and analyze supportive policies, the findings indicate that these clusters contribute to transforming scientific knowledge into industrial applications, thereby enhancing Germany's competitiveness in the sector. The study also highlights the importance of innovation support policies through industrial clusters while identifying several challenges that may hinder innovation opportunities. The study recommends strengthening strategic partnerships, developing sustainable financing policies, and improving the knowledge transfer environment to ensure the sustainability of innovation.

Keywords : Industrial Clusters, Innovation, Biotechnology Sector.

♦ **Corresponding author**

I- Introduction:

Over the past few decades, the dynamics of global economic competition have undergone a profound transformation, with innovation emerging as a pivotal determinant in bolstering the competitive advantage of both nations and enterprises. Knowledge, technological advancements, and research and development have solidified their roles as the cornerstone drivers of sustainable economic growth.

Within this framework, industrial clusters have risen to prominence as critical hubs for fostering innovation, facilitating collaboration between firms and research institutions in environments that promote knowledge exchange, product innovation, and entrepreneurial activity.

Germany exemplifies a leading paradigm in this domain, having strategically utilized advanced industrial policies to strengthen its industrial cluster framework, particularly within the biotechnology sector. This sector has become a vital catalyst for innovation in the fields of pharmaceuticals and life sciences. German industrial clusters have been instrumental in bridging the gap between scientific research and commercial application, thereby cementing Germany's status as a global leader in biotechnology.

Research Problem:

The study revolves around the following key research question:

How have industrial clusters contributed to fostering innovation in Germany's biotechnology sector?

Research Objective:

This research seeks to rigorously evaluate the function of industrial clusters in driving and amplifying innovation, with a specific emphasis on Germany's biotechnology sector as a case study. Furthermore, it aims to distill actionable insights from this analysis to foster sustainable industrial development.

Research Methodology:

To thoroughly investigate the subject, this study adopts a descriptive methodology, combining an in-depth literature review with an analytical analysis of supportive policies and the effects of clusters on research and development outcomes.

1- Literature Review.

1.1 Industrial Clusters: Theoretical Foundations and Policy Implications

The evolution of industrial societies is intricately connected to the spatial arrangement and concentration of economic activities within geographically defined local or regional ecosystems. This phenomenon, frequently identified as a enduring structural trait, persists despite the increasing globalization of economic systems. Empirical evidence reveals that local production and innovation networks not only demonstrate resilience but also achieve global expansion, forming a vital framework for the spatial structuring of industrial activities and their associated innovation dynamics.

1.1.1 Conceptualizing Industrial Clusters.

The notion of industrial clusters—defined as spatial concentrations of interconnected economic activities—has become increasingly prominent in academic discourse and policymaking. This theoretical framework has played a pivotal role in shaping modern industrial and innovation policies, particularly in light of the proven success of high-technology clusters, such as Silicon Valley and Route 128 in the United States, alongside Italy's highly specialized industrial districts. These examples have driven a reassessment of conventional industrial policy frameworks across various economies, resulting in a strategic focus on promoting interdependencies and enhancing competitiveness through networked collaborations. Notable instances include Japan's industrial innovation ecosystems, the European Union's initiatives for cluster-based competitiveness, and China's expansive technological parks.

The term "industrial cluster" is most prominently associated with the scholarship of Michael Porter, whose seminal work, The Competitive Advantage of Nations (1990), established the groundwork for its systematic examination. Porter articulated the following definition:

"A cluster constitutes a geographically proximate assemblage of interconnected enterprises and associated institutions within a specific domain, bound by shared characteristics and complementarities" (Porter, 1998, p. 10).

From this vantage point, industrial clusters are not merely co-located entities; rather, they collectively propel innovation and competitive advantage through their intricately interlinked operations.

Building upon this foundational framework, Rosenfeld (2002) introduced a complementary perspective, emphasizing the significance of systemic interdependencies within spatially delimited industrial ecosystems:

"A cluster represents a concentration of analogous firms—sufficient in number to attract specialized services, resources, and suppliers—that maintain systematic relationships grounded in integration within a circumscribed geographic area" (Rosenfeld, 2002, p. 08).

Rosenfeld's conceptualization underscores the critical role of cluster density and the structural complementarity of its constituent entities as pivotal determinants of cluster efficacy.

Expanding on this discourse, Cooke and Huggins (2003) introduced a value chain-oriented dimension to cluster analysis, proposing the following definition:

"A geographical concentration of interconnected institutions engaged in economic value chains, functioning within an environment supported by robust infrastructure, pursuing a unified strategy, and targeting a shared market" (Cooke & Huggins, 2003, p. 52).

Furthermore, Zimmer (2012) highlighted the contextual variability inherent in cluster definitions, noting that their structural composition and operational dynamics depend on factors such as the characteristics of participating entities, market orientation, and the prevailing political-economic context (Zimmer, 2012, p. 52). Despite such variability, the literature identifies three core dimensions that collectively delineate the cluster paradigm:

- **Economic Dimension**: Clusters consist of firms and institutions operating within the unified sectoral framework and value chain, promoting specialization and functional synergies.
- **Relational Dimension**: Clusters are characterized by intricate inter-organizational networks—spanning both horizontal (peer-to-peer) and vertical (supply chain) relationships—that facilitate collaborative synergies and knowledge dissemination.
- **Geographical Dimension**: Clusters derive their competitive advantage from spatial concentration, with their efficacy hinging on the density, proximity, and intensity of interactions among co-located entities.

By synthesizing these economic, relational, and geographical dimensions, the industrial cluster framework emerges as a strategic model that not only bolsters regional competitiveness but also acts as a catalyst for innovation-driven economic transformation.

1.1 The Concept of Innovation

The concept of innovation carries a positive connotation, as it is often perceived as a replacement for outdated or traditional practices. Many definitions emphasize a common characteristic: novelty.

The initial theory of innovation was introduced by the economist Joseph Schumpeter in his book *The Theory of Economic Progress*, published in 1912, where he discussed the idea that innovation consists of introducing a new product that performs a new function. (Yan Xu et al, 2024, p. 1352)

Van de Ven (1986) defines innovation as:

"*A new idea, which may be a recombination of existing ideas, a revision of an existing organizational framework, or an original approach or method perceived as new by the individuals concerned*" (Le Roy F., 2012, p. 04). Innovation was also defined by **Urban et al. (1996)** as: "*A product that shifts the market structure, represents a new technology, requires consumer learning, and induces behavior change*." (Serena M., J. González, 2021, p. 58)

The most widely accepted standard definition of innovation comes from the *Oslo Manual*, published by the Organisation for Economic Co-operation and Development (OCDE, 2005). According to this definition:

"Innovation is the implementation of a new or significantly improved product (good or service), a new marketing method, or a new organizational method in business practices, workplace organization, or external relations" (OCDE, 2005, p. 20).

