Assessing Deep-Tech Innovation Hubs in Germany: The Case of Biotechnology

A Biotech Innovation Index

ESMT BERLIN

DEEP
An institute of ESMT Berlin

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About this paper

This report is a joint publication of the Bertelsmann Stiftung und the DEEP – Institute for Deep Tech Innovation at ESMT Berlin and is published as part of the “Fostering Innovation and Entrepreneurial Dynamism“ project at the Bertelsmann Stiftung.

About us

DEEP – Institute for Deep Tech Innovation at ESMT Berlin champions deep-tech innovation by building ecosystems that reshape technology transfer, fostering global scaling of startups. It instills entrepreneurial thinking in science and beyond, developing unique activities across various verticals with partners in science, business, and startups, thus enabling a new generation of deep-tech innovators in Europe. DEEP is a part of ESMT, a leading global business school with its campus in the heart of Berlin. Focusing on leadership, innovation, and analytics, its diverse faculty publishes outstanding research in top academic journals. Additionally, the international business school provides an interdisciplinary platform for discourse between politics, business, and academia.

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Executive Summary

Recognizing the European Union's shortcomings in translating scientific research into commercially viable deep-tech solutions, this report introduces a comprehensive index designed to evaluate the regional strengths and challenges within Germany's biotech landscape. The study examines five key German biotech hubs, focusing on key stages in the biotech innovation process – from fundamental research to venture capital funding and commercialization – while also considering enabling factors such as public infrastructure and business environment. This quantitative analysis is further enriched by in-depth interviews with seasoned venture capitalists who specialize in biotech entrepreneurship and investment.

Key findings

Over the past decade, Berlin, Munich, and Heidelberg have consistently led Germany's biotech landscape, achieving index scores nearly double those of less competitive hubs like Stuttgart and Nuremberg-Erlangen. This advantage is partly attributable to higher concentrations of PhD students in life sciences, STEM, business, and economics – fields that strongly correlate with research, patents, and biotech developments in our data. However, these postgraduate numbers appear to have limited influence on a hub's ability to secure biotech funding.

Berlin ranks highest in our Biotech Index, outpacing Munich and Heidelberg, largely due to its robust public infrastructure, particularly its large number of hospitals, which foster collaboration between patient care and research. Our data show a strong correlation between the number of hospital beds and a hub's ability to establish and raise funds for biotech ventures. However, Berlin's clear lag behind Munich in biotech venturing suggests that it does not fully leverage its infrastructure to maximize biotech commercialization.

Heidelberg excels in fundamental research and patenting but struggles to translate this knowledge into successful biotech ventures. This gap highlights Heidelberg's untapped potential: while it has a strong foundation to emerge as a leading hub, it lacks the ability to effectively commercialize its research.

Munich leads in fostering biotech ventures, outperforming both Berlin and Heidelberg in key metrics such as the number of investors, funding events, total investments, and successful exits. Unlike the others, Munich emphasizes later-stage funding, demonstrating its ability to support biotech firms through advanced growth stages and competitive scaling.

While our analysis highlights the complementary strengths and potential of Germany's biotech hubs, it also reveals a concerning trend: a declining ability to translate research into biotech innovation over the past eight years, with Munich as the sole exception. Although COVID-19 temporarily boosted efficiency in Berlin, Heidelberg, and Munich, by 2023, all hubs except Munich had fallen below their pre-pandemic levels. Munich continues to strengthen its commercialization capacity.

Recommendation

The complementary strengths of Germany's primary biotech hubs suggest that integrating their capabilities could form a powerful German biotech innovation cluster that is highly competitive on the global stage. However, the current lack of collaboration among these hubs hinders Germany from fully harnessing the distinct assets each region offers. Our findings highlight an urgent need for greater integration, recommending that Germany prioritize funding initiatives aimed at fostering cross-hub collaboration. This approach would enable the country to capitalize on the synergies between hubs rather than perpetuate inefficiencies through duplicated efforts.

More generally, systematically monitoring the development of deep-tech clusters using a robust method like the one presented in this study is crucial for closing the deep-tech innovation gap in Germany and across Europe.

Contents

1 Introduction

The crucial role of deep-tech innovation

In 2015, the United Nations identified 17 Sustainable Development Goals (SDGs) – critical issues that humanity must address "to ensure that our planet is peaceful, prosperous, and safe for all." These challenges include global warming, the urgent need for clean water and achieving good health for the global population. Deep-tech innovation offers one of the most promising pathways toward achieving most of these goals. A recent study suggest technology could reduce the cost of achieving the UN SDGs by 40%,[1] while a survey of 1,277 deep-tech ventures revealed that 97% contributed to at least one of these goals.[2]

The advent of mRNA vaccines to contain the COVID-19 pandemic underscores this potential. Biotech ventures such as Moderna and BioNTech revolutionized vaccine technology, enabling a rapid and effective global response to the crisis. However, emerging threats like antibiotic-resistant diseases present an even greater challenge. The World Health Organization projects that drug-resistant infections could lead to over 10 million deaths annually by 2050.[3] As with the COVID-19 pandemic, advancing biotech innovation remains humanity's best hope for overcoming these critical crises.

Beyond healthcare, deep-tech innovation is addressing other global challenges, such as improving access to clean water and combating climate change. For example, London-based venture Desolenator is developing solar-powered systems to provide drinking water in remote, water-scarce regions,[4] while Eindhoven's Carbyon is pioneering direct air capture technology to efficiently remove CO_2 from the atmosphere.[5]

Economists have long highlighted the crucial role of deep-tech innovation in fostering sustainable economic growth[6] by boosting productivity and creating new industries. Transformative technologies, from the steam engine during the Industrial Revolution to the internet's role in e-commerce and AI's impact across sectors, illustrate its potential to foster progress and prosperity.

The deep-tech innovation gap

Deep-tech innovation involves harnessing the most recent advancements in scientific breakthroughs to create technologies once deemed inconceivable. With its thriving research landscape, Europe should be well-positioned to lead in this arena. Europe matches the U.S. and still surpasses China in scientific publications per capita. It also produces more STEM[7] graduates than the U.S – in Germany, for instance, 35.8% of graduates specialize in STEM fields, compared to 19.6% in the U.S. More broadly, five of the world's most innovative countries are in the EU, with Germany, ranked ninth, standing out for its strong research and industrial base.[8]

Yet, Europe and Germany are falling behind. More than half of recently established deep-tech companies are based in the U.S., which also invests over two and a half times more in deep-tech startups than Europe.[9] Meanwhile, China is rapidly closing the gap, investing significantly more in

1 "Technology for a Secure, Sustainable and Superior Future", Force for Good, Report, Jan. 2023
2 "Deep Tech and the Great Wave of Innovation", hello tomorrow – BCG, Report, March 2021
3 "No time to wait: Securing the future from drug-resistant infections". World Health Organization, 2019
4 Desolenator. Our Product. Retrieved from https://www.desolenator.com/product.
5 Carbyon. Technology. Retrieved from https://carbyon.com/technology/.
6 "Economic Transformations", Lipsey, Carlaw, & Bekar, Oxford University Press, 2006; "The Gifts of Athena", Mokyr, Princeton University Press, 2002
7 STEM: Science, technology, engineering, and mathematics
8 World Intellectual Property Organization (WIPO). Global Innovation Index 2023: Innovation in the Face of Uncertainty. Geneva: WIPO, 2023. https://doi.org/10.34667/tind.48220.
9 See for instance PitchBook analysis' "Why Europe struggles to scale its deep-tech startups", March 2023.

key technologies such as autonomous mobility, generative AI and nuclear fusion than European countries.[10]

Despite a growing number of reports highlighting this issue, it remains largely overlooked in public discourse, and policymakers have been slow to respond, particularly in Germany. For example, the German Federal Ministry for Economic Affairs and Climate Action only launched its Startup Factories initiative in July 2024 to create internationally recognized startup ecosystems centered around universities.[11]

Bridging the deep-tech gap is further complicated by a lack of comprehensive understanding of Europe's, and especially Germany's, innovation ecosystems. While national trends offer some insights, the absence of detailed and systematic regional analyses poses a significant challenge. Without this granular knowledge, policy interventions risk being ineffective or even counterproductive – particularly in decentralized countries like Germany, where regional dynamics play a crucial role in shaping innovation and economic outcomes.

This report aims to help fill this gap by introducing an index that systematically evaluates the capacity of regional clusters to translate scientific breakthroughs into ventures that delivering societal and economic benefits. To demonstrate our approach, we focus our analysis on biotech innovation in Germany, a sector increasingly prioritized by nations as strategically vital.

Assessing the deep-tech gap in Biotechnology – The Biotech Index

The European biotechnology sector secured approximately $11.46 billion in funding across 229 biotech companies in 2023, a figure that pales in comparison to the $56.79 billion raised by 583 U.S. biotech firms that same year.[12] Meanwhile, countries like China and India have made biotechnology a centerpiece of their "Made in China 2025" and "Made in India" strategies for self-reliance.[13] The Asia-Pacific region accounted for 23.99% of global biotech revenue in 2023 and is projected to become the fastest-growing market in the field. With the global biotech market expected to grow at a compound annual rate of 13.96%,[14] reaching approximately $5.81 trillion by 2033[15], Europe – and Germany in particular – must act swiftly to remain competitive, as underscored in the recent Draghi report.[16]

Early-stage financing, however, remains a challenge in Germany. In 2023, biotech startups raised only €203 million, the lowest figure in six years and well below the period average of €325 million.[17] Additionally, Germany lags behind countries like France and Switzerland in biotechnology initial public offerings (IPOs). For example, France's Abivax raised €235 million, and Switzerland's Oculis secured €91 million in 2023.[18] German IPO activity was notably absent from the top European biotechnology IPOs, further highlighting its relative underperformance.

10 "Deep Tech: Europe" by dealroom, Walden Catalyst and Lake Star, 2023
11 https://startup-factories.de/
12 Brian Buntz. Analyzing the Biotech Funding Landscape in 2023: U.S. Still Out Front. Drug Discovery & Development, January 5, 2024.
13 Council of the European Union. Building the Future with Nature: Boosting Biotechnology and Biomanufacturing in the EU (ST 9163/2024 INIT). 2024.
14 Grand View Research. Biotechnology Market Size, Share & Growth Report, 2030. San Francisco: Grand View Research, 2023.
15 Vision Research Reports. Biotechnology Market: Global Industry Analysis, Size, Share, Growth, Trends, Revenue, Regional Outlook and Forecast 2024-2033. Published 2023.
16 Precedence Research. Biotechnology Market Size, Share, and Trends Analysis Report 2023. Published 2023.
17 BIO Deutschland. Increasing Investment in German Biotech, but Early-Stage Financing Is a Cause for Concern: Lowest Figure in Six Years. Press release, June 5, 2024.
18 Statista. Leading Biotechnology IPOs in the European Union in 2023, by Amount Raised. Published 2023. Retrieved from https://www.statista.com/statistics/667738/biotechnology-ipos-raised-european-union-eu/.

Designing policies able to address this gap requires a detailed understanding of the strengths and weaknesses of Germany's various biotech hubs. Yet, there are no systematic tools currently in place to track the evolution of these ecosystems over time. Existing deep-tech indices typically provide a static snapshot of specific years, offering insights into the current state but failing to monitor trends or long-term progress.[19]

In addition, many existing studies prioritize financial metrics, often overlooking the scientists driving fundamental research. Understanding their motivations and backgrounds and willingness to pursue deep-tech entrepreneurship is critical for addressing the scarcity of pre-seed entrepreneurial activity – a vital step in closing the innovation gap. Furthermore, many studies focus on factors common to all deep-tech technologies, failing to account for the unique challenges faced by specific fields.[20] Biotechnology, for instance, operates within distinct regulatory environments, intellectual property frameworks, and lab and infrastructure requirements. Ignoring these complexities hinders the development of targeted strategies to overcome barriers and bridge the technology gap effectively.

This study presents a Biotech Index designed to address these shortcomings, offering a comprehensive evaluation of the strengths and weaknesses of Germany's biotech innovation hubs. By identifying favorable and unfavorable trends, the index supports the development of more targeted and effective policy interventions. Additionally, it provides a quantitative assessment in an accessible format, facilitating clearer communication and more efficient knowledge-sharing across biotech hubs.

The report is structured as follows.

Chapter 2 offers a brief overview of Germany's primary innovation hubs, identified using the Global Innovation Index.[21] Chapter 3 explains the methodology behind the construction of the Biotech Index, detailing the variables and sub-indices that represent each stage of the biotechnology innovation process, from fundamental research to commercialization. Chapter 4 evaluates and analyzes the index, highlighting Germany's leading biotech hubs, their strengths and weaknesses, and key emerging trends. Chapter 5 explores the applicability of this methodology to assess deep-tech innovation beyond the biotech sector and across other European regional hubs. Chapter 6 concludes by summarizing the key findings and emphasizing the urgent need to foster synergies among Germany's biotech innovation hubs.

19 See for instance Deutsche Börse Group "Deutschland stark in der Grundlagenforschung, aber schwach in der Kommerzialisierung" in "Strategien zur nachhaltigen Finanzierung der Zukunft Deutschlands", 2001; ESMT Berlin -BCG "Biotech Innovation Hubs in Germany – Divided and Conquered?", 2024

20 See for instance deelroom.co-Lake Star-Walden Catalyst "The European Deep Tech Report", 2023; WIPO "The global innovation Index", 2023

21 World Intellectual Property Organization (WIPO). Global Innovation Index 2023: Innovation in the Face of Uncertainty. Geneva: WIPO, 2023. Retrieved from https://doi.org/10.34667/tind.48220.

2 Germany's main innovation hubs

We identify Germany's main innovation hubs using the 2023 Global Innovation Index (GII) Report (Dutta et al. 2023), which evaluates a country's overall innovation performance.[22] These clusters are defined by high densities of patent filings and scientific publications, often spanning multiple municipalities, sub-federal states or even countries. This methodology aligns with the economic geography literature, which recognizes such densities as a key feature of innovation hubs and supports this approach.[23]

The GII's approach identifies Munich, Berlin, Nuremberg-Erlangen, Heidelberg-Frankfurt, and Stuttgart as Germany's leading innovation clusters, all ranked among the top 50 globally (see Table 1).[24] These hubs remain largely consistent with those identified in 2022.

