4 The German research base for innovation

This chapter introduces key characteristics of the research base for innovation in Germany. The innovation system in Germany is supported by a large, autonomous, and well-resourced network of research organisations and universities. Institutionalised public research is in turn complemented by a highly innovative business sector.

Introduction

The research base – meaning, the strength and competencies of the institutions and personnel dedicated to undertaken research – is an integral pillar of the innovation ecosystem. Both as a provider of expertise and capabilities and a partner in innovation activities, it plays an important role in supporting innovation in firms, particularly *Mittelstand* firms. The importance of the research base will only grow in the transitional context, where firms and research organisations will increasingly require new forms of expertise and a greater level of cross-disciplinary collaboration. Facilitating this collaboration is a central aim of the Federal Ministry for Economic Affairs and Climate Action (BMWK)'s "From the Idea to the market", an umbrella of programme families. These additional requirements are particularly important for the research base to support the types of breakthrough innovation needed to achieve the sustainable transition.

As in other economies, the German research base comprises a range of institutions, each playing a particular role in the science, technology and innovation (STI) system. They include public research organisations (PROs), which undertake different types of research supporting innovation, from basic research to more technologically specific investigation. Higher education institutions (HEIs) are another important component of the research base, as they both undertake research and produce the qualified researchers needed throughout the STI system. In Germany, these institutional groupings are supplemented by the German Research Foundation (Deutsche Forschungsgemeinschaft [DFG]), which provides publicly funded research grants to any researcher affiliated with a German research or educational institution.

This section presents a brief overview of the key characteristics of the research base in Germany. It introduces both the key research actors within the STI system and the research personnel available to them.

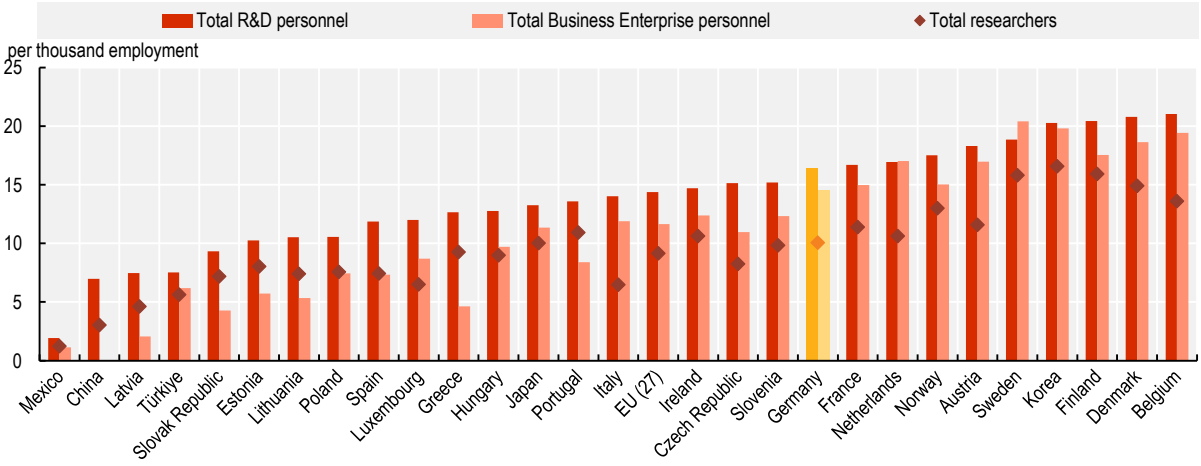
4.1. Research capacity in international comparison

With 450 700 researchers in full-time employment (FTE), Germany has one of the highest levels of permanent research capacity in the world. Only China, the United States and Japan have more FTE researchers. In the European Union, Germany has by far the highest level, ahead of France (314 100) and Italy (160 800).

As in other advanced OECD economies, the vast majority of FTE researchers in Germany are employed in the business sector (61%). The number of FTE researchers (24%) in the higher education sector is slightly lower than the OECD average (30%) and somewhat higher (13%) than the OECD average (6.5%) in the government sector. The number of FTE researchers is slightly lower than the OECD average (30%) in the education sector, and higher than the OECD average (6.5%) in the government sector.