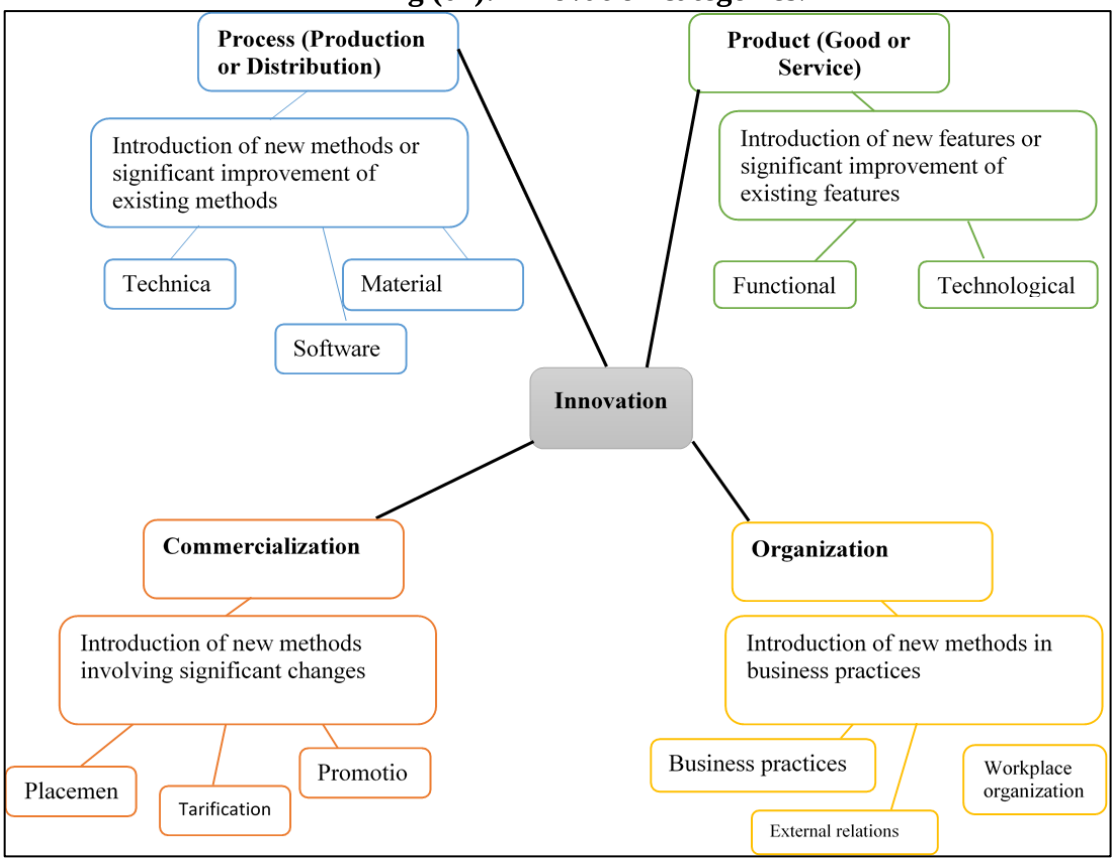
This definition highlights the multidimensional nature of innovation, encompassing technological advancements, business strategies, and organizational transformation.

Similarly**, Loilier &Tellier** (2013) proposed an innovation matrix that aligns with the previously mentioned typology, emphasizing that innovation is influenced by the intensity of technological change.

However, they introduced an additional dimension related to transformation at the business model level, which leads to what is known as disruptive innovation—the adoption of a new technology that renders existing business models obsolete or outdated (Benchrifa, 2021, p. 545).

This leads to what is known as disruptive innovation, which involves the adoption of a new technology that renders existing business models obsolete.

Fig (01): Innovation categories.



Source: Manual OCDE, 2005.

2. Innovation in Industrial Clusters: A Necessity, Not a Choice.

Industrial clusters play a vital role in enhancing firms' innovation capabilities, thereby improving productivity (Wrobel, 2015, p. 290) and boosting national competitiveness (E. Turkina, Ari V. Assche, 2018, p. 706). Innovation and knowledge serve as key elements in the growth dynamics of nations, regions, industries, and firms. These dynamics are significantly influenced by the competitive environment in which firms operate, driven by both pressures and incentives.

In this context, innovation and learning processes arise from interactions shaped by economic, social, institutional, and political factors (Boschma, 2015, p. 749).Therefore, innovation research has moved away from focusing solely on the internal dynamics of individual firms and has increasingly emphasized the relationships and interactions between firms and their external environment. (Zhang, P., Yu, Y, 2024, p. 291)

2.1 Empirical Studies on the Role of Clusters in Enhancing Innovation in Firms.

Numerous studies have highlighted industrial clusters as a critical driver of innovation due to the positive externalities they generate. These externalities manifest in various forms, including labor mobility, knowledge diffusion, and competitive pressures; all of which contribute to fostering innovation activities.

- **Baptista & Swann (1998)** explored whether firms located within industrial clusters were more inclined to innovate compared to those outside such clusters. Examining data from 248 UK manufacturing firms between 1975 and 1982, they determined that firms situated in industrial clusters—and particularly those excelling well within their respective industries—were significantly more prone to engage in innovation (Baptista, Swann, 1998).

- **Beaudry & Breschi (2003)** provided a more nuanced perspective, demonstrating that the presence of knowledge resources (e.g., patents) and innovative firms within a cluster exerted a strong positive effect on innovation. Conversely, they ascertained that the presence of non-innovative firms and high levels of employment concentration within the same industry could impede innovation. Their findings indicate that mere industrial concentration does not invariably foster innovation; rather, the presence of pioneering firms within the cluster is crucial to promoting positive innovation dynamics (Beaudry, C., & Breschi, S., 2003).
- **Innobarometer (2004)**, a European survey of firms, revealed that companies operating within clusters exhibited higher levels of innovation compared to those outside. This was primarily attributed to intense competitive pressures within clusters, which compel firms to continuously innovate to sustain a competitive edge. The study reported that 80% of firms in Turkey, 69% in Spain, 66% in Slovakia, and 63% in Ireland encountered strong competitive pressures within their respective clusters (European Commission, Innobarometer 2004, 2004). Furthermore, the report underscored that innovation clusters extend beyond the development of new products and the improvement of existing ones; they also encompass the adoption of advanced production technologies and the optimization of manufacturing processes.
- **Bell (2005)** investigated the impact of industrial clustering and network relationships on firms' innovation behavior and performance, focusing on Canadian investment fund firms. His findings confirmed that industrial clusters significantly enhance firm-level innovation. Moreover, the study highlighted that the effectiveness of networks in driving innovation hinges on the presence of strong institutional or managerial linkages (Bell, 2005).
- **Folta et al. (2006)** examined the relationship between cluster size and innovation performance, concluding that innovation levels escalated with cluster size up to a threshold of 66 firms. Beyond this point, the benefits of clustering began to diminish, suggesting the existence of an optimal cluster size, particularly in the biotechnology sector (Folta, T. B., Cooper, A. C., & Baik, Y. S., 2006).
- **Yoshino (2011)** evaluated industrial clusters in five Sub-Saharan African economies (Cameroon, Ghana, Kenya, Mauritius, and Rwanda) and determined that firms within clusters surpassed comparable firms outside clusters in terms of productivity, sales, and market access (Yoshino, 2011).
- **Fang (2018)** utilized employment, establishment, and patent data from Maryland to assess firm learning and selection processes within clusters. His findings indicated that firms in clustered industries exhibited higher levels of innovation. In a subsequent 2019 study, Fang further investigated firm-level innovation dynamics in Maryland's industrial clusters, revealing significant variation in how firms within these clusters contributed to innovation, depending on knowledge spillover intensity (Fang, L, 2018).
- **Kim et al. (2023)** analyzed factors influencing firms' innovation performance within clusters, emphasizing on the role of organizational diversity and knowledge spillovers. Their study found that diversity in firms' organizational structures and technological capabilities positively impacted innovation outcomes by facilitating valuable opportunities for cross-disciplinary knowledge exchange and collaborative innovation (Kim, 2023).
- **Kostadinović et al. (2023)** studied the impact of both internal and external cluster interactions on innovation performance, as well as the effect of innovation performance on organizational performance. Using path analysis, the study also assessed the influence of relational embeddedness—both internal and external—on

innovation success and its subsequent impact on organizational performance. The results revealed direct, positive, and statistically significant relationships between most of the examined variables (Ivana Kostadinović, 2023).