The complete list of cities covered by each hub is provided in the Appendix (see Appendix 1).

Each hub has unique institutions driving innovation and contributing to their city's biotechnology ecosystem. Berlin is home to renowned hospitals like Charité and research organizations such as the Max Planck Institute and the Max Delbrück Center. Munich benefits from similar research institutions as well as BioM, Germany's oldest network organization for the development of the biotechnology sector. Heidelberg's biotechnology hub is also represented by BioRN, the Life Science Cluster Rhine-Neckar. The cluster is further anchored by the German Cancer Research Center and the European Molecular Biology Laboratory. Nuremberg and Erlangen are strengthened by the support of the Medical Valley European Metropolitan Region Nuremberg, Siemens Healthineers, and the Fraunhofer Institute for Integrated Circuits IIS, which specializes in medical and digital health technologies. While Stuttgart's innovation capabilities are more prominent in the automotive and manufacturing sectors than in biotechnology, the hub is home to notable organizations such as the Fraunhofer Institute for Interfacial Engineering and Biotechnology an d the pharmaceutical company Wörwag Pharma.

TABLE 1 **Innovation hubs in Germany according to the Global Innovation Index report**

Hubs	Abbreviation	Cluster Intensity Rank*
1 – Berlin	Berlin	26-50
2 – Heidelberg/Frankfurt am Main	Heidelberg	26-50
3 – Munich	Munich	1-25
4 – Nuremberg-Erlangen	Nuremberg	26-50
5 – Stuttgart	Stuttgart	1-25

* The Cluster Intensity Rank (which takes values between 1 and 100) measures the position of a specific cluster within the global ranking of top clusters of the Global Innovation Index, determined by their innovation intensity.

Source: Author's Own.

22 While our study focuses on biotechnology, the Global Innovation Index report encompasses all types of technologies. Using this report as the basis for hub selection will thus facilitate cross-technology comparisons within the comprehensive European index.

23 Economic studies show that densely populated urban hubs foster both conventional and unconventional innovations through cross-disciplinary knowledge exchanges and agglomeration effects (Berkens and Gaetani, 2020; Carlino and Kerr, 2014). These hubs serve as central nodes of global innovation, driving economic growth and productivity through related variety and interconnected networks (Cortinovis and van Oort, 2015; Crescenzi et al., 2019). Additionally, European firms benefit from inter-industry economies in active clusters, where diverse sectoral interactions enhance innovation potential and firm turnover (Hafner, 2024).

24 Hamburg is also recognized as an innovation hub in Germany but its cluster intensity rank falls below average, i.e. below 50, and is thus excluded from this analysis.

3 The Biotech Index

The guiding principles behind developing the index focus on accurately tracking the translation process, which uses scientific breakthroughs as inputs and yields market-ready innovations as outputs. This process can be enhanced by various resources and the specific characteristics of the socioeconomic environment in which it takes place. Accordingly, the index is structured around two main: the translation process itself and various enabling factors.

3.1 The translation process

The translation process, from scientific research to market-ready innovations, involves several key stages, as illustrated in the figure below. It begins with *fundamental research* (Stage 1), conducted primarily by scientists, which may yield a significant scientific breakthrough. The discovery is then *patented* to safeguard the intellectual property (Stage 2). This patent acts as a valuable asset for a potential venture, facilitating the procurement of seed funding. The venture then undertakes *research and development* activities to refine the original concept (Stage 3). As the technology matures, the venture secures *additional funding* to support more *advanced technological developments* (Stages 3&4). The venture may reach an "exit" through acquisitions or IPOs (Stage 5). The new organization then conducts extensive clinical trials mandated by regulatory authorities (Stage 6). Only after the innovation successfully clears these trials is the final product approved by regulatory agencies, such as the U.S. Food and Drug Administration and the European Medicines Agency, allowing it to enter the market.

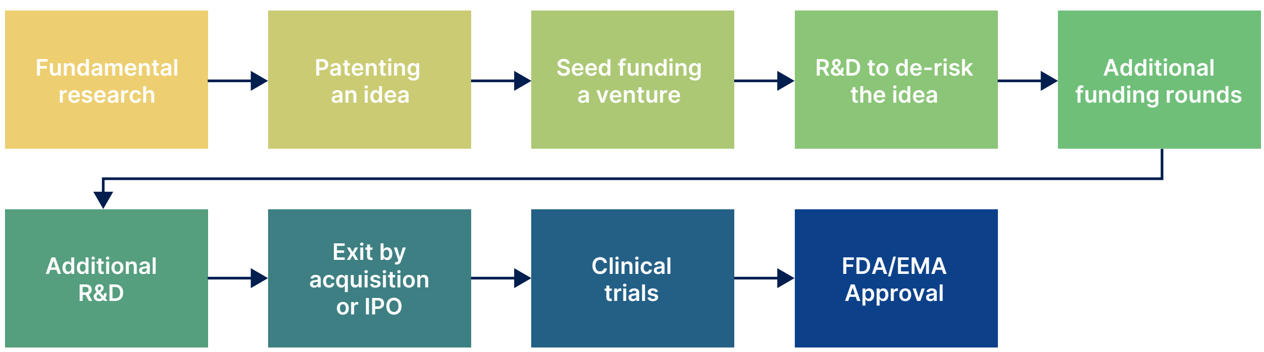
3.2 Methodology

To evaluate the process described in Figure 1, we identified variables that closely represent each stage by applying four criteria: 1) relevance to the process, 2) availability of reliable data sources, 3) comprehensiveness in characterizing the process, and 4) minimal overlap among variables to prevent double counting.

Additionally, we identified enabling variables that indirectly contribute to the success of a biotech hub. These variables 1) influence innovation indirectly and 2) are distinct from those representing the translation process to avoid redundancies. (See Appendix 2 for detailed descriptions.)

This approach resulted in 23 variables that we organized into five blocks, each representing a cohesive sub-index. Table 2 provides definitions of the sub-indices.

FIGURE 1 **The translation process from scientific research to market-ready innovations**



Source: Author's Own.

TABLE 2 **Definitions of biotech hub sub-indices and variables**

This table organizes the 23 selected variables into five cohesive sub-indices – Fundamental Research, Biotech R&D, Biotech Venturing, Public Infrastructure, and Business Environment – each reflecting a key pillar in assessing the success of biotech hubs.

Sub-index	Variables
1 – Fundamental Research	• Total number of postgraduates in biotechnology and medicine • Scientific output quantity in biotechnology: Publications • Scientific output quality in biotechnology: Citations
2 – Biotech R&D	• Willingness to engage in entrepreneurship • Patents: Quantity • Patents: Quality • Clinical trials
3 – Biotech Venturing	• Companies funded by angel investors • Startup activity in biotechnology • Private funding events in biotechnology • Private funding in biotechnology • Total number of investors for biotech • Exit – Number of companies that have been sold to big pharma • IPO
4 – Public Infrastructure	• Total number of undergraduate degrees in biotech, biology and pharmacy • Total number of PhD and Post Doc in all STEM, economics, and business fields • Number of hospitals • Number of beds
5 – Business Environment	• Willingness to engage in entrepreneurship for all sectors excluding biotech • Companies funded by angel investors for all sectors excluding biotech • Private funding events for all sectors excluding biotech • Private funding for all sectors excluding biotech • Total number of investors for all sectors excluding biology

Source: Author’s Own.

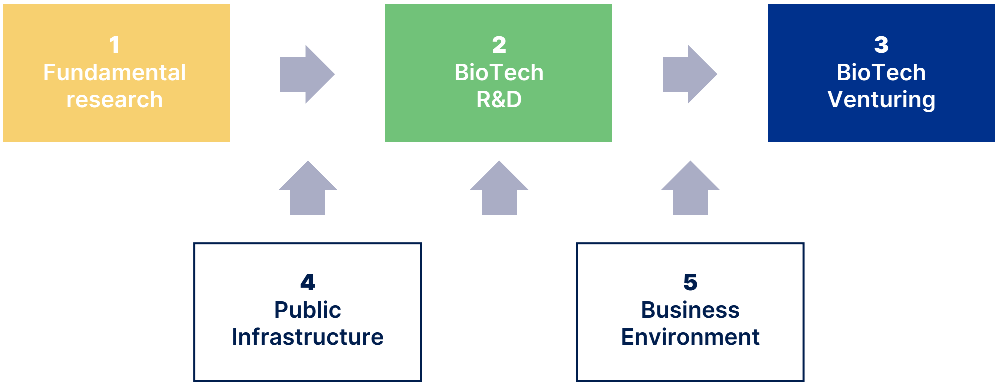
Sub-indices 1–3 correspond to different stages in the translation process depicted in Figure 2, with Sub-index 1 capturing inputs and Sub-index 3 reflecting outputs. Sub-indices 4 and 5 represen tenabling factors that facilitate this process.

We collected data for 23 variables describing the index from 11 datasets spanning the years 2016–2023 (see Appendix 2.3 for variable-to-dataset mapping and Appendix 5 for data limitations). Each variable was then normalized using a min-max approach, assigning values between 0 and 1. In this scale, a value of 0 corresponds to the lowest observed value, while a value of 1 corresponds to the highest observed value for the variable across the five hubs during the period (see Appendix 3.1.1 for details).

The five sub-indices for each hub were calculated by averaging the scores of the variables within each corresponding block (see Appendix 3.2.2). The overall Biotech Index score for a hub was then determined by averaging its five sub-indices.

FIGURE 2 **The relationship among key sub-indices**

Fundamental Research, Biotech R&D, and Biotech Venturing serve as the primary components of the index, reflecting core stages of biotechnology development. Public Infrastructure and Business Environment act as supportive sub-indices, providing essential foundations that enable growth and sustainability across the main sub-indices.



Source: Author's Own.

Both the sub-indices and the overall Biotech Hub index range from 0 to 1, with higher scores indicating stronger performance and greater potential. A score of 1 indicates that every variable for a hub reaches its highest observed value across all hubs and over the entire period from 2016 to 2023. Conversely, a score of 0 indicates that every variable for a hub was at its lowest observed value over the same period.

We tested the robustness of our index by comparing its results with five alternative approaches, varying the normalization and aggregation methods. We found that our index remained fairly robust across these different specifications (see Appendix 3.3 for details).

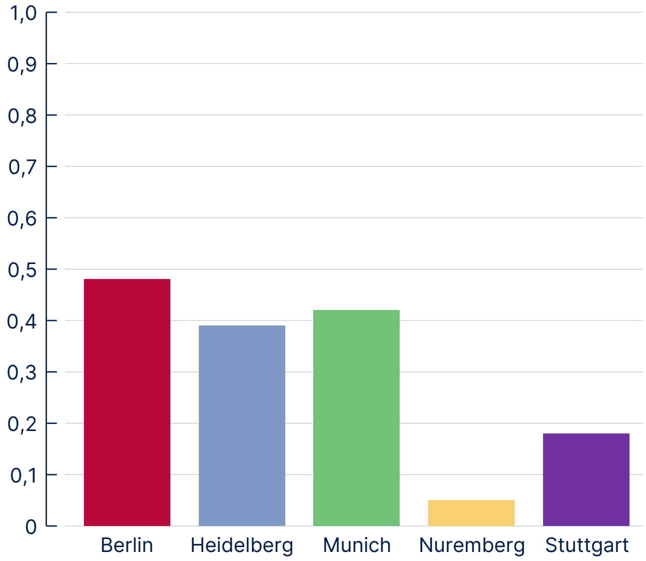
The insights derived from the index, as detailed in the following section, were validated through consultations with two independent venture capitalists with extensive experience in biotech entrepreneurship and investment.

4 An evaluation of Germany's biotech hubs

4.1 Berlin's dominance and the complementarity of German biotech hubs

FIGURE 3 **Biotech Hub index for Leading German Hubs in 2023**

The index values range from 0 to 1. A perfect score of 1 for a hub represents a hypothetical scenario in which each variable in the index for that hub achieves its highest observed value across all hubs and the entire period from 2016 to 2023. Conversely, a score of 0 indicates that each variable for the hub is at its lowest observed value across the same hubs and time frame.



Source: Author's Own.

Our analysis indicates that Berlin achieved the highest *Biotech Index* score among German hubs in 2023, reflecting both its performance and notable potential within the sector (see Figure 3 for *Biotech Hub Index* 2023 results; detailed hub-specific results are provided in Appendix 4.1.2). The index also highlights Berlin, Munich, and Heidelberg Germany's leading biotech clusters, while Stuttgart and Nuremberg-Erlangen lag behind. Notably, all hubs scored below 0.5, where 1 represents the maximum possible score if every variable constituting the index reached its peak value during the 2016–2023 period. This suggests an overall decline in Germany's hubs during this period, a point we discuss further in Section 4.4.

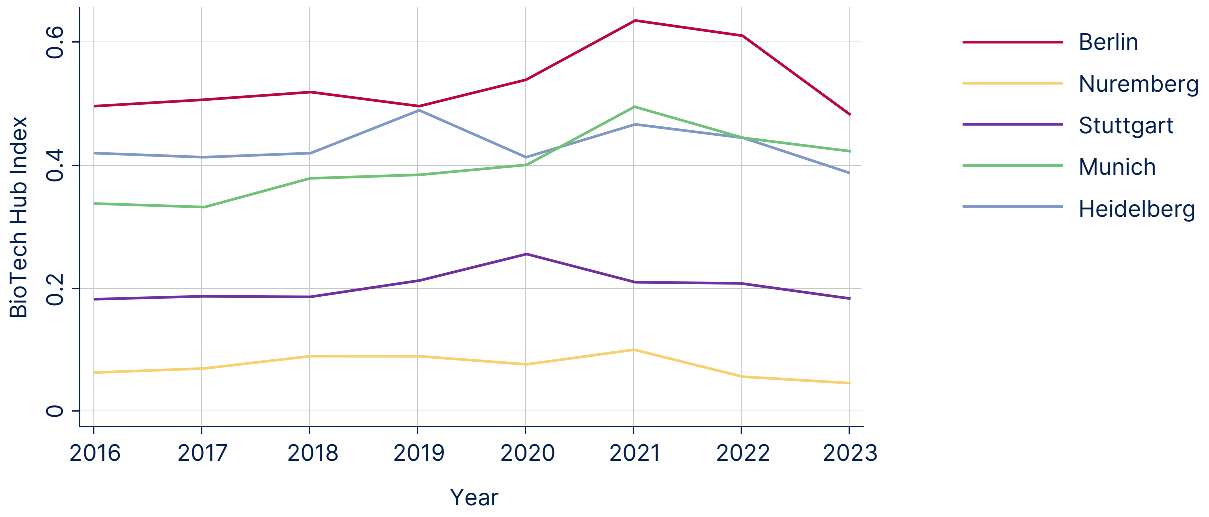
The hub rankings (1. Berlin, 2. Munich, 3. Heidelberg, 4- Stuttgart, and 5. Nuremberg-Erlangen) have remained stable over the past eight years (see Figure 4), with the exception of Munich surpassing Heidelberg following the COVID-19 pandemic. As discussed later in this report (see Section 4.3), this shift can be attributed to Munich's improved efficiency in translating biotechnology developments and patents into successful biotech ventures.