Globally, Germany had the fifth-highest number of FTE researchers in business enterprises (277 000) in 2019, behind China, the United States, Japan and Korea. In the European Union, Germany's 277 000 FTE account for 27% of total private-sector researchers, ahead of France (197 400) and Italy (78 100), the two other largest contributors to FTE private-sector researchers. The share of researchers in the work force (9.7%) is broadly similar to countries such as France (10.9%) and the United States (9.8%), but lower than in certain South Asian and Northern European countries, such as Korea (15.2%), Sweden (14.7%) and Finland (14.4%) (Figure 4.1).

Figure 4.1. Key indicators for R&D personnel capacity relative to industry (2019)

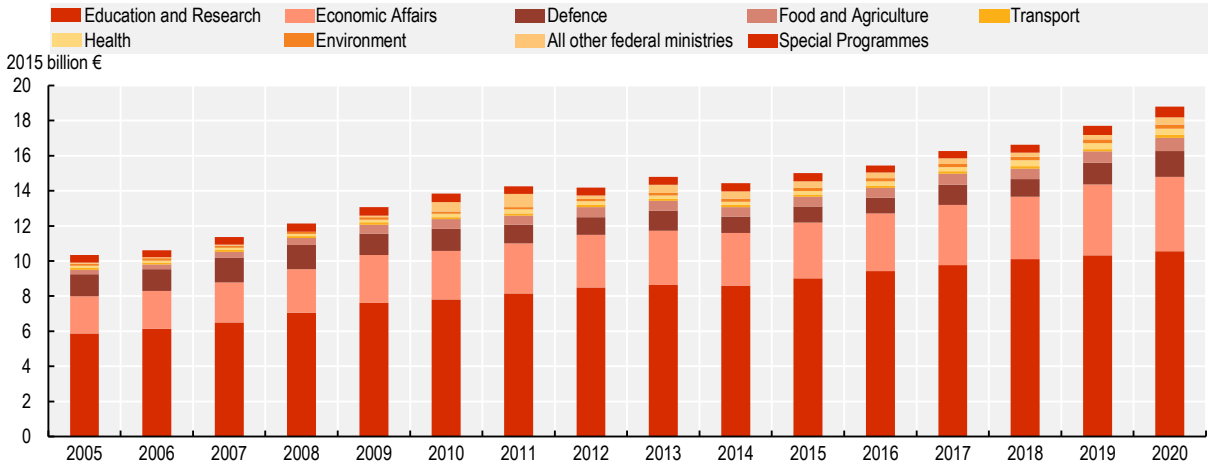


Note: R&D = research and development.
Source: OECD (2022[1]), "Main Science and Technology Indicators", OECD Science, Technology and R&D Statistics (database), https://doi.org/10.1787/data-00182-en (accessed on 22 April 2022).

Germany's strong research capacity masks a significant inclusion challenge, particularly for women. As discussed elsewhere in the review, women are underrepresented in the research system, accounting for only 28% of total FTE researchers at the aggregate level and 15% in the business sector. Gender and other inclusion related challenges in the research base are discussed in Chapter 6).

Moreover, precarious working conditions in academic are also affecting Germany's research institutions. Researchers at universities and other academic institutions often remain on a succession of fixed-term contracts that are capped at six to nine years (in practice often shorter) with limited prospects of advancing in their careers (77% of postdoctoral researchers in higher education institutions and 72% in non-university research institutions) (OECD, 2021[2]) To create better and more stable career paths in science, Germany introduced a (limited) tenure track programme in 2017, also with a view to inducing young researchers to make career choices within or beyond academia earlier in their lives. It should remain a priority for further policy action to ensure that basic and applied research in academia presents an attractive career path for talented graduates from all disciplines and backgrounds, e.g. by promoting inclusive governance schemes at research institutions or by their improving human resource management (ibid).

Figure 4.2. R&D financing by the Federal Government of Germany, by federal ministry (2005-20)



Source: BMBF (2022[3]), Federal Government expenditure on science, research and development, by departments (database), Federal Ministry for Education and Research (BMBF), https://www.datenportal.bmbf.de/portal/en/K1.html (accessed on 1 March 2022).