- **Horzela-Miś (2024)** examined the critical role of industrial clusters in strengthening firms' competitiveness and fostering innovation. Drawing on tested hypotheses, the study demonstrated that clusters operate as dynamic ecosystems that promote collaboration, enhance operational efficiency, and accelerate innovation. The findings revealed that firms embedded within clusters exhibit significantly higher levels of innovation than independent firms, owing to an enabling environment characterized by resource sharing, knowledge diffusion, and intensive collaboration among economic actors (HORZELA-MIŚ, 2024).

Thus, industrial clusters function as a catalyst for innovation by fostering both collaboration and competition among their constituent entities. The geographic proximity within clusters creates an optimal environment for knowledge exchange and continuous learning. Firms operating within a cluster benefit from lower costs associated with acquiring, accessing, and sharing information, which enhances the transformation of knowledge into tangible innovations.

Moreover, the transfer of technological knowledge within clusters proceeds more efficiently due to its tacit and non-codified nature, thereby amplifying the dynamism of local innovation. Additionally, the stage of cluster development plays a crucial role in shaping the level of innovation among affiliated firms. The life cycle of a cluster influences knowledge recombination processes, contributing to the acceleration of innovation at each stage of its growth and evolution.

2.2 Factors Influencing Innovation Generation at the Industrial Cluster Level.

Industrial clusters play a pivotal role in fostering innovation by enabling firms within them to benefit from various externalities, including knowledge acquisition, access to new markets, reduced production and R&D costs, and workforce training. However, the effectiveness of these benefits depends on several factors, including the regional context, which shapes the reputation of firms within the cluster, as well as inter-organizational relationships and interactions with firms both within and outside the region (Bathelt, 2004). Collective strategies and public policies supporting innovation are instrumental in building a regionally competitive advantage. Clusters can develop a unique cultural identity that fosters entrepreneurial activity and knowledge exchange, though cultural insularity may obstruct the inflow of innovations (Asheim, 2011). In this regard, innovation-oriented culture plays a critical role, as governments implement policies that support regional economic development, such as promoting technological innovation, fostering partnerships between firms and universities, and enhancing human capital, all of which contribute to cluster competitiveness and long-term sustainability (Eraydin, 2016).

Additionally, geographical proximity facilitates knowledge transfer and trade, thereby enhancing the innovative capacity of clusters. However, this requires not only the absorption of external knowledge but also its internal dissemination and the promotion of collaboration among cluster actors. Such interactions help mitigate conflicts and generate mutual benefits (Drivas, 2015). Furthermore, continuous interaction among firms transforms knowledge into innovative products and solutions, where the ability to absorb and apply knowledge for commercial purposes becomes a key factor in achieving a competitive advantage.

Within this framework, governance plays a significant role in fostering innovation by reducing behavioral uncertainty and strengthening trust among stakeholders (Cassiolato, 2003). Infrastructure, financial, and human resources also serve as fundamental pillars for supporting innovation, as they provide advantages such as lower transaction costs, enhanced access to a skilled labor, and shared infrastructure (Lai, 2014). These factors establish an environment conducive to promoting economic growth and competitive sustainability, rendering clusters ideal for innovation.

3. Innovation Support Policies in German Industrial Clusters (Biotech Clusters)

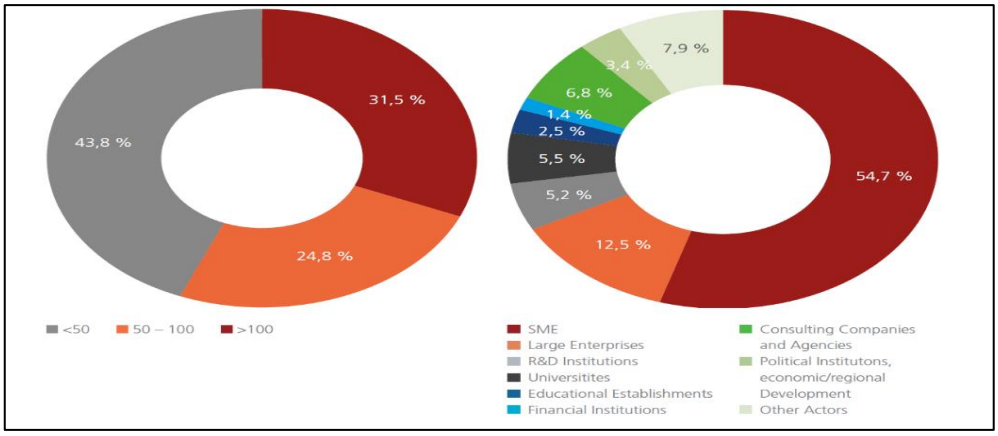
Germany's cluster policy, initiated in the mid-1990s, has been followed by the implementation of various support programs at both the national and federal levels. Since its inception, the cluster landscape has continued to evolve, adapting to global challenges.

3.1 The Cluster Landscape in Germany.

Germany's cluster landscape is highly diverse, encompassing numerous regional initiatives and national networks. The "Cluster Plattform Deutschland" database identifies 483 clusters spanning 37 technological and applied fields, with key sectors including production technology, clean technologies, automotive manufacturing, healthcare/life sciences, information technology/digital integration, and transport/logistics. Notably, over 66% of these clusters have existed for more than a decade (clusterplattform, 2024).

Among these, 105 cluster initiatives were launched, between 2015 and 2018, collectively involving more than 13,000 members, with an average of 125 actors per cluster. The number of entities within each cluster varies significantly, ranging from 7 to 554. Small and medium-sized enterprises (SMEs) constitute the largest participating group, with over 7,100 firms involved, followed by large companies, which account for more than 1,600 entities. Additionally, the cluster ecosystem includes approximately 675 research and development divisions, as well as around 720 research institutes and individual academic chairs at universities (Institute for Innovation and Technology, 2019, p. 09)

Fig (02): Classification of German Industrial Clusters and Their Components



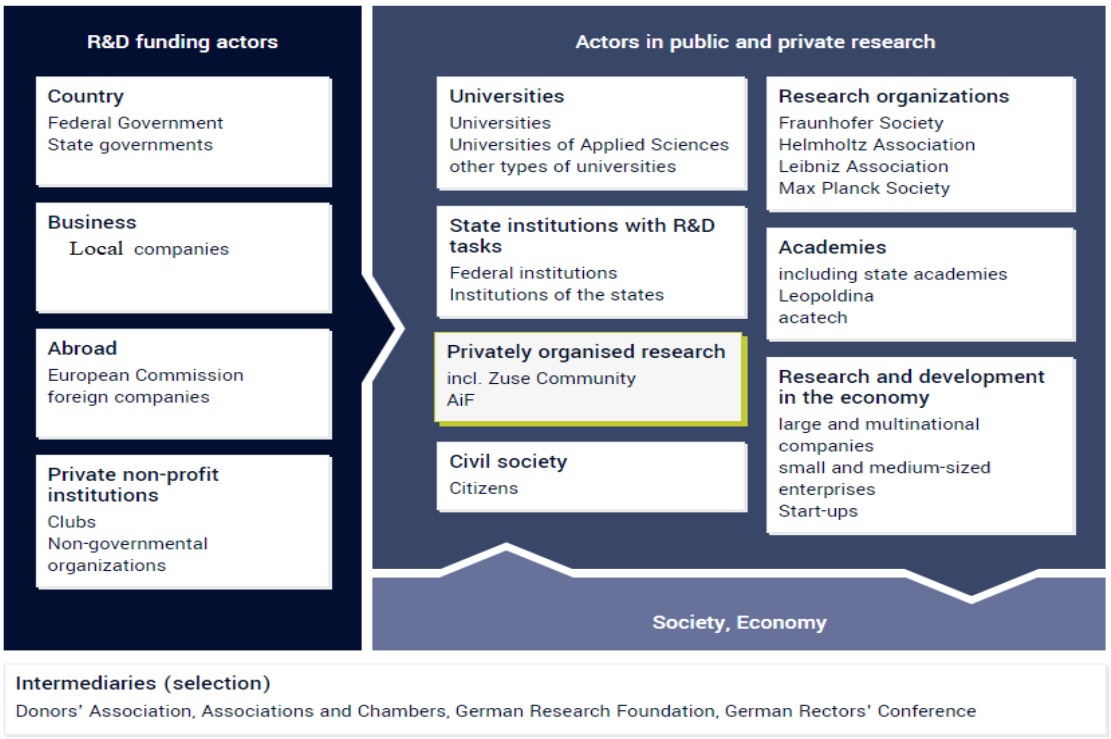
Source : (Institute for Innovation and Technology, 2019, p. 10)