All hubs experienced a surge in their indices during the COVID-19 pandemic, with a strongest gains seen in the three dominant hubs. This growth was driven by increased funding for biotech ventures and a rise in angel and late-stage investors, fueled by the global focus on healthcare and biotech innovations during the pandemic. The BIO Deutschland 2022 report also noted record turnover and R&D investments in biotechnology during this period.[25] Academic publications and clinical trials also rose with the growing demand for medical testing and interventions. However, momentum has since waned, with most hubs seeing index values drop slightly below pre-pandemic levels – Munich being the exception.

The divide between strong biotech hubs (Berlin, Munich, and Heidelberg) and weaker ones (Stuttgart and Nuremberg-Erlangen) has also remained constant over time. Strong hubs consistently score about twice as high as weaker ones. This disparity can be partly attributed to differences in the number of postgraduate students in biotech-relevant fields, including life sciences, STEM, business, and economics. Indeed, our

25 BIO Deutschland, Biotechnology Sector Posts Record Turnover and R&D Investments, 2022. Available at: https://www.biodeutschland.org/en/press-releases/biotechnology-sector-posts-record-turnover-and-r-d-investments.html?year=2022.

FIGURE 4 **Biotech Hub Index comparison across major hubs (2016–2023)**



Source: Author's Own.

analysis suggests that these numbers serve as key indicators of a biotech hub's strength. Berlin, Munich, and Heidelberg have significantly more PhD students in these areas compared to Stuttgart and Nuremberg, and our data reveal a strong correlation between the number of PhD students and a hub's capacity for scientific research, patent activity, and biotechnology development,[26] highlighting the essential role of academic talent in driving biotech innovation hubs. However, our findings show no correlation between the number of PhD students and the ability to fund biotech ventures; instead, the maturity of the hub plays a more decisive role, as discussed in Section 4.3.

Berlin's dominance over Munich and Heidelberg in biotech is largely due to its robust public infrastructure (see Figure 5 for the five sub-index scores), particularly its high number of hospitals and hospital beds.[27] This infrastructure facilitates extensive clinical trial access, real-world data collection, and collaboration between patient care and research facilities. Our data show a strong correlation between the number of hospital beds and a hub's ability to establish and raise funds for biotech ventures.[28] This setup provides Berlin with a solid foundation in our index. However, Berlin's clear lag behind Munich in *Biotech Venturing* suggests that it does not fully leverage this infrastructure to maximize biotech commercialization.

In contrast, Heidelberg excels in *Fundamental Research* and *Biotech R&D*, outperforming both Berlin and Munich in these areas. Yet it struggles to convert this knowledge into viable biotech ventures, as reflected in its lower performance in *Biotech Venturing*. This gap suggests an untapped potential in Heidelberg, as it has the right inputs to become a leading biotech hub but lacks the capacity to effectively commercialize its research.

Munich, meanwhile, dominates both Berlin and Heidelberg in fostering biotech ventures, with its 2023 *Biotech Venturing* sub-index score approxi-

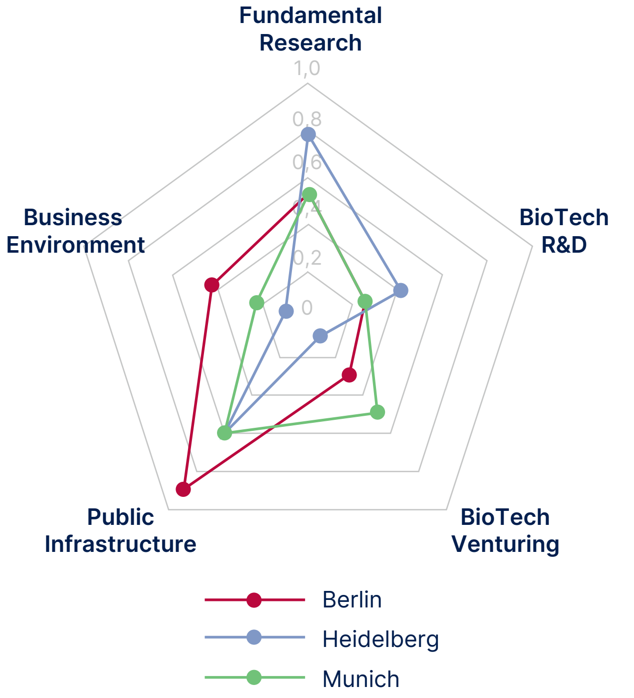
26 The regression results indicate that the p-value is less than 0.01 when Life Sciences is regressed on PhD students and hospitals. Similarly, the p-value is less than 0.01 for the regression on Biotech R&D, while the regression on Biotech Venturing yields a p-value of 0.35. Additionally, when analyzing the transition from Life Sciences to Biotech R&D, the p-value for PhD students in the biotech field is less then 0.01.

27 For instance, Berlin is home to Charité, one of Europe's largest university hospitals.

28 The regression analysis demonstrates the significance of hospitals and beds for Biotech Venturing, with both variables showing p-values less than 0.01.

FIGURE 5 **Sub-indices for three main hubs**

This radar plot displays the strengths of Germany's three leading biotech hubs across the five different sub-indices of the index presented in Table 2.



Source: Author's Own.

mately 65% higher than Berlin's and six times that of Heidelberg's. Munich also matches Berlin when it comes to *Fundamental Research* and *Biotech R&D*.

Together, the strengths of Berlin, Munich, and Heidelberg create a highly complementary biotech landscape. A unified hub that combines their capabilities could form a globally competitive German biotech innovation cluster. However, collaboration among these hubs remains limited, preventing Germany from fully capitalizing on the regionally dispersed assets each offers.

4.2 Heidelberg's unique potential

Heidelberg excels in *Life Science Research* and *Biotech R&D*, particularly in high-demand fields such as therapeutics and biologics (see Figure 6 for the *Fundamental Research* sub-index). This success is fueled by a concentration of strong academic institutions that prioritize rigorous, theory-oriented R&D.[29] Heidelberg's reputation as a research hub has drawn top scientists and substantial research funding, creating a solid foundation for high-quality academic output.

However, this research-centric focus also means that Heidelberg's ecosystem remains largely centered on advancing scientific knowledge rather than on developing biotech ventures, which limits the translation of its research achievements into commercial applications. The relatively low willingness of life science PhD students to work in startups further reflects this emphasis. Approximately 40% of PhD students in Heidelberg report little or no interest in pursuing careers within startups, compared to just 24% in Munich.[30]

In addition, ventures based on therapeutics and biologics – Heidelberg's primary research areas – require substantial funding due to the intensive R&D demands and lengthy regulatory pathways involved. These areas carry particularly high investment risks compared to other biotech fields, such as MedTech.[31] Over 90% of new drugs fail the clinical trials required for approval, and this failure rate is even higher when accounting for drugs that do not reach the trial phase.[32] This high-risk profile tends to dampen venture capital interest, as the extended timelines and capital needs increase uncertainty and delay returns, limiting investor appetite for early-stage funding in these areas.

29 This includes institutions such as Max Planck Institute for Medical Research, the Heidelberg Institute for Stem Cell Technology and Experimental Medicine or the Institute of Molecular Biology.

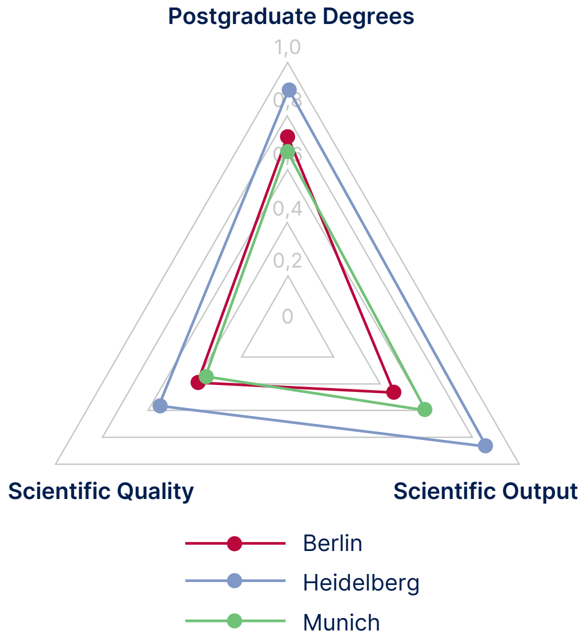
30 In response to the question regarding "Attractiveness of career options: Working in a startup company" (see variable id_4 – willingness to engage in entrepreneurship), 39% of respondents in Heidelberg rated this at 1 or 2 on a scale of 1 to 5, compared to 34% in Berlin and 24% in Munich.

31 MedTech involves devices and digital tools that support the delivery and monitoring of therapies, while therapeutics-based biotech focuses on biologically based therapeutics that modify or target disease mechanisms at the molecular or cellular level. MedTech is hardware-driven, whereas therapeutics are biology-driven.

32 Sun D, Gao W, Hu H, Zhou S. Why 90% of clinical drug development fails and how to improve it? Acta Pharm Sin B. 2022;12(7):3049-3062.

FIGURE 6 **Fundamental Research sub-index for the top three hubs**

This figure compares the various variables defining the Fundamental Research sub-index for Germany's three leading biotechnology hubs – Berlin, Munich, and Heidelberg – illustrating their respective strengths in academic research and scientific output within the biotech sector.



Source: Author's Own.

Moreover, until relatively recently, Heidelberg's startup infrastructure lacked the robust support available in hubs like Berlin and Munich, where venture capital, incubators, and entrepreneurial networks are firmly established. The fact that Heidelberg did not open its first major dedicated congress center – an essential venue for connecting researchers, investors, and industry leaders – until April 2024 highlights this gap.

These factors highlight Heidelberg's challenges in building a deep-tech venture ecosystem. However, they also underscore its significant potential. if the cluster can enhance its capacity to launch and fund biotech ventures. By strengthening venture support and funding mechanisms, Heidelberg could better translate its excellence in *Fundamental Research* into commercial success. Such improvements would position the hub as an even stronger contributor to Germany's biotech landscape.

4.3 Munich's unique performance in biotech venturing

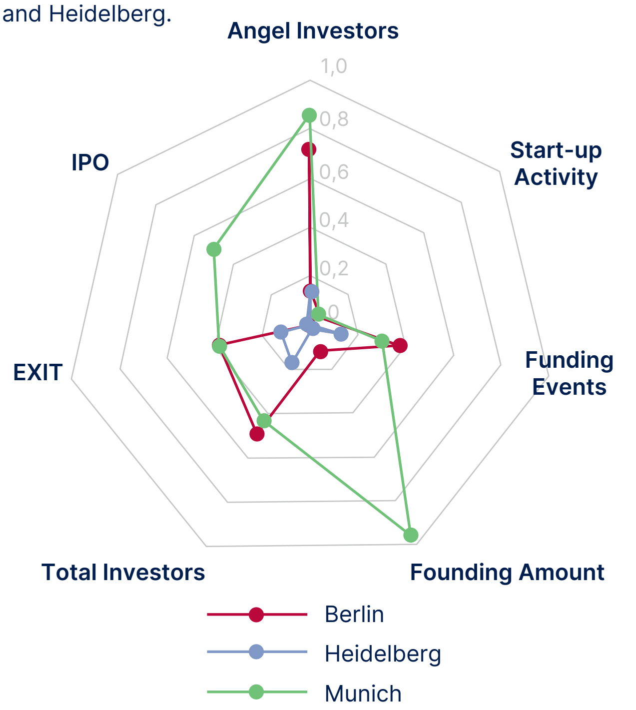
Our index clearly highlights that Munich's biotech cluster as the leader in *Biotech Venturing* in Germany, outperforming other hubs like Berlin and Heidelberg across nearly every metric in this sub-index. These include the number of angel investors, frequency of funding events, total funding volumes, and rate of successful exits (see Figure 7 for the radar chart of the sub-index *Biotech Venturing*). As Germany's oldest biotech cluster, Munich's BioM, founded in 1997, benefited early from national funding initiatives, establishing the region as a biotech hotspot. This initial boost attracted foundational companies like MorphoSys, which paved the way for a strong investment pipeline and set Munich apart in its ability to support large-scale biotech growth. In comparison, Berlin and Heidelberg, while significant biotech centers, are relatively younger clusters with less of the foundational momentum seen in Munich.

The maturity of Munich's biotech hub has cultivated a resilient network of seasoned entrepreneurs and executives who have successfully navigated the journey from startup to market-ready enterprises. Unlike Berlin, which boasts a dynamic but primarily early-stage startup ecosystem, or Heidelberg, with its focus on academic and research strengths, Munich has retained a wealth of experienced biotech leaders who have guided companies through advanced stages of growth. This entrepreneurial mindset also permeates Munich's scientific community. For instance, life science PhD students in Munich are 10% more likely to pursue opportunities in a startup environment compared to their peers in Berlin.[33]

33 In response to the question regarding "Attractiveness of career options: Working in a startup company" (see variable id_4 – willingness to engage in entrepreneurship), respondents in Munich answer 3.3 on a scale of 1-5, against 3 in Berlin. In addition, 12% of respondents in Munich expressed a strong interest in working a startup (rating 5), compared to 10% in Berlin.