Federal funding for the research base is important and has grown over the past decades. In 2019, 50.1% of federal R&D financing went to PROs (including government agencies), 10.7% to HEIs, 12.6% to the DFG (which, in turn, funds projects at HEIs), 18.3% to businesses (including a very small share of businesses located outside Germany) and 8.3% to international organisations (BMBF, 2022[3]). Overall, federal R&D funding grew in real terms by around 3.9% per year between 2005 and 2020 (Figure 4.2). R&D financing for HEIs and DFG grew markedly faster (respectively by +5.8 and +6.8% per year in real terms) as a result of the Excellence Initiative. PRO funding grew by 3.5% per year in real terms, but business enterprises (+3.1%), international organisations and programmes, and other recipients abroad experienced slower growth (+2.6%).

4.2. Overview of research-performing organisations

Germany's research base is made up of several components. The country numbers over 1 000 publicly financed research-performing organisations (not including HEIs) spanning fundamental and applied research, and both scientific and innovation-focused work (Figure 4.3) (BMBF, 2022[4]).This figure includes the institutes operated by Germany's four large PROs (Fraunhofer Society, Helmholtz Association, Leibniz Association and Max Planck Society), which have representation throughout the country. Additionally, around 40 federal research institutions and 144 state-level institutions provide scientific information to the federal and regional governments to support policy making (BMBF, 2022[4]).

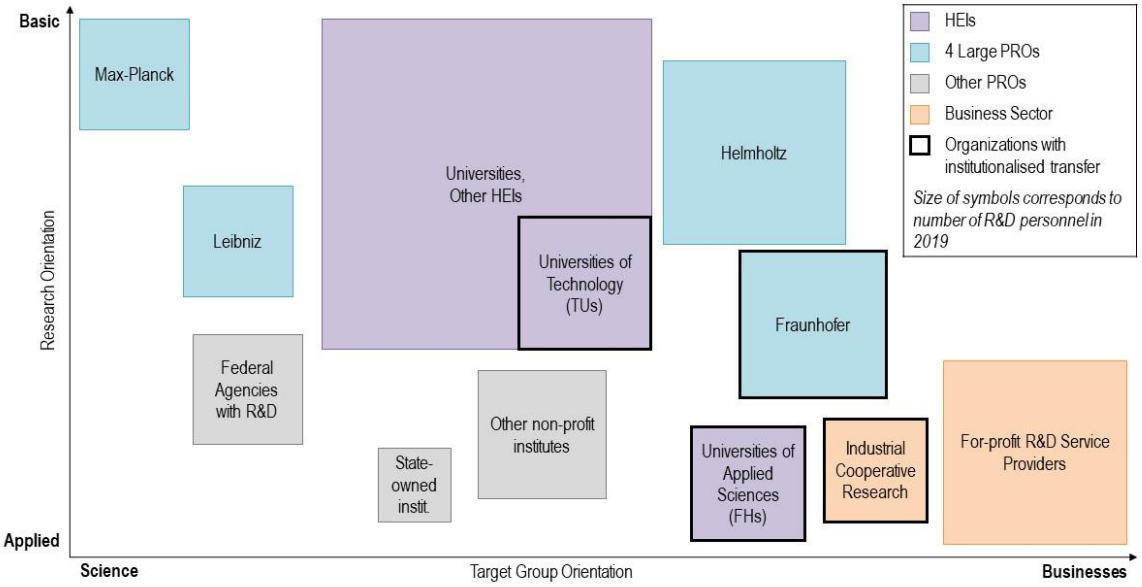
In addition to the 1 000 institutions in the publicly funded network of research organisations, the German research base also comprises over 400 HEIs, including 120 universities (*Universitäten*), over 200 universities of applied sciences (*Fachhochschulen*), and around 60 art and music colleges (BMBF, 2022[5]). In 2020, around 760 000 people worked at HEIs, one-third of whom are considered academic staff (Destatis, 2022[6]). With more than 100 000 employees working in higher education in each of the following *Länder*, North Rhine-Westphalia, Baden-Württemberg and Bavaria lead the 16 *Länder* in terms of higher education personnel. Next to HEIs, over 1 000 non-university PRIs, funded by federal or state governments, complete the research base and are often tightly linked to the innovation system (OECD, 2011[7]). Many research projects at HEIs and PROs are funded by the central research-funding organisation DFG, which is endowed by the federal (69%) and state (30%) governments with an annual budget of around EUR 3 billion, including EU funds and private donations (DFG, 2020[8]).