Many countries have developed cluster policies and programs to enhance the impact of their research and innovation strategies, viewing them as a strategic tool for development rather than an end in themselves. In this context, Germany stands out as a leader in Europe, with its policy for supporting small and medium-sized enterprises (SMEs) focusing on increasing productivity and promoting innovation through close collaboration with regionally concentrated partners along the value chain.

3.2 Research and Development in Germany.

Germany ranks among the leading innovation-driven economies. In 2024, its performance reached 111.6% of the European Union average, thereby exceeding the 111.3% benchmark that defines strong innovators (European Commission, 2024, p. 75). The success of Germany's research and innovation system stems from its diversity and integration, with research and development (R&D) activities being conducted across a wide range of public and private institutions.

Fig (03): Actors in the German Research and Development System.



Source : (Federal Ministry of Education and Research, 2024)

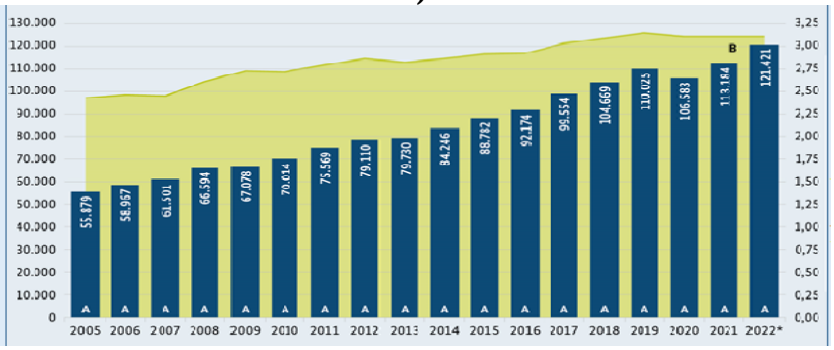
This diagram illustrates the diversity and excellence of Germany's research and development (R&D) system, which relies on multiple funding sources, including the federal government, state governments, local private sector contributions, and nonprofit organizations. This demonstrates the synergy between the state and society in supporting innovation. Additionally, funding is not confined to local sources but also encompasses international entities such as the **European Commission** and foreign companies, fostering global scientific collaboration.

On the research side, institutions range from universities and government research centers to major scientific organizations such as the **Fraunhofer Society, Helmholtz Association, and Max Planck Society**. Furthermore, structured private-sector research is undertaken through organizations like the **Zuse Community** and **AiF**, creating a comprehensive research environment.

R&D-in the economic sector- plays a fundamental role, with major corporations, medium-sized enterprises, and startups contributing significantly, ensuring the integration of scientific research with economic applications. Additionally, intermediary organizations such as the **German Research Foundation** and the **German Rectors' Conference** play a crucial role in coordinating efforts and strengthening links between various actors in the system.

In 2021, Germany's R&D expenditures reached a record level of **€113.2 billion**, according to final data. In 2022, this spending increased to **€121.4 billion**, making a significant contribution within the private sector, which increased its expenditure by **€6.0 billion (an 8.0% increase).** Additionally, the federal and state governments have elevated their R&D spending by **€2.2 billion (a 5.9% increase),** reflecting a continued commitment to advancing innovation and scientific progress (Bundesministeriums für Bildung und Forschung, 2024, p. 09) **.**

Fig (03): Evolution of Research and Development Expenditures in Germany (2005-2022) – Billion Euros



Source : (Bundesministeriums für Bildung und Forschung, 2024, p. 09)

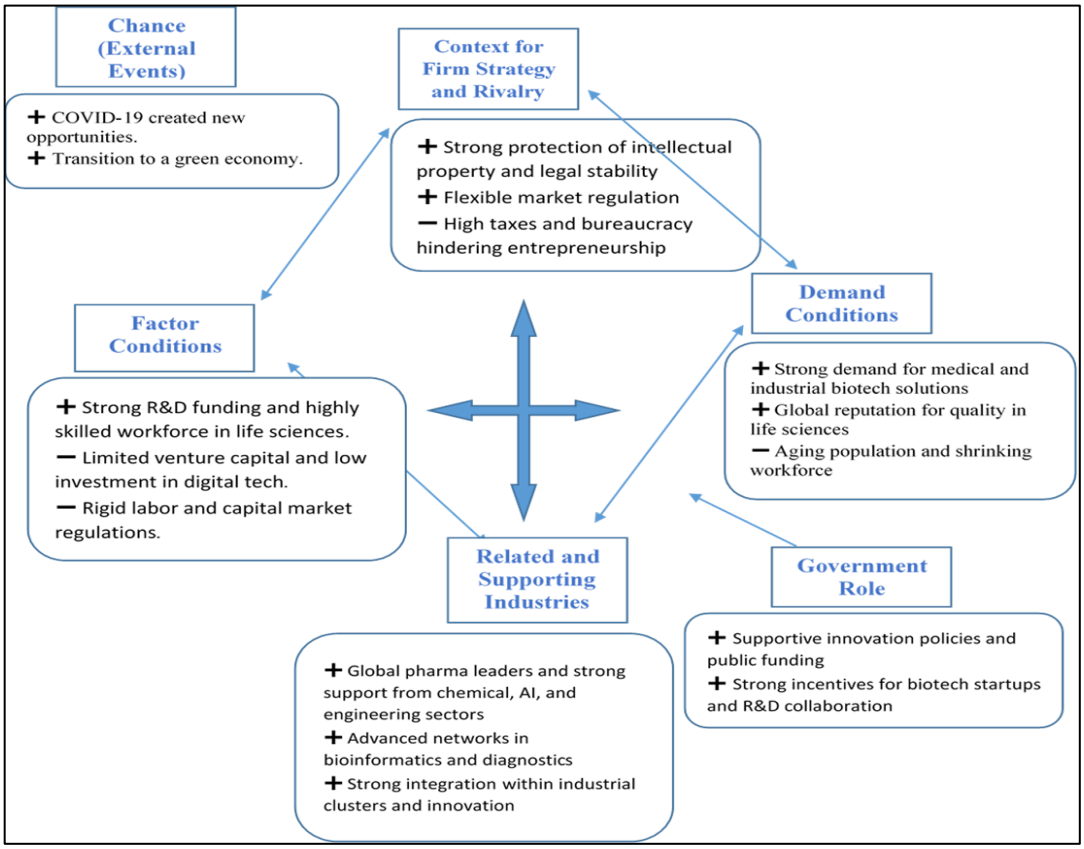
3.3 The Innovation Environment in German Biotech Clusters

Biotechnology functions as a key driver of innovation in the pharmaceutical industry, particularly in the development of new treatments and innovative diagnostic methods. Modern technologies and research tools have facilitated a deeper understanding of disorders, enabling strategies that address both causes and symptoms. The healthcare sector heavily relies on advancements in this field.