FIGURE 7 **Biotech Venturing activities across major hubs**

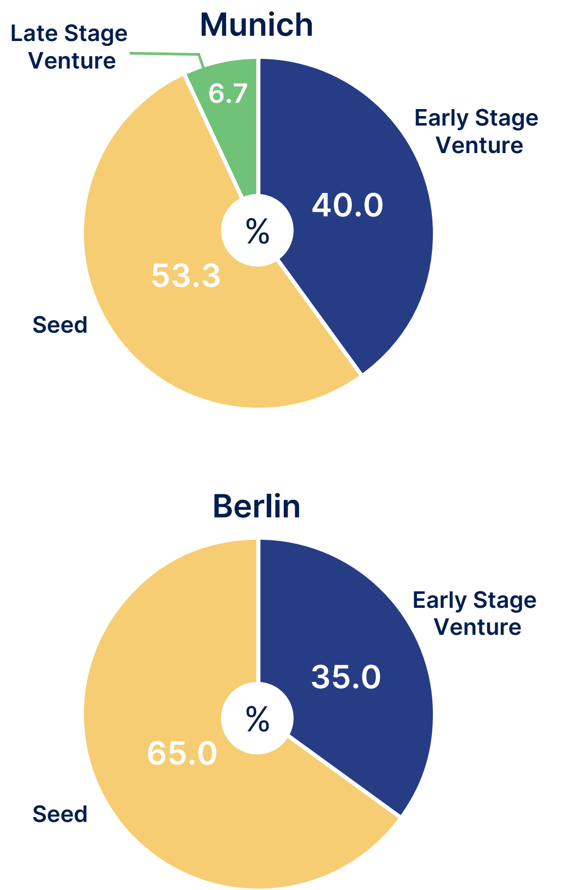
This figure illustrates Biotech Venturing activities for the primary biotechnology hubs in Germany, showcasing metrics such as startup formation, funding events, and investor engagement across Berlin, Munich, and Heidelberg.



Source: Author's Own.

FIGURE 8 **Percentage distribution of funding events**

by investment stage in 2023, with no late-stage investments recorded in Berlin.



Source: Author's Own.

These accomplished entrepreneurs and investors play essential roles in reinvesting in Munich's biotech community, supporting new ventures through targeted venture capital and mentorship. This reinvestment has shaped a unique funding landscape in Munich's ecosystem. While Berlin and Heidelberg primarily focus on seed and (to a lesser extent) early-stage funding, Munich's funding events also target later-stage ventures (see Figure 8). This approach demonstrates Munich's capacity to nurture companies through advanced growth stages, providing a robust platform for biotech firms to scale and succeed in the competitive market.

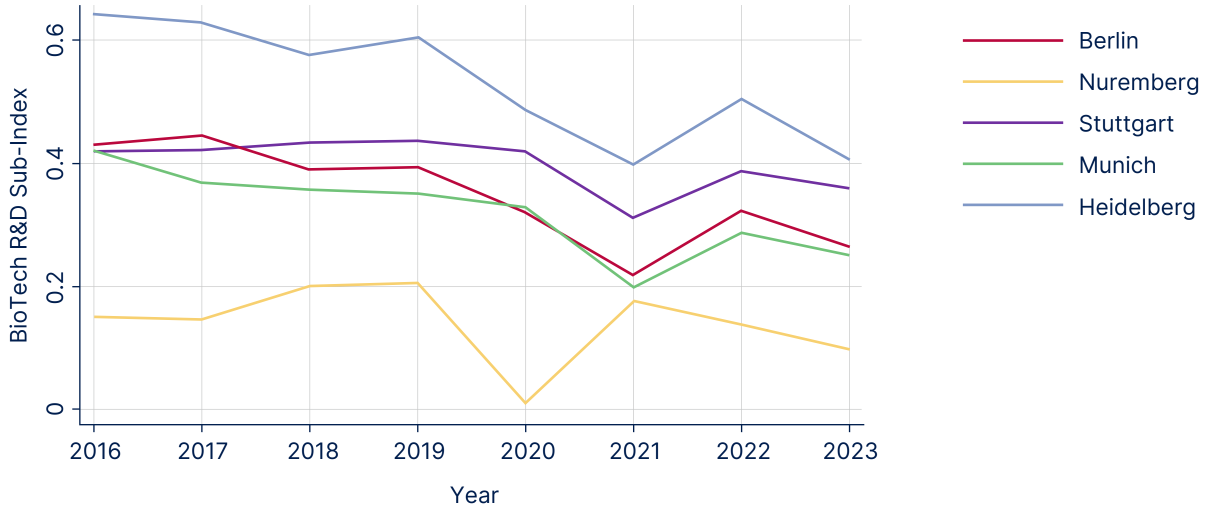
4.4 The decline in efficiency of Germany's biotech hubs

While our analysis highlights the potential and complementarity of Germany's biotech hubs, it also reveals a concerning trend: their declining ability to translate fundamental research into biotechnological advancements and successful ventures. Notably, the *Biotech R&D* sub-index – which measures a hub's capacity for biotech development, including patenting scientific discoveries – has consistently declined across all hubs over the past eight years. Although the COVID-19 pandemic temporarily reversed this trend by spurring renewed activity in biotech development, the 2023 sub-index values have fallen below their 2016 levels (see Figure 9).

The decline in *Biotech R&D* has led to reduced efficacy across Germany's biotech hubs. Specifically, the effectiveness of translating scientific

FIGURE 9 **Biotech R&D sub-index across all hubs (2016–2023)**

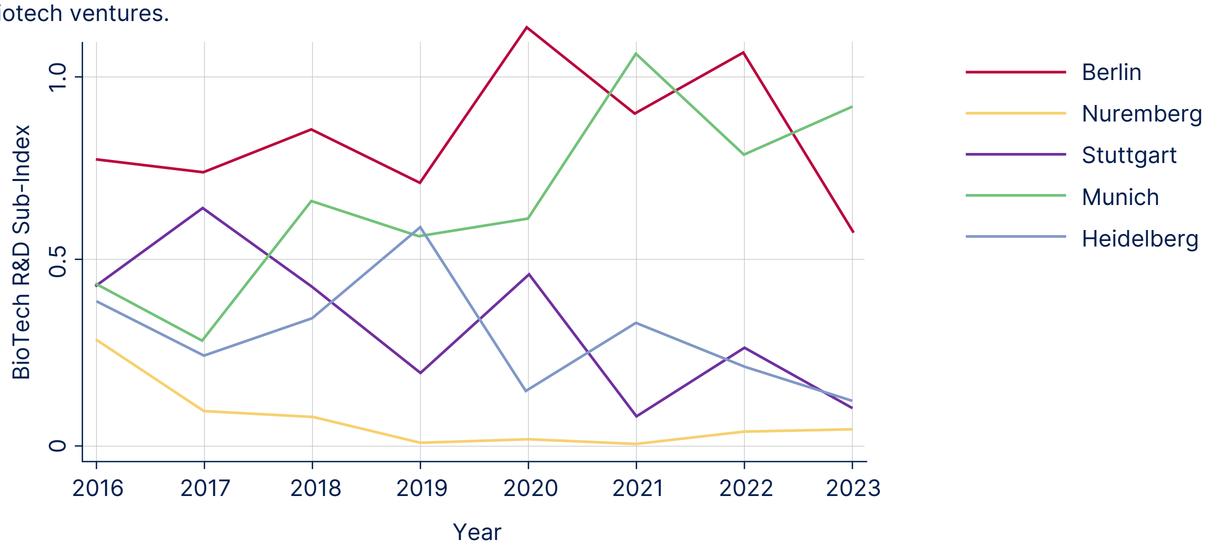
This figure displays the Biotech R&D Sub-Index for Germany's biotechnology hubs – Berlin, Munich, Heidelberg, Nuremberg, and Stuttgart – from 2016 to 2023, highlighting each hub's performance in research and development activities, including patenting and clinical trials.



Source: Author's Own.

FIGURE 10 **Overall efficiency of each hub (2016–2023)**

in Translating Life Sciences into Biotech Ventures. This figure shows the overall efficiency of Germany's biotechnology hubs – Berlin, Munich, Heidelberg, Nuremberg, and Stuttgart – from 2016 to 2023. Efficiency is measured as the ratio of Biotech Venturing to Life Sciences, reflecting each hub's capacity to convert foundational research into commercial biotech ventures.

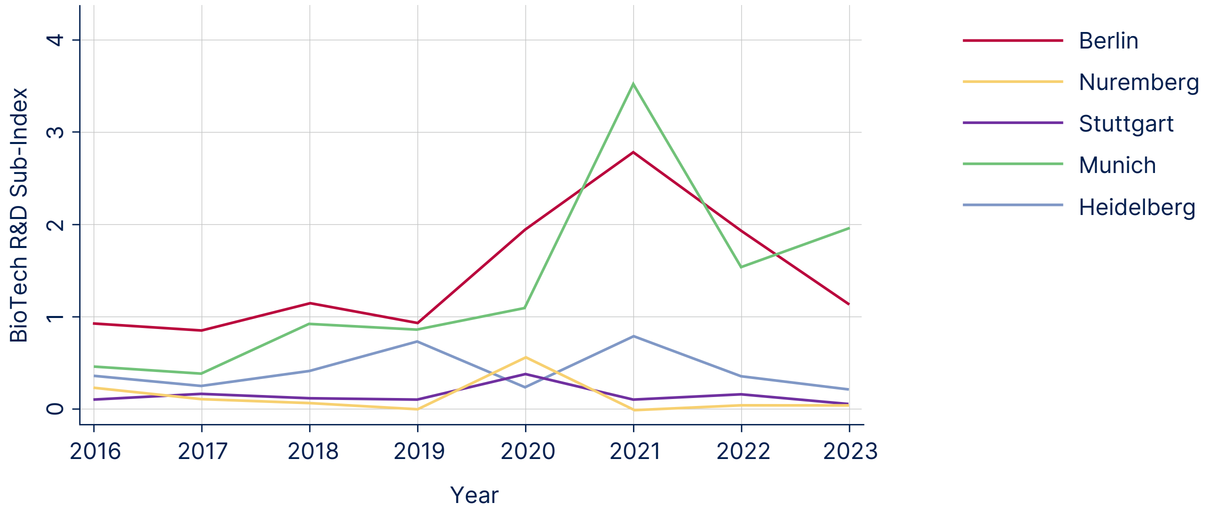


Source: Author's Own.

breakthroughs into biotechnologies can be measured by examining the *Biotech Venturing* sub-index as the output and the *Fundamental Research* as the input (see Figure 5). A hub's efficiency in this translation process is thus reflected in the ratio of its *Biotech Venturing* sub-index to its *Fundamental Research* sub-index. This metric provides insight into each hub's capacity to convert foundational research into commercially viable biotech ventures.

FIGURE 11 **Late-stage efficiency in converting biotech R&D into ventures (2016–2023)**

This figure illustrates the late-stage efficiency of Germany's biotechnology hubs – Berlin, Munich, Heidelberg, Nuremberg, and Stuttgart – from 2016 to 2023. Efficiency is measured as the ratio of Biotech Venturing to Biotech R&D, indicating each hub's effectiveness in transforming research and development into successful biotech ventures.



Source: Author's Own.

Figure 10 illustrates the efficiency of each hub over time in translating fundamental research into biotech ventures. The data shows a general decline in efficiency across most hubs, with Munich as the notable exception, as its efficiency appears to be on an upward trend.

Both Berlin and Munich experienced an efficiency boost during the COVID-19 pandemic; however, by 2023, Berlin's efficacy had fallen below pre-pandemic levels, while Munich continued to show improvement, indicating a strengthening of Munich's capacity to convert research into commercial biotech applications. Apart from the COVID-19 period, efficiency levels across all hubs remained below one, indicating a systemic inefficiency where each (normalized) unit of *Fundamental Research* input generates less than one (normalized) unit of *Biotech Venture* output.

Munich's improved efficiency is primarily driven by its strength in the later stages of the translation process, where it excels at converting patents and biotechnology developments into successful bio-tech ventures. In our framework, this downstream process is measured by using *Biotech R&D* as the input and *Biotech Venturing* as the output. A hub's late-stage efficiency is represented by the ratio of its *Biotech Venturing* sub-index to its *Biotech R&D* sub-index. Figure 11 shows late-stage efficiency across hubs over time, revealing relatively stable efficiency in most hubs, while Munich displays a distinctive upward trend. This trend can be attributed to Munich's maturity as a biotech hub, where experienced entrepreneurs and venture capitalists provide critical expertise in securing both early- and later-stage funding.

5 Outlook

The methodology introduced in this study can be expanded to other emerging technologies, such as next-generation computing and space tech, as well as additional European hubs. Including major European biotech centers like London, Paris, and Amsterdam would enable broader benchmarking, providing a more comprehensive view of Germany's position within the European biotech ecosystem. This expanded scope would highlight Germany's strengths and identify areas for potential development relative to other leading hubs.

While most sub-indices would remain consistent across different technologies, specific updates would be needed to tailor the index to each technology. Key sub-indices such as *Fundamental Research*, *Biotech R&D* (with the exception of clinical trials), *Biotech Venturing*, and *Business Environment & Entrepreneurship* would require adjustments to reflect the unique attributes of each technology.

However, the relevant public infrastructure captured in the *Public Infrastructure* sub-index would vary significantly depending on the technology. For instance, the current sub-index includes data points related to hospitals, which are crucial for biotech but may be less relevant for other technologies. To ensure consistency across European hubs, alternative national data sources will also be necessary for certain variables. Currently, seven of the 23 variables in the index rely on German-specific data sources.

Finally, annual updates to the index with the most recent data will also be essential to capture evolving trends in the European deep-tech sector and maintain the index's relevance as a benchmarking tool.

By implementing these steps, the index can be refined and adapted to assess and benchmark biotech and other emerging technology hubs across Europe.