The German universities and PROs – and indeed the DFG – have organisational and governance structures that insulate them from governmental micromanagement. Unlike their equivalents in many countries, they are not government agencies but rather self-governing associations. Organisations within the state have a high degree of institutional autonomy, above and beyond the international norm that universities should be free to decide what to teach and to research. The *Wissenschaftsfreiheitsgesetz* (Scientific Freedom Law) of 2012 continued the process of increasing universities' independence by granting them a greater level of budgetary autonomy.

Germany has four main PRO networks. The first is the Fraunhofer Society (Fraunhofer-Gesellschaft), which has 76 institutes and research institutions across Germany focused primarily on applied research. The second is the Helmholtz Association of German Research Centres (Helmholtz-Gemeinschaft Deutscher Forschungszentren), whose 18 centres operate research infrastructures for the innovation system, including accelerators, telescopes, research ships and supercomputers. The third is the Leibniz Association (Leibniz-Gemeinschaft), which acts as an umbrella organisation for nearly 100 research institutions investigating scientific problems of societal and international relevance. The fourth is the Max Planck Society (Max-Planck-Gesellschaft), which focuses on advanced basic research. Each of these PROs is highly autonomous, while also benefiting from significant public funding (see Section 4.3).

The DFG, which provides investigator-initiated research funding, is similarly autonomous. All five organisations' governing structures are topped by various forms of general assemblies of members and appoint their own members, removing any opportunity for the government to directly control the organisations or their policies. In practice, these organisations rely on public funding and the government therefore retains a high degree of control, but at an aggregate level that impedes micromanagement.

Figure 4.3. Science-based R&D-performing organisations in Germany, by research orientation and target group orientation



Source: OECD authors' elaboration based on Destatis (2022[6])

4.3. Public research institutions in the German STI system

Germany's particularly large PRO sector stands out in comparison to many other countries. The sector features four main public research organisations with very different missions:

- The Helmholtz Association comprises 18 medium-sized to large independent research centres focusing on big science and infrastructure.
- The Fraunhofer Society operates 105 institutes and centres focusing on applied sciences, engineering and innovation.
- The Max Planck Society runs 82 institutes across all disciplines, focusing on basic research.
- The Leibniz Association comprises 93 independent institutes from a wide variety of disciplines, mostly in the humanities (including museums), arts and social sciences.

The PRO sector also includes R&D-performing federal agencies ("government labs") and R&D institutes operated by state governments (Table 4.1). R&D statistics on PROs include R&D across all disciplines, performed at libraries, museums and numerous publicly co-financed R&D institutes, many of which operate similarly to private non-profit organisations.

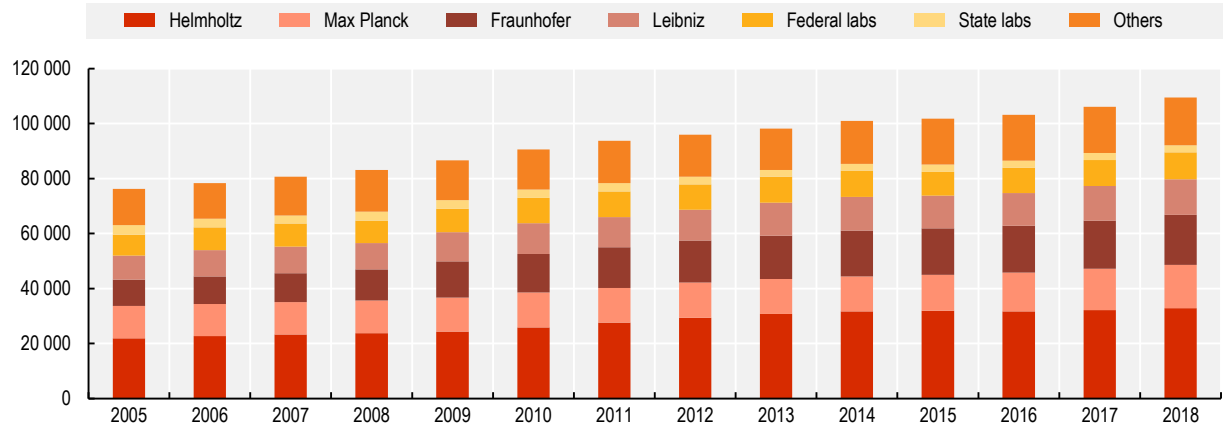
Table 4.1. Public research organisation (PRO) groupings in Germany