In the latest update on key biotechnology indicators published by the OECD (2024), a clearer picture emerges of the countries leading the way in this dynamic sector. Based on company count, the United States continues to dominate the global biotechnology landscape, boasting the highest number of active biotech firms (2,840). Germany ranks seventh globally and fourth in Europe, with a total of 798 active companies in the sector (OECD, 2025). This position places Germany in an increasingly competitive environment, especially as countries such as the United Kingdom, Belgium, France, China, and Canada continue to show strong and accelerating growth in biotechnology.

We use the Diamond Model theory, developed by economist Michael Porter in 1990, as an analytical framework to explain the competitive advantage of the biotechnology industry in Germany and its ability to succeed in international markets.

Fig (04):Porter's Diamond Model – Biotech Sector in Germany

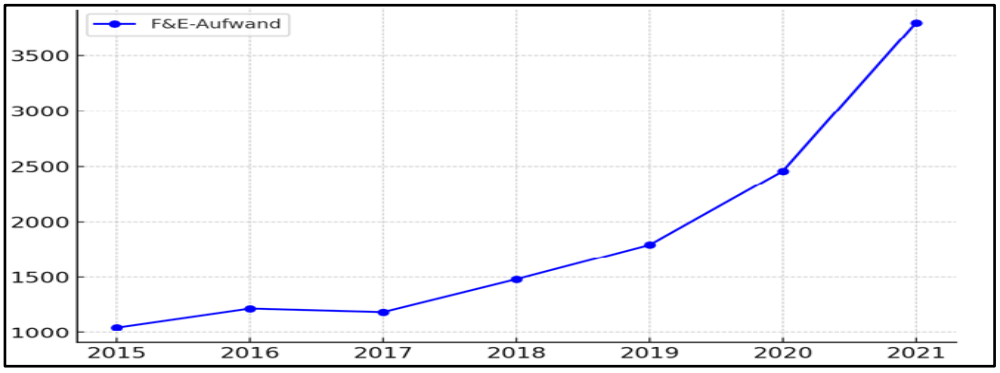


Source: Prepared by the researchers.

In order to make optimal use of its advantages to face global competition, and in light of the rapid growth of several countries such as the United Kingdom, Belgium, France, China, and Canada, Germany has established specialized biotechnology zones known as **"BioRegions"**, operate as specialized regional clusters that support modern life sciences. These clusters foster collaboration between universities, research institutes, and private-sector companies, establishing themselves as leading research and development centers in Europe over the past three decades. There are currently **30 biotech clusters**, hosting **774 institutions** (William MacDougall, GTAI, 2023, p. 01), with the majority located in the states of **North Rhine-Westphalia, Bavaria, and Baden-Württemberg**. These clusters have developed strong partnerships with other industrial sectors and maintain extensive international collaborations. They act as fundamental drivers of innovation by integrating academic and industrial expertise across the value chain within an advanced innovation ecosystem for life sciences. This environment includes universities, research centers, and non-academic research institutes affiliated with leading institutions such as the **Fraunhofer Society, Helmholtz Association, Leibniz Association**, and universities like **Technische Universität München (TUM), Hochschule Ansbach, Leibniz Universität Hannover, Universität Stuttgart,** and the **Innovation and Start-up Center for Biotechnology (IZB),** among others.

Germany's robust research and development (R&D) environment, coupled with diverse funding options, sustains high levels of research activity in the biotechnology sector. In **2020**, total annual R&D expenditures in this field exceeded **€2 billion**, reaching **€2.5 billion** (William MacDougall, 2022, p. 09). By **2021**, this figure had risen to **€3.8 billion**,

generating returns of **€26.3 billion**. Each year, institutions engage in thousands of research projects in collaboration with industrial and scientific partners, reinforcing Germany's



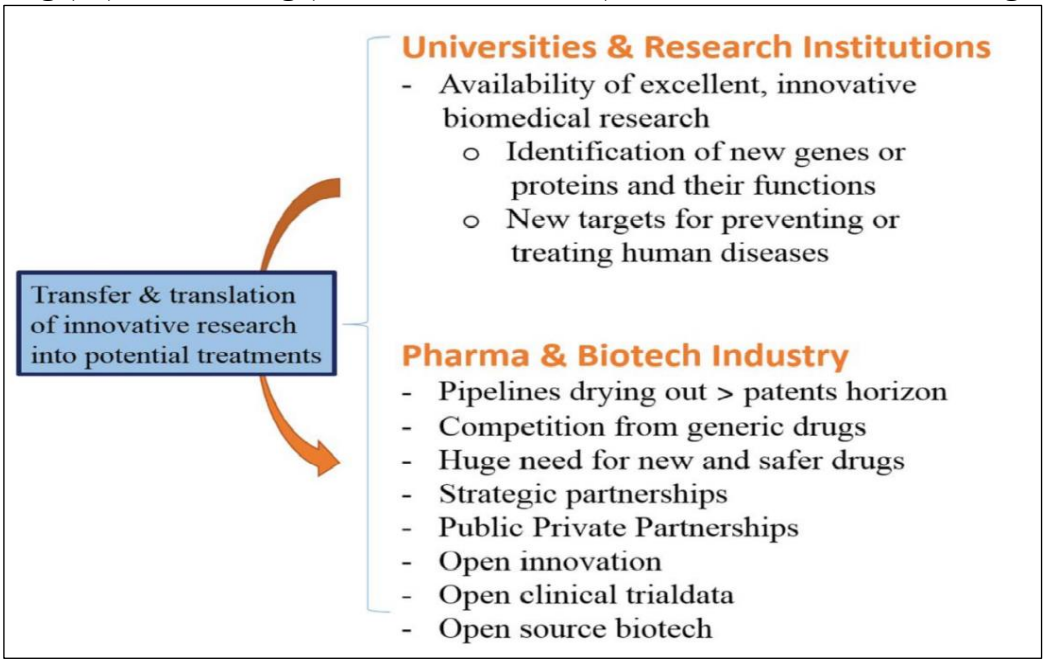
reputation as one of the world's leading environments for biotechnology innovation.