6 Conclusion

This analysis has highlighted significant strengths and challenges of Germany's main biotech innovation clusters. Berlin, Munich, and Heidelberg emerge as leading biotech centers, each with unique assets. Berlin excels in infrastructure and venture activity, Munich shows pronounced success in venture support and later-stage funding, and Heidelberg demonstrates a robust foundation in scientific research and biotech R&D. However, the persistent gap in commercialization and venture activity between Heidelberg and the other hubs underscores the need for improved support mechanisms to fully leverage its research output.

The study also reveals a concerning trend in the declining efficiency of German biotech hubs to transform foundational research into market-ready ventures. With Munich as a notable exception, many hubs have struggled to maintain the momentum seen during the COVID-19 pandemic, indicating potential systemic inefficiencies. Overall, Germany's capability in biotech innovation appears fragmented and shows little progress in strengthening its capacity to innovate in this sector.

Despite these challenges, the complementary strengths of these hubs suggest that integrating their capabilities could form a globally competitive German biotech innovation cluster. Unfortunately, the apparent lack of collaboration between hubs hinders Germany from fully harnessing the distinct assets each region offers. Each ecosystem seems to focus on developing its own local networks, relying on state funding and private investments that primarily benefit their immediate communities. This issue is exacerbated by the structure of federal initiatives, which support innovation but often distribute resources across multiple regions (15 in the case of the EXIT Startup Factories program).[34]

Economists have long highlighted the importance of resource concentration in driving technological

34 https://startup-factories.de/

innovation.[35] The density of a skilled workforce provides diverse learning opportunities, fostering cross-disciplinary knowledge exchange and enabling groundbreaking innovations.[36] Our study supports this, showing that the number of PhD students in life sciences and related fields within a hub is linked to greater biotech innovation. Moreover, it has been established that knowledge exchange and innovation within dense European hubs enhance regional economic performance, particularly in technologically advanced areas with strong innovation capacities.[37]

This positive effect of concentration helps explain the shift in the geography of innovation over the past two decades, which has evolved into a globalized hub-to-hub system.[38] This shift has given rise to a few highly concentrated deep-tech clusters, such as Boston in the United States and London in the United Kingdom, in the biotechnology sector. Germany, however, lacks such a dense cluster due to its highly decentralized hub system, which may exacerbate its deep-tech gap. For example, in 2023, investment in biotech ventures in London was 25% higher than the combined investment across the five German hubs analyzed in this study. [39]

Our findings underscore the urgent need to foster greater integration among Germany's biotech hubs. While the country's decentralized political system has certain advantages, it poses significant challenges for developing deep-tech innovation capabilities. To the best of our knowledge, no decentralized hub system has successfully replicated the benefits of resource density in the deep-tech sector, and there are few best practices to guide such efforts. If Germany wants to remain competitive with a decentralized system, it must innovate in building bridges across its clusters. At a minimum, policymakers should shift from duplicating efforts to funding initiatives that actively promote cross-hub collaboration.

Overall, this study has developed a robust index capable of offering meaningful insights into key trends and patterns across Germany's main biotech hubs. The methodology can provide a valuable tool for analyzing and understanding the evolution of similar technology clusters in other European countries. Expanding this approach would, however, require adaptations to account for the unique characteristics of each technology sector and the availability of national datasets.

35 For instance, denser metropolitan areas exhibit higher rates of patenting - see Carlino et al. (2007)

36 Berkes, E., & Gaetani, R. (2020). The geography of unconventional innovation. The Economic Journal, 131(636), 1466–1514. DOI: 10.1093/ej/ueaa111.

37 Cortinovis, N., & van Oort, F. (2015). Variety, economic growth and knowledge intensity of European regions: A spatial panel analysis. Annals of Regional Science, 55, 7–32. DOI: 10.1007/s00168-015-0680-2.

38 World Intellectual Property Organization (WIPO). (2019). World Intellectual Property Report 2019: The geography of innovation: Local hotspots, global networks. Geneva: World Intellectual Property Organization. DOI: 10.1093/ej/ueaa111.

39 Analysis based on Crunchbase data on total investments in biotech ventures, excluding seed funding.

Appendix

1 Definition of hubs

Berlin hub includes the following administrative regions: Berlin, Brandenburg, Bernau, Biesenthal, Birkenwerder, Blankenfelde-Mahlow, Eberswalde, Erkner, Hennigsdorf, Kleinmachnow, Luckenwalde, Marienwerder, Neuenhagen, Potsdam, Schoeneiche, Schönefeld, Teltow, Wildau, Zossen.

München hub includes the following administrative regions: Munich, Aschheim, Augsburg, Dachau, Eching, Erding, Feldkirchen, Finning, Forstinning, Freising, Garching, Gauting, Geretsried, Germering, Gilching, Gräfelfing, Grafing, Grafrath, Greifenberg, Grobenzell, Grunwald, Haag in Oberbayern, Haar, Halfing, Herrsching, Hohenkirchen-Siegertsbrunn, Holzkirchen, Ismaning, Jetzendorf, Karlsfeld, Kirchdorf (an der Amper), Kirchseeon, Landsberg am Lech, Langenbach, Neubiberg, Oberding, Oberhaching, Odelzhausen, Ottobrunn, Penzberg, Pfaffenhofen (an der Ilm), Planegg, Poing, Puchheim, Pullach, Rohrdorf, Rosenheim, Seefeld, Starnberg, Stephanskirchen, Sulzemoos, Taufkirchen, Unterfoehring, Unterhaching, Vaterstetten, Warngau, Webling, Weilheim in Oberbayern, Pfaffenhofen (an der Glonn).

Heidelberg hub includes the following administrative regions: Heidelberg, Bad Homburg, Bad Vilbel, Eschborn, Hofheim, Kelkheim, Kronberg im Taunus, Langen, Neu-Isenburg, Offenbach, Oberursel, Schwalbach am Taunus, Rödermark, Rodgau, Dietzenbach, Maintal, Mühlheim (am Main), Hanau, Hattersheim (am Main), Flörsheim (am Main), Raunheim, Rüsselsheim, Rüdesheim (am Rhein), Wiesbaden, Mainz, Dreieich, Mörfelden-Walldorf, Egelsbach, Kelsterbach, Griesheim, Bad Soden, Sulzbach, Oberursel (Taunus), Kronberg im Taunus, Darmstadt, Adelsheim, Bad Schonborn, Brackenheim, Bretten, Bruchsal, Deidesheim, Dieburg, Durmersheim, Eggenstein-Leopoldshafen, Erbach im Odenwald, Ettlingen, Fischbachtal, Griesheim, Heilbronn, Herxheim, Ispringen, Karlsruhe, Kirchardt, Knittlingen, Lauffen am Neckar, Ludwigshafen, Mannheim, Maxdorf, Neckarsulm, Osterburken, Pfinztal, Pforzheim, Pfungstadt, Reinheim, Rheinstetten, Rulzheim, Sankt Leon-Rot, Schifferstadt, Speyer, Stutensee, Vaihingen an der Enz, Waghausel, Waibstadt, Walldorf, Weinheim, Weiterstadt, Worms, Zwingenberg.

Nuremberg hub includes the following administrative regions: Nürnberg, Fürth, Erlangen, Schwabach, Stein, Roth, Herzogenaurach, Cadolzburg, Feucht, Oberasbach, Zirndorf, Altdorf bei Nürnberg, Langenzenn, Neumarkt in der Oberpfalz, Röthenbach an der Pegnitz, Lauf an der Pegnitz, Hersbruck, Rothenburg ob der Tauber, Ansbach, Heilsbronn, Weißenburg, Treuchtlingen, Gunzenhausen, Bad Windsheim, Emskirchen, Höchstadt an der Aisch, Scheinfeld, Uffenheim, Wendelstein, Schwanstetten, Rednitzhembach, Feuchtwangen, Dinkelsbühl, Erlangen-Höchstadt.

Stuttgart hub includes the following administrative regions: Stuttgart, Aichtal, Backnang, Bempflingen, Besigheim, Bietigheim-Bissingen, Bissingen an der Teck, Böblingen, Ditzingen, Esslingen am Neckar, Fellbach, Filderstadt, Gerlingen, Heimsheim, Herrenberg, Holzgerlingen, Kernen im Remstal, Kirchheim unter Teck, Kornwestheim, Korntal-Münchingen, Künzelsau, Leinfelden-Echterdingen, Leonberg, Löchgau, Ludwigsburg, Magstadt, Markgröningen, Möglingen, Mühlacker, Nagold, Nürtingen, Ostfildern, Plochingen, Reichenbach an der Fils, Remseck am Neckar, Renningen, Rutesheim, Schönaich, Sindelfingen, Steinheim an der Murr, Stuttgart, Tamm, Tübingen, Uhingen, Vaihingen an der Enz, Waiblingen, Weil der Stadt, Weinstadt, Weißach, Wendlingen am Neckar, Winnenden.

2 Variable Definition and Data Source

2.1 Variable identification

To evaluate this process, we identified variables that closely represent each stage by applying four criteria: 1) relevance to the process, 2) availability from a reliable data source, 3) comprehensiveness to characterize the process, and 4) minimal overlap among variables to prevent double counting. In particular with respect to 2), since our goal is to develop this index at the hub level, it is essential to measure these variables at the municipal level.

The following outlines the variables identified for the various stages of the translation process depicted in the translation figure above.

Fundamental Research: Most scientific breakthroughs with potential for innovation are predominantly driven by PhD students and postdoctoral researchers, who play a pivotal role in transforming ideas into ventures. To capture this initial stage, we measure the number of PhD students and postdoctoral researchers in the life sciences for each city. Additionally, we assess both the quantity and quality of scientific output. We have intentionally excluded senior researchers, such as established professors, as their critical contributions to biotech innovation – such as co-founding or joining the board of ventures – are sufficiently reflected in the quality of the scientific output.

Patenting the Idea: The next stage involves assessing the quantity and quality of patents, a widely recognized metric in innovation research. A key challenge is attributing patents to the city where the idea was originally conceived.

Seed Funding a Venture: Angel investors and grants are the primary funding sources for biotech ventures. hile grant data proved inaccessible despite our efforts, grants are typically awarded based on the scientific quality of a project – a factor already captured in earlier stages of our analysis.

A critical element overlooked by existing indices of deep-tech innovation is the willingness of young scientists to transition from academia to entrepreneurship. Academic research has shown that this factor is particularly significant in the United States (Roach and Sauermann 2016). The omission of this aspect in other indices is primarily due to the challenges associated with measuring individuals' intentions and risk aversion. However, we have located a survey that monitors the socioeconomic backgrounds of all PhD students in Germany. Within this survey, two questions specifically assess the willingness to engage in entrepreneurship.

R&D to de-risk the idea & Additional R&D: This stage has the least available data, as progress within a venture's research development is typically highly confidential. Besides the founders, investors, who are closest to these developments, provide the most reliable insights. Therefore, we use the level of private funding as a proxy to gauge the state and quality of the research conducted within the venture.

Additional funding rounds: Measuring additional funding rounds is standard in entrepreneurship research. This typically involves tracking the frequency and size of funds raised, as well as the total number of investors participating.

Exit: In the biotech sector, successful ventures are often acquired by larger organizations, particularly pharmaceutical companies, which have the resources and capabilities to conduct clinical trials. Initial public offerings, usually on the Nasdaq exchange, are another potential outcome, though less common. Due to the infrequency of exits, we are considering a five-year moving window to better capture trends over time.

Clinical Trials: Successful exits usually generate sufficient funds to finalize the technology, conduct costly clinical trials, and ultimately bring the innovation to market. We assess this by measuring the number of compounds in both pre-clinical and clinical trials. However, attributing clinical trials to the city where the original invention occurred remains a challenge.

FDA/EMA Approval: The final stage in the translation process is obtaining approval from from the FDA in the U.S. or the EMA in Europe, based on clinical trial results. However, we have chosen to exclude this stage from our analysis due to the typical 12-year lag between a venture's formation and obtaining approval for successful innovations. As a result, success at this stage reflects the state of the cluster over a decade ago rather than its current status.

2.2 Enablers of the translation process

In addition to the translation process itself, we consider variables that indirectly contribute to the success of a cluster. These variables are selected based on two criteria: 1) they influence innovation indirectly, and 2) do not overlap with those already included in the translation process, ensuring there is no redundancy.

Business & entrepreneurship environment: We assess the overall business and entrepreneurship culture of the hub, specifically excluding biotech-related aspects to avoid overlap with the metrics used in the translation process.

Hospitals: Hospitals play a pivotal role in biotech innovations as they provide opportunities to adapt and test ideas in line with the clinical needs of patients and to understand the practical implications of implementing these innovations in a clinical setting. We measure this by counting the number of beds and hospitals in the hub.

Universities: While activities related to fundamental research in life sciences are already included inputs in the translation process, other academic fields can also impact biotech innovation. To capture this, we consider the number of PhDs in STEM, business, and economics. Additionally, the number of undergraduates in these fields, as well as in life sciences, is included, as they a valuable talent pool for ventures.