PRO grouping	Institutional funding Federal : State	No. of institutes/ centres	No. of personnel (FTE, 2018)		
			Total	Scientists	R&D personnel
Helmholtz	90 : 10	18	32 962	16 685	32 853
Fraunhofer	90 : 10	105	15 736	9 146	15 736
Max Planck	50 : 50	82	18 206	9 207	18 206
Leibniz	50 : 50	93	14 622	7 228	12 946
Federal agencies	100 : 0	38	19 286	9 644	9 747
State R&D institutes	0 : 100	53	5 976	2 937	2 620
Libraries/museums	varying	176	11 128	3 402	3 548
Others	varying	463	17 152	10 078	13 831
TOTAL		1 028	135 066	68 325	109 487

Source: Destatis (2022[9])

The number of FTE personnel in the PROs has grown steadily, from 76 000 in 2005 to 110 000 in 2018 (Figure 4.4), with Fraunhofer growing slightly faster than the others. In contrast to the others, employment at *Länder*-owned institutes ("state labs") fell by about 2% per year over 2005-18.

Figure 4.4. R&D personnel at PROs, by organisation (2005 to 2018)



Source: BMBF (2022[3]). Federal Government expenditure on science, research and development, by departments (database), Federal Ministry for Education and Research (BMBF), https://www.datenportal.bmbf.de/portal/en/K1.html (accessed on 1 March 2022).

The big four PROs have strongly similar governance systems. Each features a self-selecting membership, which directly or indirectly appoints the president, top management and other governing committees. Thus, while federal and *Länder* governments are sometimes represented in these structures, the big four PROs are autonomous.

4.3.1. Helmholtz Association

The Helmholtz Association comprises Germany's 17 "big science" institutes, which are not only large in employment terms but also tend to rely on large research infrastructures. The association originated in a working group of organisations developing nuclear reactors established in 1958 and comprising the research centres at Karlsruhe and Jülich, along with several university institutes. Throughout the 1960s, other big science centres in areas such as aerospace, high-energy physics, materials and health joined the working group, which in 1970 established the *Arbeitsgemeinschaft der Großforschungseinrichtungen* (Association of major research institutions) to manage their relationship with the state, reduce governmental micromanagement of the centres and increase their autonomy.

In absolute terms, Helmholtz had the largest share of the increase in R&D capacity from 2005 to 2018 (33.1%), with most of the change happening by 2014. Fraunhofer was the next-largest, accounting for 25.9% of the total increase. In terms of scientific disciplines, growth in R&D capacities at PROs was evenly distributed across natural sciences, engineering and medicine, with a CAGR in 2005 of 2.7% to 2.9% in 2018. Most of the absolute increase in R&D capacity took place at PROs doing research in natural sciences (45.8%) and engineering sciences (24.5%); social sciences grew about twice as fast in percentage terms, but from a low base.

4.3.2. Max Planck Society

The Max Planck Society's organisational predecessor was the Kaiser Wilhelm Society for the Advancement of Science (Kaiser-Wilhelm-Gesellschaft zur Förderung der Wissenschaften), founded in 1911, whose institutes conducted a mix of fundamental scientific, applied technical, industrial and defence research. The Allies dissolved the Kaiser Wilhelm Society in 1946, as some of the institutes had been involved in research and technical support to the Holocaust. The Max Planck Society was established in 1948, building on some of its predecessor's physical and manpower, but with a focus on basic research. More than other German institutes, Max Planck still follows the "Harnack Principle", established by Adolf von Harnack, the first president of the Kaiser Wilhelm Society, which holds that an institute should be

established around the capabilities of a leading researcher and should only continue after the researcher's retirement if a suitably prominent successor can be found. Other institute groupings take a more corporate and collective view.

The Max Planck Society is governed by its members, who may include paying, scientific, ex officio or honorary members. The general assembly elects some members of the senate, which also comprises two representatives of the Federal Government and three representatives of *Länder* governments. The senate, in turn, elects the president and executive management, and decides on the opening or closure of individual institutes.