Fig (05): Evolution of R&D Expenditures in German Biotech Clusters (2015–2021) – Million Euros

Source : (William MacDougall, GTAI, 2023, p. 04)

According to **Debackere (2014),** institutions within biotechnology clusters demonstrate greater opportunities for innovation compared to those outside them**,** despite some similarities in company size and industry focus**.** This advantage arises from a complementary relationship between universities (scientific innovation) and pharmaceutical companies (competitive pressure)**,** which drives the translation of academic research and scientific discoveries into medical extracts and commercially viable therapeutic products**.**

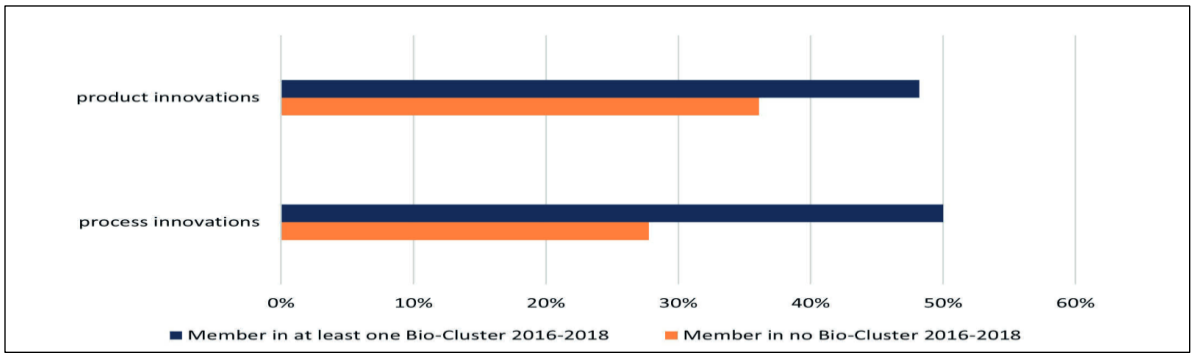
Fig (06): Translating (Innovative Academic) Research into Potential Drugs



Source : (Debackere, 2014)

This advantage results from the ease of access to vertical and horizontal networks, as well as the funding opportunities available within clusters. The data substantiate this argument, indicating that half of the companies within biotechnology clusters introduced innovations in products or processes at rates of 48% and 50%, respectively. In contrast, companies outside the clusters achieved a rate of 36% for product innovations and 28% for process innovations only.

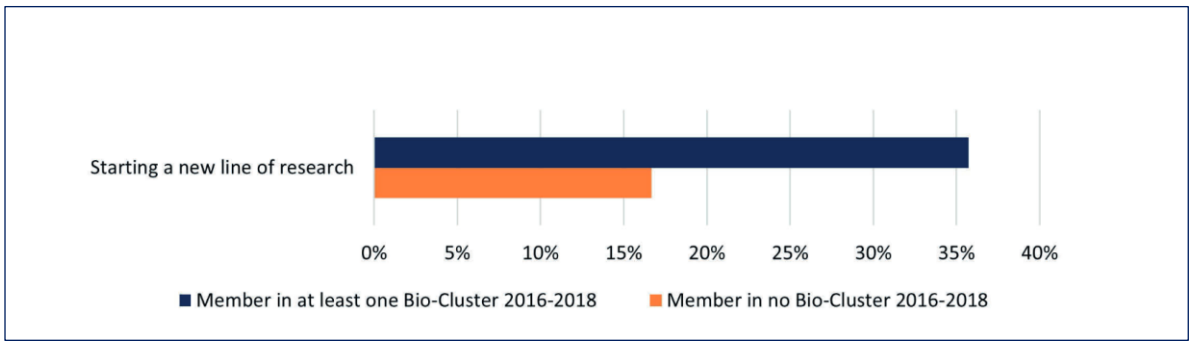
Fig (07): The Impact of Bio-Cluster Membership on Innovation in Products and Processes



Source: (Blandinieres, Krieger, & Pellens, 2021, p. 14)

As illustrated in **Figure (07)**, companies within biotechnology clusters benefit from stronger collaboration networks and greater resource availability compared to those outside these clusters. This is evidenced in the significantly higher percentage of firms that introduced new research areas into their portfolios, reaching **36% within clusters** compared to **17% outside them**.

Fig (08): The Impact of Bio-Cluster Membership on New Research Lines



Source: (Blandinieres, Krieger, & Pellens, 2021, p. 15)

For these reasons, biotechnology clusters receive dedicated funding initiatives to enhance innovation, such as BioRegio, BioProfile, Spitzencluster, GoCluster, among others.

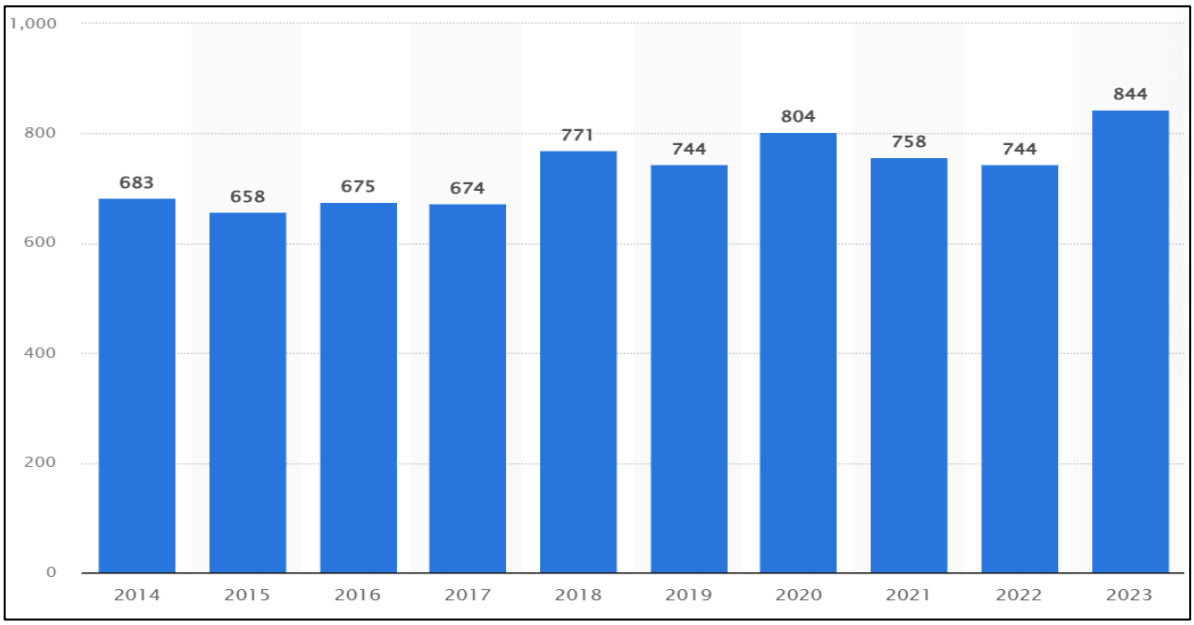
Tab (01): Initiatives to Enhance Innovation in Biotechnology Clusters in Germany

Initiative	Objective	Funding	Outcomes
BioRegio	Stimulate biotechnology development and accelerate innovation.	150 million German Marks + additional funding from the **Biotechnology 2000** program	Create a competitive environment among regions and promote innovation.
BioProfile	Support specialized regions with lower capacities than **BioRegio**.	50 million euros	Support lagging biotechnology clusters and stimulate innovation.
Spitzencluster	Enhance Germany's innovation capacity by supporting leading clusters.	600 million euros (2009–2017)	Promote R&D, increase local collaboration.
GoCluster	Support cluster management organizations and stimulate innovatin.	Various funding sources, including consulting, quality certifications, and project funding.	Improve cluster management, strengthen international relations.

Source: Prepared by the researchers based on multiple sources.

Since biotechnology is recognized as a highly innovative industry, patent registration functions as critical mechanisms for safeguarding innovations (Thumm, 2003, p. VII). Consequently, patent statistics effectively reflect inventive activities in this sector.

Fig (09): Number of Patents in the Biotechnology Sector in Germany 2014 - 2023



Source : (Mikulic, 2025)

Patent registration activities in biotechnology have exhibited dynamic growth, evolving significantly following the implementation of a wide range of innovative policy programs by the German government. These programs are designed to expand the number of companies and innovations, facilitate the transfer of university knowledge to the private sector, stimulate collaborative research and development activities, and strengthen local industrial clusters. For instance, in 2023, Germany led the European Union by registering 844 patents.