2.3 Summary and data sources

TABLE 3 **Sub-index blocks, variables, definitions, and data sources for Biotech Hub Index**

Sub-index	Sub-Index ID Number	Performance Indicator	Description	Data Source
Life Science Fundamental Research	1	Total number of postgraduate degrees in biotechnology and medicine	Number of PhD students in departments related to biotechnology and medicine	DeStatis Statistisches Bundesamt, Statista, Statistisches Landesamt Rheinland-Pfalz, Bayerischen Landesamts für Statistik, Amt für Statistik Berlin-Brandenburg, Statistisches Landesamt Baden-Württemberg, Hessisches Statistisches Landesamt
	2	Scientific output quantity in biotechnology: publications	Number of biotechnology-related scientific publications at the hub level since 2016	Web of Science
	3	Scientific output quality in biotechnology: citations	Quality index that is developed by using citations of the identified publications on hub level	Web f Science
Biotech R&D	4	Willingness to engage in entrepreneurship	Total number of PhDs working in Life Sciences and STEM fields, interested in turning research into work	NASCAP
	5	Patents in biologics: quantity	Number of biotechnology-related patents filed since 2016 on hub level	ESMT Internal
	6	Patents in biologics: quality	A quality index is developed by using backward and forward citations of patents in variable five	ESMT Internal
	7	Clinical trials	Clinical studies conducted within the biotechnology sector across the identified hubs	Clinicalgov.com (National Library of Medicine – National Centre for Biotechnology Information)

Sub-index	Sub-Index ID Number	Performance Indicator	Description	Data Source
Biotech Investments & Biotech Venturing Activities	8	Companies funded by angel investors	Number of companies funded by angel investors each year. Data includes companies only in biotech sector	Crunchbase
	9	Startup activity in biotechnology	Number of companies established in selected regions each year. Data focuses only on biotech companies	Crunchbase
	10	Private funding events in biotechnology	Number of private investment events received by companies in biotechnology each year. Only investment events that are included in the Crunchbase database are included	Crunchbase
	11	Private funding in biotechnology	Funding received through private investment across the biotechnology space each year. Investment dollars are tied to the investment events above	Crunchbase
	12	Total number of investors for biotechnology	Number of unique investors investing in biotech sector each year	Crunchbase
	13	EXIT – Number of companies that have been sold to pharmaceutical companies	Number of companies have been sold to pharmaceutical companies each year	Crunchbase
	14	IPO	The number of biotech companies that go public each year through an IPO	Crunchbase
Public Infra-sturucture (University) Public Infra-sturucture (University)	15	Total undergraduate degrees in biotechnology, biology and pharmacy	Number of students in undergraduate, bachelor's or equivalent level for life sciences (STEM, economics, business, biotech, biology and pharmacy)	DeStatis Statistisches Bundesamt, Statista, Statistisches Landesamt Rheinland-Pfalz, Bayerischen Landesamts für Statistik, Amt für Statistik Berlin-Brandenburg, Statistisches Landesamt Baden-Württemberg, Hessisches Statistisches Landesamt
	16	Total number of PhDs and Post Docs (all STEM+ Economics + Business)	Number of PhD and Post Docs in all STEM, economics and business fields, except biotech, biology and pharmacy to prevent double counting	DeStatis Statistisches Bundesamt, Statista, Statistisches Landesamt Rheinland-Pfalz, Bayerischen Landesamts für Statistik, Amt für Statistik Berlin-Brandenburg, Statistisches Landesamt Baden-Württemberg, Hessisches Statistisches Landesamt

Sub-index	Sub-Index ID Number	Performance Indicator	Description	Data Source
Public Infra-structure (Hospitals)	17	Number of hospitals	Number of hospitals in the hub regions, encompassing publicly owned hospitals, not-for-profit private hospitals, and for-profit private hospitals	DeStatis Statistisches Bundesamt, Statista, Statistisches Landesamt Rheinland-Pfalz, Bayerischen Landesamts für Statistik, Amt für Statistik Berlin-Brandenburg, Statistisches Landesamt Baden-Württemberg, Hessisches Statistisches Landesamt
	18	Number of beds	Total number of hospital beds in hub regions, covering publicly owned hospitals, not-for-profit private hospitals, and for-profit private hospitals	DeStatis Statistisches Bundesamt, Statista, Statistisches Landesamt Rheinland-Pfalz, Bayerischen Landesamts für Statistik, Amt für Statistik Berlin-Brandenburg, Statistisches Landesamt Baden-Württemberg, Hessisches Statistisches Landesamt
Business Environment & Entrepre-neurship	19	Willingness to engage in entrepreneurship for all the rest	Total number of PhDs working in all fields (except life sciences and STEM), interested in turning research into work	NASCAP
	20	Companies funded by angel investors for all, excluding biotech	Number of companies funded by angel investors each year. Data includes companies in all sectors, except biotech	Crunchbase
	21	Private funding events for all except biotech	Number of private investment events received by companies in all sectors (except biotech) each year. Only investment events that are included in the Crunchbase database are included	Crunchbase
	22	Private funding for all except biotech	Funding received through private investment across all sectors (except biotech) each year. Investment funds are tied to the investment events above	Crunchbase
	23	Total number of investors for all except biology	The number of unique investors investing in all sectors except biotech each year	Crunchbase
Other	24	Population	Population data available for the respective hubs	DeStatis Statistisches Bundesamt, Statista, Statistisches Landesamt Rheinland-Pfalz, Bayerischen Landesamts für Statistik, Amt für Statistik Berlin-Brandenburg, Statistisches Landesamt Baden-Württemberg, Hessisches Statistisches Landesamt

Source: Author's Own.

3 Building the index and robustness check

Our approach to constructing the index begins by normalizing the various variables, enabling their aggregation. The index is then created through a linear aggregation of these normalized variables.

3.1 Normalization methods

3.1.1 Min-max normalization (main approach)

Min-max normalization serves as the primary approach for constructing the Biotechnology Hub Index in this study. To ensure comparability among variables, we apply min-max normalization to each variable. This technique scales each variable to a range between 0 and 1. Specifically, the normalized value for variable v_i^h of hub h (where i is the variable's ID) is calculated as follows:

$$\text{normalized } v_i^h = \frac{v_i^h - \min(v_i)}{\max(v_i) - \min(v_i)}$$

where $\min(v_i)$ and $\max(v_i)$ represent the minimum and maximum values of variable v_i across the five hubs. This normalization ensures that all variables are transformed into a common scale, facilitating comparability within the index.

3.1.2 Z-score normalization

As a secondary approach, we apply Z-score normalization to serve as a robustness check for our primary min-max normalized index. This technique ensures comparability among variables by rescaling them based on their standard deviation, providing an alternative perspective on the data. While various normalization methods exist, we chose the Z-score approach to examine the consistency of results and further validate the index structure.

Specifically, the z-score for variable v_i^h of hub h (which corresponds to ID=i) is equal to

$z_i^h = \frac{v_i^h - \mu_i}{\sigma_i}$ where $\mu = \frac{1}{5}\sum_{h=1}^{5} v_i^h$ is the average and $\sigma_i = \sqrt{\frac{\sum_{i=1}^{4}(v_i^h - \mu_i)^2}{5}}$ the standard deviation of variable v_i^h (with five hubs).

This method gives greater weight to an indicator in those hubs with extreme values. In this sense, we seek to reward "exceptional" behavior. In contrast, other scaling methods might exaggerate the importance of indicators with little variation across data points.

3.2 Aggregation methods

3.2.1 Linear aggregation (Method 1)

The index corresponds then to a weighted average of the sub-indices. Formally, the index i for hub h is equal to, given that we have 23 variables,

$$I^h = \sum_{i=1}^{23} w_i \times z_i^h \quad (1)$$

where w_i corresponds to the weight associated with normalized variable z_i. Note that the weights are themselves normalized such that they add to one, i.e. $\sum_{i=1}^{23} w_i = 1$.

3.2.2 Sub-indexing (Method 2 – primary approach)

Not all variables seem to contribute equally to the ability to translate research into impactful innovations. For example, patenting should carry more weight than the total number of undergraduates in a hub.

To address this disparity, we organize the variables into blocks, each representing a cohesive sub-index. This approach allows us to identify sub-indices that contribute equally to the overall index, offering a less stringent alternative to imposing equal weights on all variables.

We have identified five distinct blocks that collectively represent different stages of the translation process and the enabling factors.

Block/Sub-Index	Variables ID	# Variables
1 – Fundamental research	1-3	3
2 – Biotech R&D	4-7	4
3 – Biotech Venturing	8-14	7
4 – Public Infrastructure	15-18	4
5 – Business Environment	19-23	5

This partition yields the following weights for the linear aggregation of I_h.

Block/ Sub-index	#Variables	w_i of the variables within each block
1	3	0.07
2	4	0.05
3	7	0.03
4	4	0.05
5	5	0.04

Each of the five sub-indices is assigned an equal weight of 1/5. Within each block, the variables contribute equally to their respective sub-index, with each variable's weight determined by dividing 1 by the number of variables in that block (#Variables). The final weight of a variable is thus calculated as 1/5 multiplied by 1/#Variables. For example, the weight of each variable in the first block, which contains three variables, is 1/5 x 1/3 = 0.067.

Note that alternative partitioning into blocks is possible, which induces different weights for the variables. We may adjust the proposed blocks to ensure the robustness of the index (see Section 5). Further refinement of the individual weights within each block may also be necessary.

3.2.3 Rank sum (Method 3)

To test the robustness of our main approach, we employ an alternative method that does not rely on a linear aggregation of variables. Instead, this method ranks the hubs for each variable and calculates the total by summing these rankings across all variables. This approach relies on ordinal rather than absolute data.

More specifically, the index is equal to

$R_h^{Sum} = \sum_{i=1}^{23} Rank_i^h$ where $Rank_i^h$ denotes

the rank (between 1 and 5 with five hubs) of hub h with respect to variable ID=i. Note that in this case, a lower value of R_h indicates a more innovative hub.

3.3 Robustness check

Our primary approach, method 2, employs a sub-indexing technique, while methods 1 and 3 serve as benchmarks to assess our index's robustness and performance. By comparing our index with one derived from a linear aggregation method (Method 1), we can evaluate the effects of our chosen blocks and sub-indices on the index structure. Additionally, by comparing it with the sum rank method (Method 3), which is less sensitive to extreme values, we gain insights into the potential influence of outliers on our results.

3.3.1 Robustness to normalization

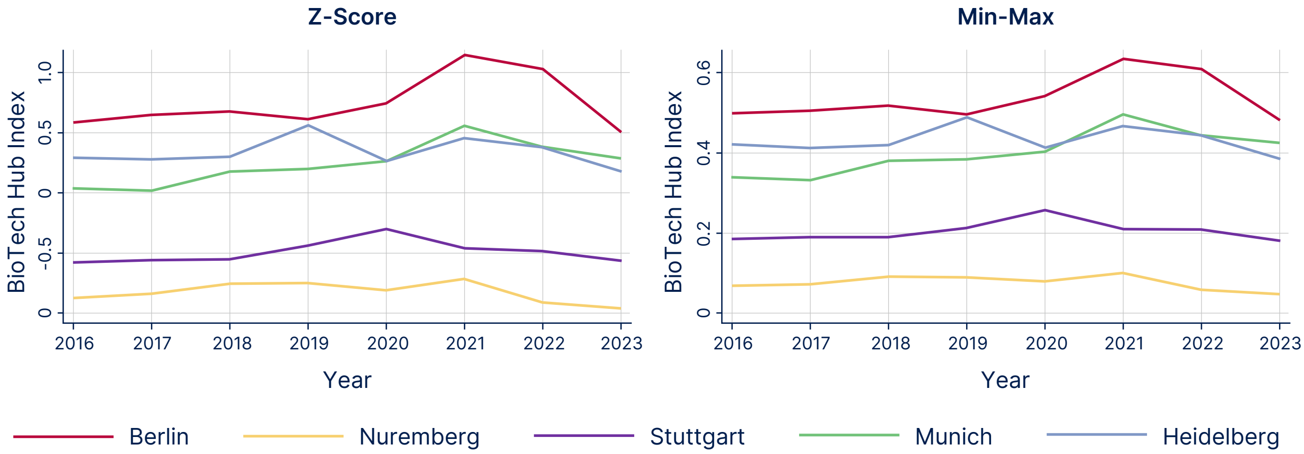
Using min-max normalization, we scale each variable between 0 and 1, which highlights the relative highest and lowest values within each variable's range. This approach accentuates the strengths of hubs that perform exceptionally well in specific metrics, such as Heidelberg in areas like *Life Sciences Research* and *Biotech R&D*, by stretching their top scores to the maximum value (1) in the normalized range. As a result, min-max normalization emphasizes each hub's standout areas, especially where it consistently ranks high.

In contrast, z-score normalization standardizes values based on their distance from the mean, which brings attention to deviations from the average performance across hubs. This method captures more variation in each hub's performance, highlighting fluctuations around their average. Z-score normalization thus provides a more balanced perspective, showcasing each hub's strengths while also exposing areas where performance falls below average. This approach is particularly useful for identifying both stable strengths and year-to-year variability in hubs like Berlin or Munich.

The overall index trends are consistent between the min-max and z-score normalization methods. In both, Berlin, Munich, and Heidelberg consistently rank as the top three hubs, while Stuttgart and Nuremberg maintain lower rankings. However, the z-score normalization highlights more subtle shifts within the dominant hubs over time. Notably, Munich's upward trajectory post-COVID

FIGURE 12 **Biotechnology Hub Index (2016–2023) using z-score normalization and using min-max normalization.**

The figure on the left displays the overall Biotechnology Hub Index calculated using z-score normalization for the years 2016 to 2023, while the figure on the right shows the index calculated using min-max normalization for the same period.



Source: Author's Own.

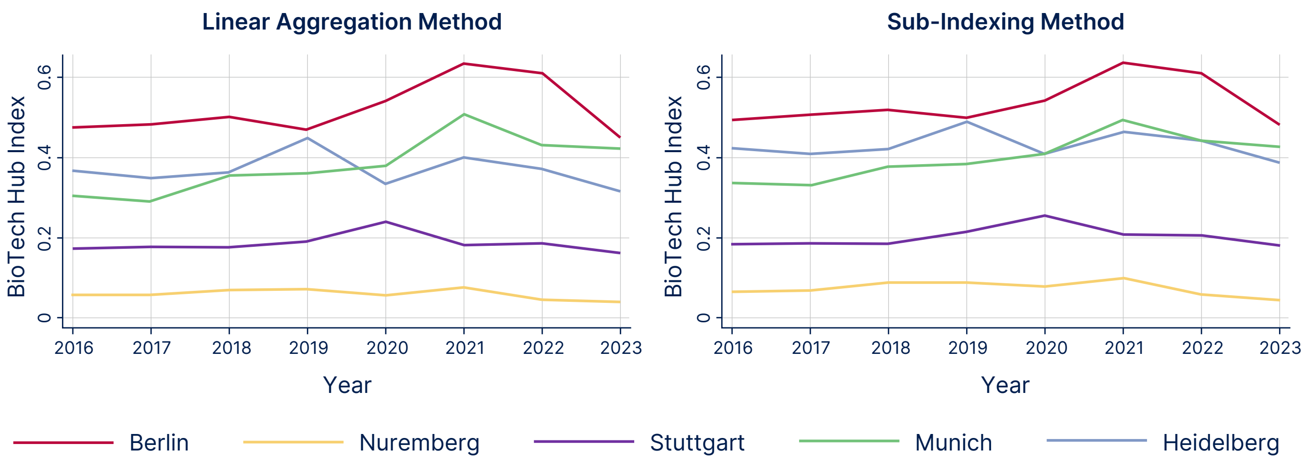
appears more pronounced with z-score scaling, suggesting stronger growth in biotech commercialization efforts than is visible with min-max normalization.