4.3.3. Fraunhofer Society

The Fraunhofer Society (Fraunhofer-Gesellschaft) was originally founded in 1949 by the Bavarian and federal governments and recognised by the then-Federal Ministry for Economy as the third major block in the national research system, after the DFG and the Max Planck Society. Fraunhofer opened its first institutes in 1954 and pursued a mix of industrial and defence research up to 1969, when it had 19 institutes and around 1 200 employees. A commission on the development of the Fraunhofer Society then devised the "Fraunhofer model" of financing, wherein the government provides roughly one-third of Fraunhofer's income in the form of institutional funding. The institutes are expected to win a further third from competitive state sources (now including the EU framework programme) and the remaining third from industry. The federal-state commission for education planning and research funding (Bund-Länder-Kommission für Bildungsplanung und Forschungsförderung [BLK], since 2008 replaced by the Joint Science Conference (Gemeinsame Wissenschaftskonferenz [GWK])) agreed on the new funding model in 1973, and Fraunhofer redeployed its activities on industrial technologies and R&D, with a special focus on small and medium-sized enterprise development, its current role. The Fraunhofer Society took over some of the German Democratic Republic (GDR)'s industrial research institutes after reunification, though many of the GDR's research facilities were also closed. The post-1973 version of the Fraunhofer Society is internationally seen as the leading role model among PROs. However, it deviates from the normal PRO model in that it has a collection of small offices, institutes and collaborations outside Germany, which appear not only to provide international "antennae" and marketing for the Fraunhofer Society, but also to serve as vehicles for German scientific diplomacy. Fraunhofer is a bigger exporter of R&D and technical services than most other PROs.

Fraunhofer is more decentralised than other large PROs, such as the Netherlands Organisation for Applied Scientific Research (TNO) or the VTT Technical Research Centre of Finland. The Fraunhofer model means that in practice, institute directors have high autonomy, provided they satisfy Fraunhofer budget requirements. In the past two decades, top management has succeeded in networking together institutes in related areas, strengthening administrative and management services, and establishing both a technology transfer office and an international division. Nonetheless, Fraunhofer's strategic business units are the individual institutes, which remain fiercely independent. Institute directors are required to be part-time university professors, usually at an adjacent university, cementing links to fundamental research and providing a flow of PhD students working in Fraunhofer-related areas. Fraunhofer aims explicitly to recruit from this group and has a minimum target for labour turnover, on the principle that most PhD graduates should spend a few years honing their skills at one of its institutes and then move on to industry. These arrangements also mean that Fraunhofer institutes work at a more theoretical and fundamental level than technology support and transfer organisations such as the Steinbeis Foundation, the German Federation of Industrial Research Associations (Arbeitsgemeinschaft industrieller Forschungsvereinigungen [AiF]) and Deutsche Industrieforschungsgemeinschaft Konrad Zuse e. V.

The Fraunhofer Society is governed by a general assembly of members. Ordinary membership is open to "natural persons and legal entities, including associations and societies without legal capacity (federations), that wish to support the work of the Organisation" (Fraunhofer, 2015[10]). Official membership

is available to members of the senate, the executive board, institute directors and senior managers, and the governing boards.

4.3.4. Leibniz Association

The Leibniz Association originated in a 1949 meeting during which the *Länder* agreed that several existing institutes were too big for any single *Land* to fund and that they should make arrangements to fund them jointly. In 1969, the German Basic Law (the 'constitution') was modified to enable joint funding of research organisations by the federal and *Länder* governments. After intensive negotiations that finally ended in 1977, a list of 46 institutes designated for joint funding was drawn up on a piece of blue paper. In 1990, these Blue List (*Blaue Liste*) institutes established an *Arbeitsgemeinschaft* (consortium). By 1992, following the German reunification, the Blue List had grown to include 81 institutes. The consortium set up a committee to consider the institutes' future, which resulted in the creation of a *Wissenschaftsgemeinschaft* (scientific community) in 1995, whose name was changed in 1997 to Wissenschaftsgemeinschaft Gottfried Wilhelm Leibniz, now referred to simply as the Leibniz Association.

The Leibniz Association has five sections, or groups of institutes, specialising in:

- humanities and education research
- economics, social and spatial research
- life sciences
- mathematics, natural sciences and engineering
- environmental sciences.

The Leibniz Association's membership is made up of the institutes, whose top managements appoint the president and vice-presidents and decide on institutes' admission during a general assembly. The executive board comprises both the top management and the heads of the association's five sections. The senate comprises top management, representatives of the five sections and a mix of representatives from the federal and *Länder governments*. Unlike in the other three major PROs, the senate's role is advisory.