Among the notable examples within the German biotechnology cluster system are:

- **BioM Munich Biotech Cluster:** Established in 1997, this cluster spans the Greater Munich area and comprises approximately 527 companies, employing 58,000 people in the fields of biotechnology and pharmaceuticals (Schüller, 2024, p. 10), in addition to associated service providers. The region's core strength lies in developing innovative therapies, diagnostics, and supporting technologies, with a particular emphasis on diagnostic medicine. Innovative ideas and emerging projects are primarily sourced from two elite universities: the Technical University of Munich (TUM) and Ludwig-Maximilians University (LMU). BioM coordinates the network of Bavarian biotech regions as part of the state's cluster initiative. It offers comprehensive support to Bavarian biotechnology companies at all stages of their development through a unique support program designed specifically for startups and entrepreneurs in the life sciences sector. Notable initiatives include the virtual incubator **BioM inQlab** and the physical incubator **MAxL – Munich Life Science and Medicine Accelerator**, dedicated to pre-establishment projects and startups in biotechnology and health technology (Bio-M, 2025).
- **BioRN Cluster:** Serving as a key innovation center in the Rhine-Main-Neckar region, particularly in Heidelberg—which is recognized as one of the strongest biotechnology hubs in Germany—this cluster comprises 150 members, including 13 research organizations (universities, research institutions, and technology parks), as well as ten global pharmaceutical companies that own R&D sites or participate in the BioRN network. The BioRN cluster fosters a supportive environment for

startups in this field, by enabling companies to adopt an open innovation approach. This is characterized by the exchange of information, shared knowledge, and research tools. Additionally, startups benefit from close ties with major pharmaceutical companies, which enhance collaboration opportunities and accelerate the development of drugs and biotechnological techniques. This ecosystem is further enriched by the presence of small and medium-sized enterprises, local government agencies, and groups dedicated to advancing the biotechnology sector— contributing to Heidelberg's prestigious scientific reputation and robust scientific output (Schüller, 2024, p. 10)**.**

4- **Challenges Facing Industrial Clusters and Innovation in Germany:**

Biotechnology innovations are experiencing rapid developments and an increasing trajectory of international competition, which makes institutions aware of the importance of strategic collaboration within clusters and networks to ensure the continuity of research and development. However, these efforts do not exempt them from encountering a set of challenges that may impede their opportunities to enhance innovation.

- **Financial Challenges:**

Projections suggest that future innovation processes will become more complex, leading to a significant increase in the funding needs for research and development. Biotechnology clusters in Germany face a clear paradox between the growing demand for funding to support innovation and the diminishing available funding options. Confidence in funding R&D through bank loans has diminished extremely low, even though the financial market, under low interest rates, still offers attractive financing conditions (Michael Astor, 2016, p. 81) . This indicates a fundamental contradiction between the current market mechanisms and the expectations of economic actors, reflecting an increasing lack of trust between institutions and the banking sector.

Studies show that financing for small and medium enterprises, startups, and high-tech companies is increasingly dependent on self-financing and government assistance, while the importance of bank loans, venture capital, and alternative sources such as crowdfunding is declining (Bundestag, 2021, p. 12) . However, excessive reliance on public funding may result in financial bottlenecks, as the long-term returns on innovation gradually decline due to continuous developments, potentially restricting the ability of institutions to continuously invest in innovation.

Although an increase in government funding can be regarded an indicator of the effectiveness of government programs in supporting innovation, there are potential risks associated with it, including:

1. **Erosion of a Risk-Taking Culture:** Focusing on government funding may contribute to a decline in entrepreneurial risk-taking, as institutions increasingly rely on the conditions of government support rather than pursuing independent investment decisions.
2. **Shift Toward Government-Directed Innovation:** Adapting to the conditions and mechanisms of government programs may steer research and development activities to align closely with the priorities of funding agencies, rather than responding dynamically to actual market needs.

This creates an imbalanced innovation environment that relies primarily on government incentives rather than true economic viability.

- **Challenges in Human Capital:** The demographic changes currently affecting Germany have led to a significant decline in the available workforce, signaling a severe shortage of labor and specialized skills in several critical sectors, including the biotechnology sector (Michael Astor, 2016, p. 67). This directly impacts the clusters' capacity for innovation, as these fields heavily depend on high-level expertise. Despite efforts to address this shortfall through immigration and attracting foreign talent, these solutions remain partial and do not fully meet market needs due to legal constraints as well as linguistic and cultural barriers.
- **Collaboration and Networks in Innovation Management:** One of the main challenges in managing innovation within clusters is achieving a balance between openness and knowledge protection, while ensuring that members can keep pace with global developments. By engaging collaborative partners, these institutions can overcome some of the constraints associated with limited resources and the need for specialization. However, open innovation processes carry the risk of knowledge leakage to external parties and may prolong project durations due to the need for coordination among cluster members.

5 Conclusion:

Industrial clusters in Germany, particularly in the biotechnology sector, have experienced significant development, establishing themselves as a successful model for promoting innovation and supporting a knowledge-based economy. Government policies have played a crucial role in developing these clusters and creating an integrated, dynamic, and stimulating innovation environment that includes the country’s most prestigious universities and research centers, alongside a diverse institutional fabric. These efforts have contributed to transforming scientific research outputs into industrial and commercial applications that have led to a better understanding of disorders, enabled the development of strategies to address both underlying causes and symptoms, and achieved considerable financial gains—thereby enhancing Germany's competitiveness in Europe and globally.

As a key driver of innovation, biotechnology clusters face major challenges that affect their sustainability and competitive capacity. Notably, the complexity of financing processes is a significant hurdle, as there is an increasing reliance on government support while confidence in private financing declines, potentially limiting institutional independence. Furthermore, a shortage of human capital, resulting from demographic changes, poses another challenge by hindering the attraction and retention of talent and diminishing the dynamism of innovation. In addition, there is a pressing need to develop more efficient mechanisms for knowledge transfer and sustainable training to ensure a continuous flow of skills and expertise within the clusters.

To address these challenges, an integrated approach is imperative —one that combines the improvement of financing policies, the strengthening of strategic partnerships, and investment in human capital development. Government policies should also prioritize creating a flexible regulatory environment that fosters innovation and ensures the sustainability of industrial clusters. Moreover, expanding international cooperation and adopting open innovation strategies will enable these clusters to maintain their leadership in the biotechnology sector.

Bibliography:

Book:

1- Porter, M. E. (1998). Location, Clusters, and the "New" Microeconomics of Competition. *Business Economics*.
2- Yoshino, Y. (2011). *Industrial Clusters and Micro and Small Enterprises in Africa: From Survival to Growth.* Washington: The World Bank.