3.3.2 Robustness to aggregation

When applying the linear aggregation method, Berlin consistently ranks as the hub with the highest index throughout the period from 2016 to 2023. Munich and Heidelberg follow, with notable shifts between them over time. Heidelberg's index score sees a notable increase in 2019, mirroring trends observed with the sub-indexing method. Figure 13 highlights the shifting dynamics between Munich and Heidelberg, especially during the COVID-19 period and its aftermath. Munich shows a distinct upward trend, illustrating its resil-

FIGURE 13 **Biotech Hub Index across all hubs using linear aggregation and sub-indexing methods**

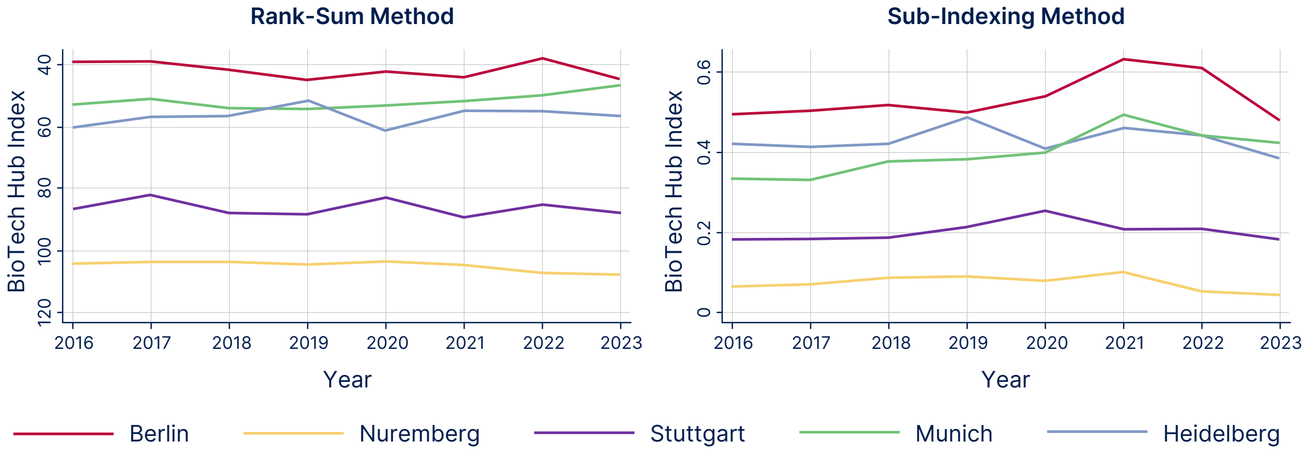
The figure on the left presents the Biotech Hub Index for Germany's biotechnology hubs – Berlin, Munich, Heidelberg, Nuremberg, and Stuttgart – calculated using the linear aggregation method. This method combines sub-index scores to generate an overall index, providing a comprehensive view of each hub's performance across key biotech indicators. The figure on the right displays the Biotech Hub Index calculated using the sub-indexing method.



Source: Author's Own.

FIGURE 14 **Comparison of Biotech Hub Indices using rank sum and sub-indexing methods (2016–2023)**

This figure compares Germany's biotechnology hubs – Berlin, Munich, Heidelberg, Nuremberg, and Stuttgart – using the rank sum and sub-indexing methods from 2016 to 2023. The rank sum method ranks each hub by variable and aggregates these ranks, offering an alternative comparison that reduces the impact of outliers, highlighting consistent patterns in hub performance over time.



Source: Author's Own.

ience and growth during these challenging years. In contrast, Nuremberg and Stuttgart maintain relatively stable but lower index values across the period.

When comparing the two graphs, the primary difference lies in Munich's performance relative to other cities. In the first graph (using the linear aggregation method), Munich's index is notably higher than Heidelberg's and shows a steady increase, positioning it above several other hubs. In contrast, the second graph (sub-indexing method) positions Munich slightly lower, with a narrower gap between Munich and Heidelberg, offering a more balanced perspective across the hubs. The overall trends for Berlin, Nuremberg, and Stuttgart remain relatively stable across both graphs, while Munich's performance is more pronounced under the linear aggregation approach.

The rank sum index graph (Figure 14) provides a longitudinal comparison of biotech hubs from 2016 to 2023. Berlin consistently ranks as the leading hub throughout the period, indicating its dominance in the biotech landscape. Munich and Heidelberg follow, with Munich showing a gradual rise over time and even surpassing Heidelberg in some years, particularly from 2020 onward. This upward trend for Munich suggests its increasing strength and resilience, particularly during and following the COVID-19 pandemic, potentially reflecting growth in entrepreneurial activity and investment in the sector.

Heidelberg maintains a strong but slightly more stable position, reflecting its foundational role in biotech, which is possibly due to its academic and research infrastructure. On the other hand, Nuremberg and Stuttgart display lower and more stable index values across the years, indicating that their biotech ecosystems are comparatively smaller and less dynamic.

Overall, these results indicate that the index based on min-max normalization and sub-indexing is fairly robust to variations in aggregation and scaling methods.

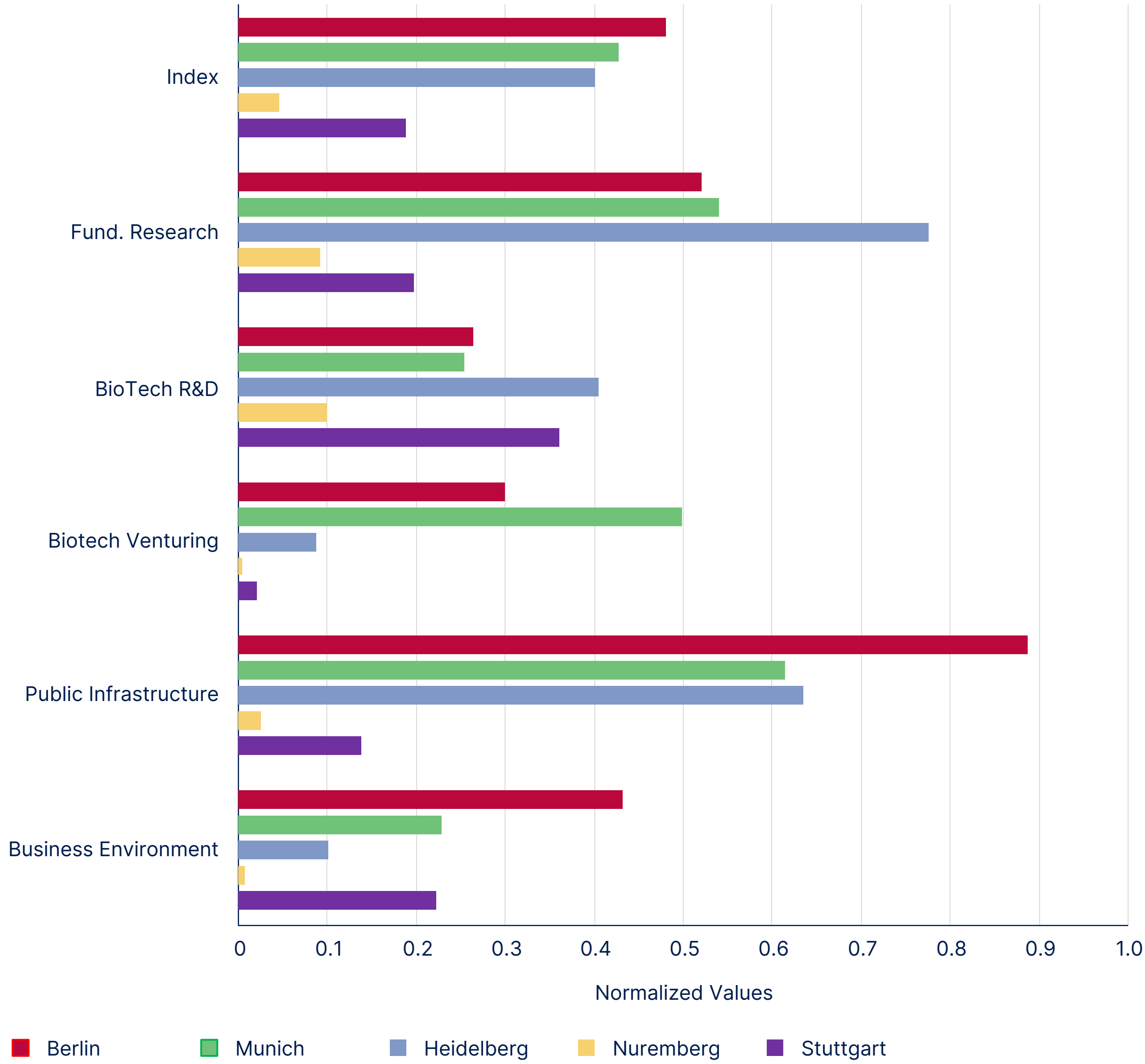
4 Hub comparison: detailed results

In this appendix, we present detailed results comparing the index of the five innovation hubs. We begin with a focus on 2023, followed by an analysis of trends from 2016 to 2023.

4.1.1 Main index and sub-indices for 2023

FIGURE 15 **Biotech Hub Index and sub-index scores across major hubs**

This figure displays the overall Biotech Hub Index alongside its constituent sub-index scores – Life Science Research, Biotech R&D, Biotech Venturing, Public Infrastructure, and Business Environment – for Germany's primary biotechnology hubs. The visualization provides a detailed breakdown of each hub's strengths across these critical areas, highlighting the relative contributions of each sub-index to the overall index score.

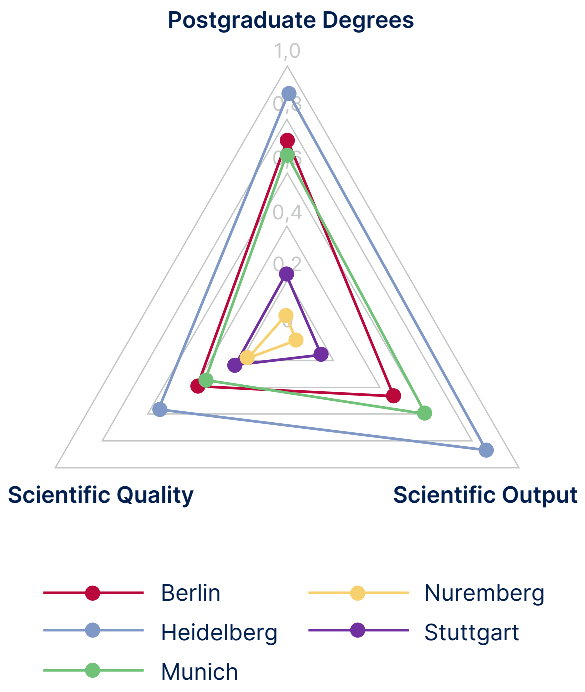


Source: Author's Own.

4.1.2 Sub-index variables in 2023

FIGURE 16 **Sub-index of all hubs for Fundamental Research in 2023**

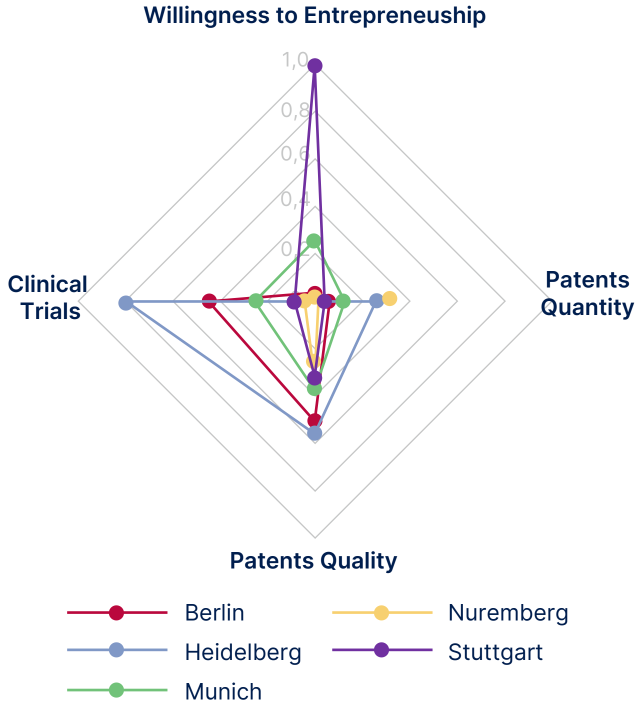
This radar chart presents a comparison of five biotech hubs – Berlin, Heidelberg, Munich, Nuremberg, and Stuttgart – across three key indicators: postgraduate degrees, scientific quality, and scientific output.



Source: Author's Own.

FIGURE 17 **Sub-index of all hubs for Biotech R&D in 2023**

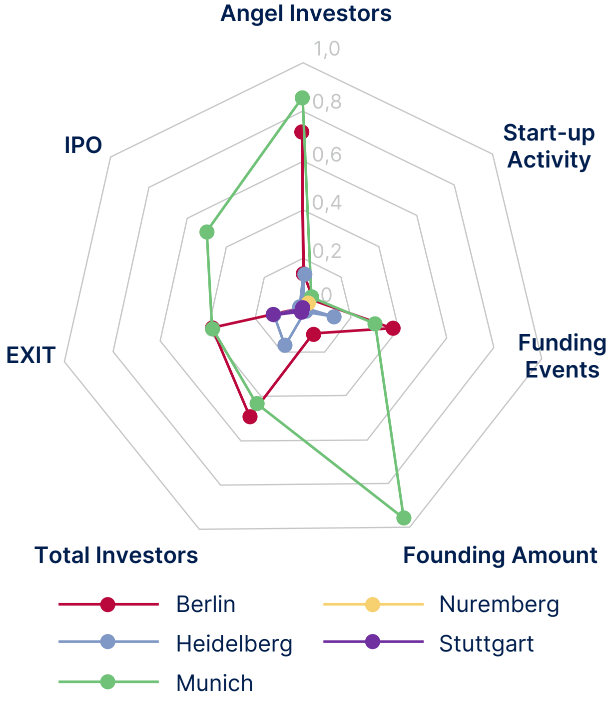
This radar graphic compares five biotech hubs – Berlin, Heidelberg, Munich, Nuremberg, and Stuttgart – across four indicators related to innovation and entrepreneurship: willingness to engage in entrepreneurship, clinical trials, patent quantity, and patent quality.