4.4. Higher education institutions

Almost all larger general universities are public and receive basic funding from their respective state governments. Many other HEIs have private (usually non-profit) ownership. All public HEIs are governed by state governments, except for a few federal universities. The general universities differ little in research quality and performance: 51 German universities are listed among the top 1 000 universities in the Shanghai Ranking for 2021, and 4 feature among the top 100 (University of Munich is ranked 48th, Technical University (TU) of Munich 52nd, Heidelberg University 57th, and University of Bonn 84th) (Shanghai Ranking, 2021[11]). Around 20 general universities focus on engineering and technical sciences; many of these use the name "'technical university" and traditionally work in close co-operation with industry.

Table 4.2. Germany's HEIs

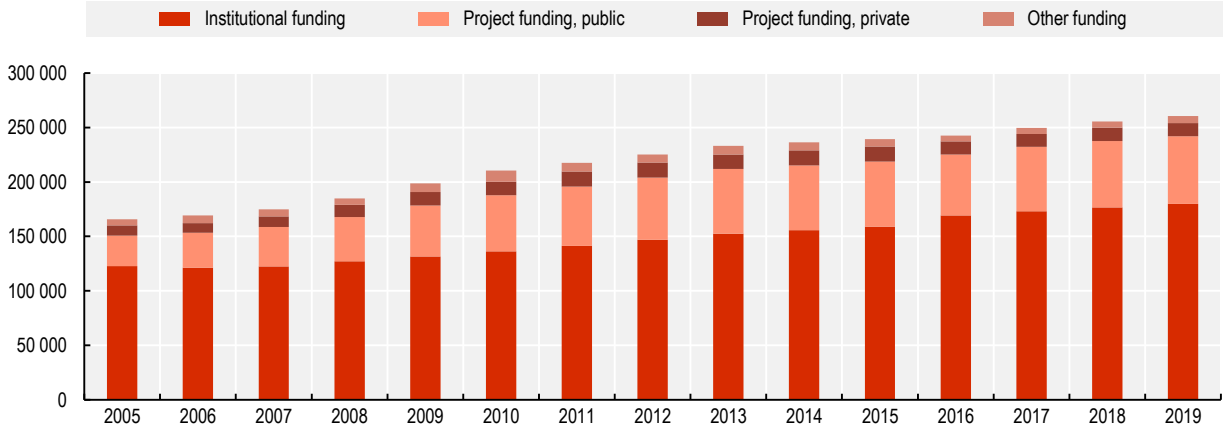
Type of HEI	No. of organi-sations	No. of personnel (headcount, 2019)			No. of students (2019/20)	No. of graduations (2019)	
		Total	Scientists	Professors		Total	PhD
General universities	112	574 545	213 658	24 854	1 749 734	301 961	28 509
(including TUs[1])	*20*	*130 797*	*58 806*	*5927*	*478 843*	*86 608*	*7 902*
Universities of applied sciences	236	136 782	38 578	20 234	1 023 146	182 907	0
Colleges[2]	108	26 435	8 375	3 459	118 169	27 417	181

TOTAL	456	737 762	260 611	48 547	2 891 049	512 285	28 690

Note:
1. 20 universities with a large engineering faculty: RWTH Aachen, TU Berlin, Ruhr University Bochum, TU Brunswick, TU Chemnitz, TU Clausthal, TU Cottbus-Senftenberg, TU Darmstadt, TU Dortmund, TU Dresden, University of Erlangen-Nuremberg, TU Freiberg, TU Hamburg, Leibniz University Hannover, TU Ilmenau, TU Kaiserslautern, Karlsruhe IT, TU Munich, University of Stuttgart, University of Wuppertal.
2. Educational colleges, theological colleges, schools or arts, administrative colleges and others.
Source: Destatis (2022[6])

Driven by a policy of increasing student numbers, the university sector has grown substantially, from about 349 000 first-year students in 2005 to 496 000 in 2019 (Table 4.2). The proportion of young people in Germany who begin their first year of university study has risen from one-third to half. The student body is nonetheless rather international: a quarter of first-year students do not have German citizenship. The number of academic personnel has risen correspondingly (Figure 4.5), with the research agendas of the universities likely to be influenced both by students' subject choices (as the universities must hire academics to teach them) and the thematic priorities of external research funders.