Article:

3- Asheim, B. T. (2011). Constructing regional advantage: Platform policies based on related variety and differentiated knowledge bases. *Regional Studies*, 893-904.
4- Baptista, Swann. (1998). Do firms in clusters innovate more? *Research Policy*, 525-540.
5- Barkley, D. L., & Henry, M. S. (2002). ADVANTAGES AND DISADVANTAGES OF TARGETING INDUSTRY CLUSTERS. *Regional Economic Development Research Laboratory*.
6- Bathelt, H. M. (2004). Clusters and knowledge: Local buzz, global pipelines and the process of knowledge creation. *Progress in Human Geography*, 31-56.
7- Beaudry, C., & Breschi, S. (2003). Are firms in clusters really more innovative? *Economics of Innovation and New Technology*, 325–342.
8- Bell, G. G. (2005). Clusters, Networks, and Firm Innovativeness. *Strategic Management Journal*, 287-295.
9- Benchrifa, H. (2021). Innovation, what is it exactly? *IJAFAME*.
10- Blandinieres, F., Krieger, B., & Pellens, M. (2021). Cluster support activities in the German biotechnology. *Econstor*, 14.
11- Boschma, R. (2015). Towards an evolutionary perspective on regional resilience: The role of space and place. *Regional Studies*.
12- Bruno, A. B. (2023). How to Be More Innovative in Clusters? The Influence of Geographical Agglomerations on Its Firms,. *Journal of the Knowledge Economy*, 2603-2629.
13- Carbonara, N. (2004). Innovation processes within geographical clusters: a cognitive approach. *Technovation 24*.
14- Cassiolato, L. &. (2003). Regional clusters and innovative performance: The role of inter- firm cooperation in the Spanish manufacturing sector. *International Journal of Entrepreneurial Behavior & Research*, 215–239.
15- Cooke, P., & Huggins, R. (2003). *High-technology clustering in Cambridge (UK).* Ashgate UK: Aldershot.
16- Debackere, K. (2014). *Academic Entrepreneurship and Spin Outs. European Entrepreneurship Colloquium.* Leuven: Vlerick Business School.
17- Drivas, B. &. (2015). The Impact of Geographic Proximity on Patent Cooperation and Innovation Performance in Industrial Clusters. *Journal of Technology Transfer*, 675–701.
18- Eraydin, A. (2016). The role of regional policies along with the external and endogenous factors in the resilience of regions. *Cambridge Journal of Regions*, 217–234.

19- Fang, L. (2018). Industrial clusters and firm innovation: Learning and selection effects in Maryland. *American Association of Geographers Annual Meeting*.
20- Folta, T. B., Cooper, A. C., & Baik, Y. S. (2006). Geographic cluster size and firm performance. *Journal of Business Venturing*, 217-242.
21- Jaffe, A. B., Trajtenberg, M., & Henderson, R. (1993). Geographic localization of knowledge spillovers as evidenced by patent citations. *The Quarterly Journal of Economics*, 577–598.
22- HORZELA-MIŚ, A. (2024). THE ROLE OF CLUSTERS IN ENHANCING BUSINESS COMPETITIVENESS AND INNOVATION. *Scientific Papers of Silesian University of Technology Organization and Management Series*.
23- Ivana Kostadinović. (2023). DO INDUSTRIAL CLUSTERS CONTRIBUTE TO ORGANIZATIONS' INNOVATION PERFORMANCE? PATH ANALYSIS. *ECONOMIC THEMES*.
24- Kim, H. H.-J. (2023). Industry cluster, organizational diversity, and innovation. *International Journal of Innovation Studies*, 187–195.
25- Lai, K. H. (2014). Innovation, clustering and regional development: A comparative analysis of European regions . *Regional Studies*, 873–888.
26- Le Roy F., R. M. (2012). Quels liens entre l'innovation technologique et managériale? Pour une distinction entre l'innovation produit et l'innovation procédé. *Conférence de l'Association Internationale de Management Stratégique (AIMS)*. Lille, France.
27- Michael Astor, C. R. (2016). *Innovativer Mittelstand Herausforderungen, Trends und Handlungs empfehlungen für Wirtschaft und Politik.* Berlin: ZEW.
28- Rosenfeld, S. A. (2002). *Just Clusters Economic development strategies that reach more people and places.* North Carolina: Regional Technology Strategies, Inc.
29- Schüller, T. (2024). Biotech Clusters in Europe. *Ma r k e t s & st r at e g y*.
30- Serena M., J. González. (2021). Role of Technology Transfer, Innovation Strategy and Network: A Conceptual Model of Innovation Network to Facilitate the Internationalization Process of SMEs. *Technology and Investment*.
31- Wrobel, M. (2015). One for all and all for one': Cluster, employment, and the global economic crisis. Evidence from the German mechanical engineering industry. *Papers in Regional Science*, 290.
32- Yan Xu et al. (2024). The Impact of Global Value Chain Position on Emerging Industrial Cluster Innovation Efficiency in China. *INTERNATIONAL JOURNAL OF ACADEMIC RESEARCH IN BUSINESS AND SOCIAL SCIENCES*.
33- Zimmer, B. (2012). *Structuration d'un cluster d'innovation : Application aux projets d'innovation dans une grappe d'entreprises en gérontechnologie,*. Paris: ECOLE CENTRALE DES ARTS ET MANUFACTURES -ECOLE CENTRALE PARIS-.

Papers Presented at Conferences:

34- Judith Terstriep, Christian Lüthje. (2012). DO CLUSTERS AS OPEN INNOVATION SYSTEMS ENHANCE FIRMS' INNOVATION PERFORMANCE? *Proceedings of the 19th International Product Development Management Conference "Transformative Research in Product and Service Innovation",.* Manchester, UK: https://www.iat.eu/aktuell/veroeff/2012/terst01.pdf.

Report:

35- Bundesministeriums für Bildung und Forschung. (2024). *Daten und Fakten zum deutschen Forschungs- und Innovationssystem.* Berlin: Bundesministerium.
36- Bundestag, D. (2021). *Finanzierung von kleinen und mittleren Unternehmen (KMU) in Deutschland* . Berlin: Wissenschaftliche Dienste.
37- European Commission. (2004). *Innobarometer 2004.* Brussels: EOS Gallup Europe.
38- European Commission. (2024). *European Innovation Scoreboard.* Brussels: European Commission.
39- Institute for Innovation and Technology. (2019). *Development Dynamics of Cluster Initiatives in Germany Over Time.* Berlin: Institute for Innovation and Technology.
40- OCDE. (2005). *Manuel d'Oslo 2018 : Lignes directrices pour le recueil, la communication et l'utilisation des données sur l'innovation.* Paris: Éditions OCDE.
41- OCDE. (2018). *Manuel d'Oslo 2018 : Lignes directrices pour le recueil, la communication et l'utilisation des données sur l'innovation.* Paris: Éditions OCDE.
42- Thumm, N. (2003). Research and Patenting in Biotechnology A Survey in Switzerland. *Federal Institute of Intellectual Property*, VII.
43- William MacDougall. (2022). *HEALTH MADE IN GERMANY :The Medical Biotechnology Sector.* Berlin: Germany Trade and Invest.
44- William MacDougall, GTAI. (2023). Biotechnology Clusters in Germany. *FACT SHEET*.

Electronic Sources:

45- bio-m. (2025, 02 18). *https://www.bio-m.org/en/our-cluster/bavaria-excellence-in-biotech.html*.
46- clusterplattform. (2024, july 21). *https://www.clusterplattform.de/*. Retrieved from https://www.clusterplattform.de/CLUSTER/Navigation/DE/Home/home.html: https://www.clusterplattform.de/SiteGlobals/CLUSTER/Forms/Suche/DE/Clustersuche_Formular.html?oneOfTheseWords=Suchbegriff%20eingeben
47- Federal Ministry of Education and Research. (2024, july 19). *https://www.bundesbericht-forschung-innovation.de/index.html*. Retrieved from https://www.bundesbericht-forschung-innovation.de/de/Akteure-des-deutschen-Forschungs-und-Innovationssystems-2134.html: https://www.bundesbericht-forschung-innovation.de/de/Akteure-des-deutschen-Forschungs-und-Innovationssystems-2134.html
48- Mikulic, M. (2025, 02 23). *www.statista.com/statistics*. Retrieved from https://www.statista.com/statistics/460486/number-patents-in-biotechnology-sector-germany/: https://www.statista.com/statistics/460486/number-patents-in-biotechnology-sector-germany/