Source: Author's Own.

FIGURE 18 **Sub-index of all hubs for Biotech Venturing in 2023**

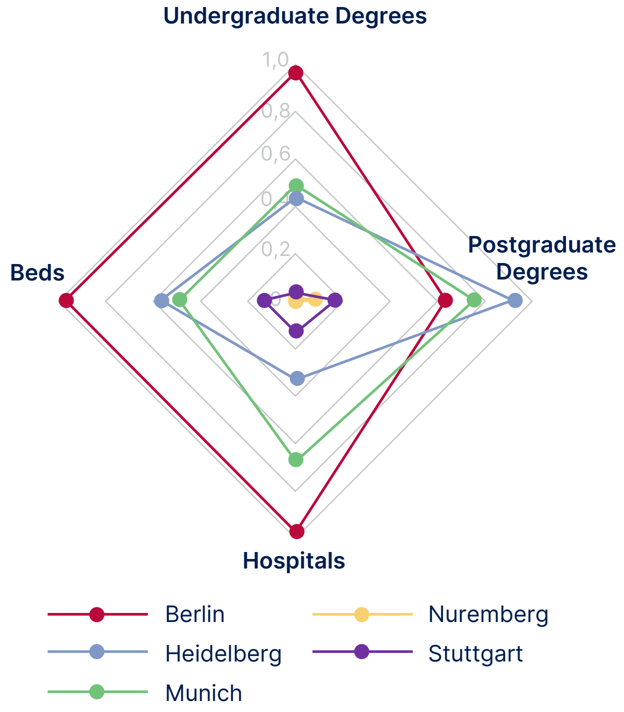
This radar graphic provides a comparison of five biotech hubs – Berlin, Heidelberg, Munich, Nuremberg, and Stuttgart – across key indicators of venture and investment activity: angel investors, startup activity, funding events, funding amount, total investors, exit events, and IPO activity.



Source: Author's Own.

FIGURE 19 **Sub-index of all hubs for Public Infrastructure in 2023**

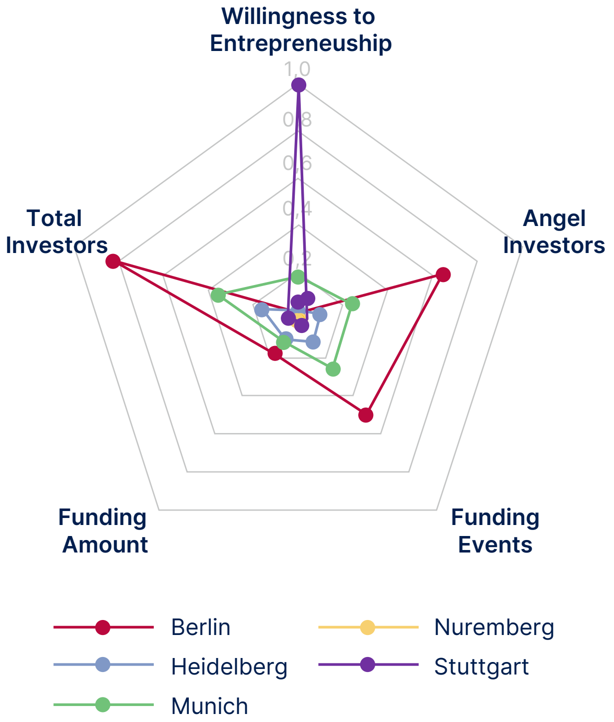
This radar graphic compares five biotech hubs – Berlin, Heidelberg, Munich, Nuremberg, and Stuttgart – across healthcare and academic capacity indicators: undergraduate degrees, postgraduate degrees, hospitals, and hospital beds.



Source: Author's Own.

FIGURE 20 **Sub-index of all hubs for Business Environment in 2023**

This radar chart illustrates the comparison of five biotech hubs – Berlin, Heidelberg, Munich, Nuremberg, and Stuttgart – across venture and entrepreneurial indicators: willingness to entrepreneurship, angel investors, funding events, funding amount, and total investors.

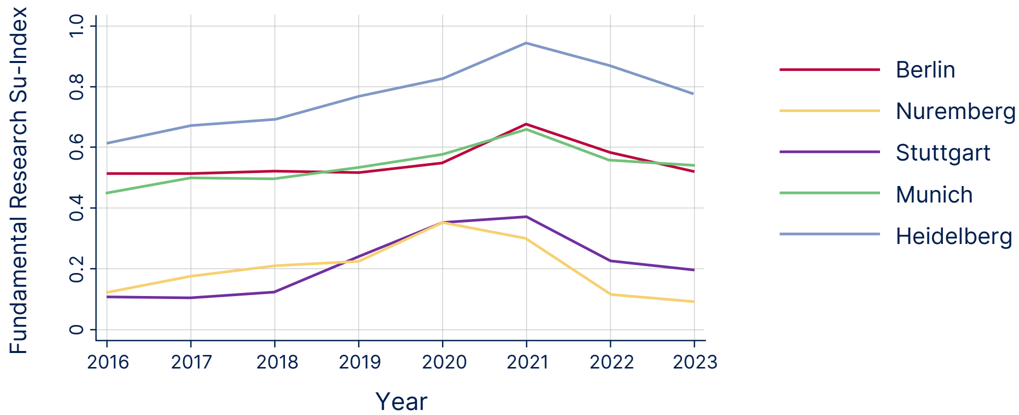


Source: Author's Own.

4.1.3 Trends, 2016 – 2023

FIGURE 21 **Trends in the Fundamental Research sub-index across hubs (2016–2023)**

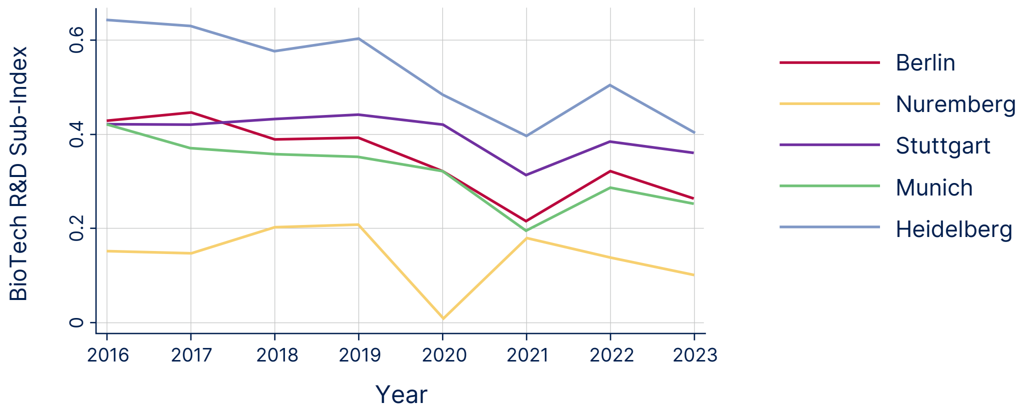
This graph illustrates the evolution of the Fundamental Research sub-index for each biotechnology hub from 2016 to 2023, highlighting shifts in research strength and capacity across Germany's leading biotech hubs.



Source: Author's Own.

FIGURE 22 **Trends in the Biotech R&D sub-index across hubs (2016–2023)**

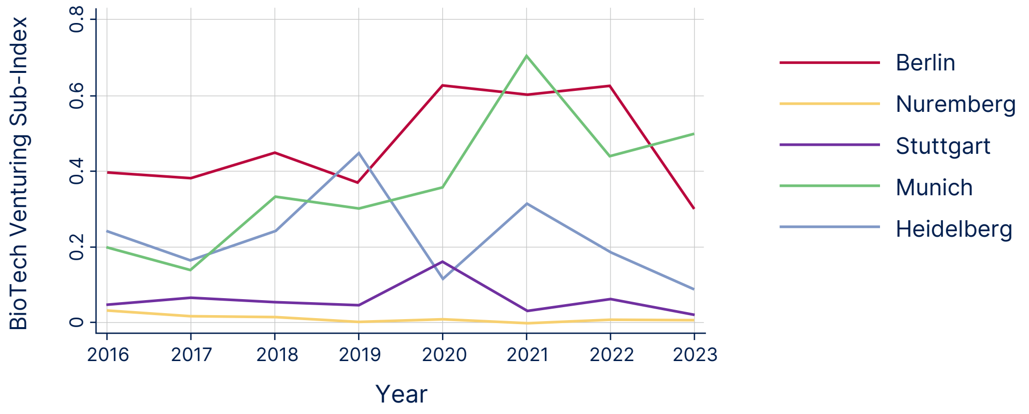
This graph displays the progression of the Biotech R&D sub-index for each hub, showing changes in research and development capabilities across Germany's biotechnology hubs over time.



Source: Author's Own.

FIGURE 23 **Trends in the Biotech Venturing sub-index across hubs (2016–2023)**

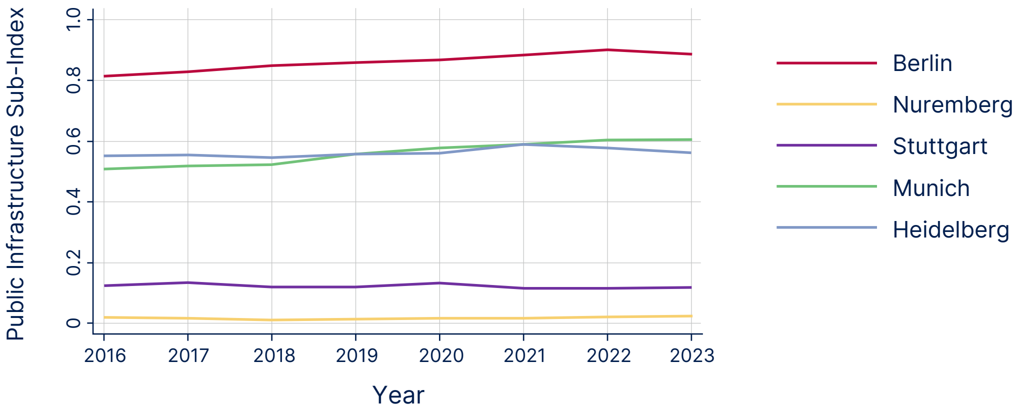
This graph tracks the development of the Biotech Venturing sub-index for each hub, reflecting changes in venture activity, funding levels, and entrepreneurial growth in Germany's biotech ecosystem over time.



Source: Author's Own.

FIGURE 24 **Trends in the Public Infrastructure sub-index across hubs (2016–2023)**

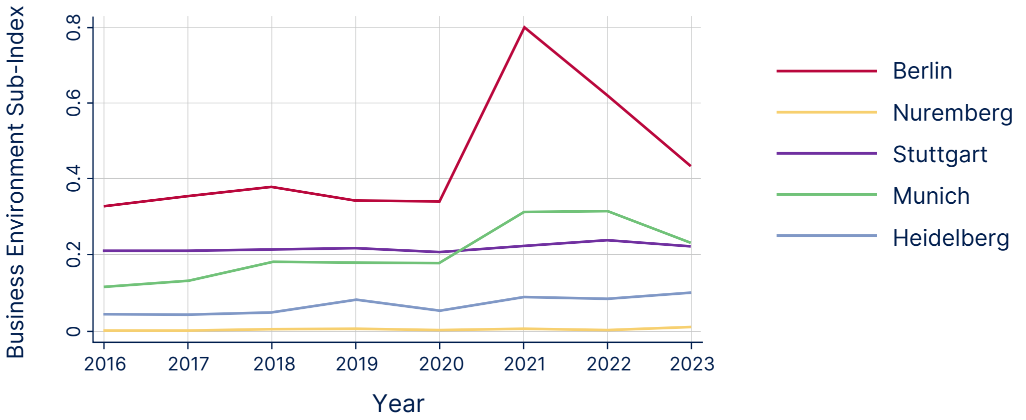
This graph shows the evolution of the Public Infrastructure sub-index for each hub, indicating the shifts in healthcare and academic resources supporting biotech innovation across different regions.



Source: Author's Own.

FIGURE 25 **Trends in the Business Environment sub-index across hubs (2016–2023)**

This graph illustrates the trends in the Business Environment sub-index, capturing the shifts in each hub's investment climate, entrepreneurial intent, and support systems for biotechnology ventures from 2016 to 2023.



Source: Author's Own.

5 Limitations

The quality of our findings is inherently onstrained by the quality of the data used to assess the various variables in the index. A primary limitation lies in our reliance on Crunchbase for business and enterprise variables. Crunchbase data is derived from user contributions, public records, and partnerships, which may impact its comprehensiveness and accuracy. In contrast, PitchBook, which gathers data from regulatory filings and proprietary research, provides a high level of reliability and depth.

For educational and healthcare data, including metrics on undergraduate and graduate students as well as hospitals, we rely on surveys and annual reports. However, these sources lack consistent coverage for years prior to 2016, leading us to limit our analysis to the period from 2016 to 2023.

Another limitation pertains to the R&D Spending variable, which is only available at the Bundesland (state) level. This limits the precision of city-specific analysis, as cities like Munich and Nuremberg share the same value for Bayern, Frankfurt reflects Hessen's figures, and Heidelberg falls under Baden-Württemberg. Such aggregation obscures regional distinctions that could impact the index's accuracy for city-level comparisons. Consequently, we have excluded R&D Spending from our index to avoid misleading conclusions in our analysis of individual hubs.

Finally, the variable measuring graduate students' willingness to engage in entrepreneurship is currently limited to data from 2020. Additional data points are expected to become available in the near future.

About the authors

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