Figure 4.5. Number of scientific personnel at HEIs, by source of funding (2005 to 2019)



Note: * including student fees and unknown sources.
Sources: Destatis (2022[6]); ZEW (2021[12])

Universities (especially the TUs) may co-operate with (or even host) one or more '"An-Institute". Although they are formally outside the university structure, An-Institutes are generally located on campus or nearby. Many of them are involved in industrial extension or other forms of technology transfer, sometimes in co-operation with an industrial association or even a single company. An-Institutes may also enable co-operation with other parts of the research sector. Members of the four big PRO networks – especially Fraunhofer and Max Planck – may also be co-located with universities. The directors of these institutes are required to hold part-time university chairs, often located at the neighbouring university.

Changes to the Higher Education Framework Act (*Hochschulrahmengesetz*) in 1998 and 2000 aimed to increase competition within the university sector by reducing regulation and introducing performance-related incentives; restricting ministries' role in university governance; and strengthening internal university leadership, by reducing the relative power of the collegium. The *Länder* have different models for university boards, which were introduced around 2012. At that point, 12 of 15 *Länder* required university councils to be primarily composed of external members (one *Land* did not set rules for university boards) (Stockinger, 2018[13]). University rectors continue to be elected by the university senate and council, but are usually appointed formally by the competent ministry.

While German universities enjoy a high degree of academic freedom, their financial freedom is more limited. Since 2011, they have not been allowed to charge tuition fees. Although they can borrow money (within limits), they may not own buildings. Academics are civil servants and therefore subject to fixed salary scales that prevent universities from hiring "superstar" professors; their civil-servant status means they are also difficult to fire (EUA, 2017[14]).

Starting in 1999, the Bologna Process strengthened the movement to establish fixed-length degrees and promoted regular evaluation of the universities. Combined with the increased use of English in university teaching, this prompted the dramatic growth in the number of foreign students enrolled at German universities.

4.5. Government labs

The Federal Government operates a total of 42 government labs (*Ressortforschungseinrichtungen*) with a combined R&D spending of around EUR 1.2 billion in 2020 (BMBF, 2021[15]). Unlike the PROs, these are ministry agencies. They cover the normal range of functions, including metrology, public health, geology and social policy. As elsewhere, the proportion of research compared to other tasks, such as data collection and more routine technical functions, varies greatly among institutes.

Since 2004, the German Science and Humanities Council (*Wissenschaftsrat*) has been responsible for evaluating the government labs. These labs have been formally organised since 2005 in a working group (*Arbeitsgemeinschaft der Ressortforschungseinrichtungen)*.

In 2007, based in part on evaluations of some of the government labs, BMBF produced quality and management guidelines and a plan for the government labs, which defined their tasks as (BMBF, 2007[16]):

- R&D
- science-based advisory and information services
- science-based services such as testing, certification and licensing.

While the plan recognised the labs as major providers of these services to the government, it acknowledged that universities, PROs and others could also be asked to provide similar services. The plan aimed to increase the labs' financial autonomy, stating they should be free to earn income from third parties in addition to the institutional funding provided by their parent ministries. The plan outlined several measures, such as membership in research networks, personnel placements and exchanges, and participation in collaborative research to support labs' wider participation in the wider scientific community.

Having been asked to develop proposals to improve the government lab system, the German Science and Humanities Council recommended in 2010 that government labs engage more actively in international co-operation, in the ongoing process of rationalisation and re-division among government labs and intensify agenda-setting activities in the EU's Framework Programmes (Wissenschaftsrat, 2010[17]), which would involve better co-ordination at both the national and EU levels. The council further proposed that the labs undergo periodic review and be further integrated into the national research community. It stated that R&D-intensive labs (in practice, almost all of them) should be free to spend at least 15% of turnover on research topics of their own choosing. It also recommended that labs operating significant research infrastructures open them inasmuch as possible to use by other members of the research community.

There appears to have been little further policy development since 2010. Although the German Research Council occasionally evaluates individual labs at the request of their parent ministries, the overall role of the government labs has not been revisited. Many of the *Länder* also maintain their own labs at the regional level, with no national oversight or evaluation.

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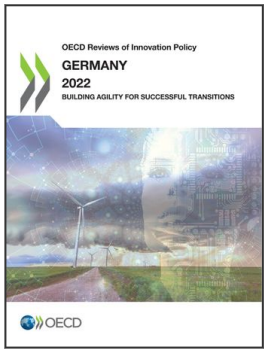

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