Performance and Structures of the German Science System in an International Comparison 2010 with a Special Analysis of Public Non-university Research Institutions

Analyses carried out for the annual report of the
Expert Commission on Research and Innovation

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1 Introduction to this issue

The scientific capability of a country is an essential basis for its technological performance, which is why this topic has been regularly analysed for many years in the context of studies of the German innovation system. The crucial contribution of science to technology development consists in educating highly skilled personnel whose quality depends to a considerable extent on their research capability. It goes without saying that the results of scientific research are also an essential foundation for technical development, whereby the connections between science and industry are frequently of an indirect nature and less obvious, particularly because in many cases a substantial time lag can be observed between activities in science and their impact on technology.

Scientific performance is difficult to measure, especially as the structures of the individual disciplines frequently vary distinctly. Statistical analyses of publications by experts have proved to be meaningful, inasmuch as they are conducted with a meticulous regard for methodology. The analyses presented here refer not only to science areas with a close link to technology, but to the natural, life and engineering sciences as a whole. In this context, the number of publications and citations is analysed as a performance indicator in an international comparison. The German profile, and as a comparison, the EU profile is considered in more detail.

A special feature refers to the situation of scientific activities of German public non-university institutions.

The data for the analysis of scientific performance of Germany in an international comparison were provided in October 2010.

2 Scientific Performance Reflected by Bibliometric Indicators

2.1 Methodological Basis

The bibliometric analyses were carried out utilising the Web of Science (WoS), a multidisciplinary database covering a broad spectrum of disciplines. The searches primarily cover the natural and engineering sciences, as well as medicine and life sciences. In addition, the fields of social sciences and humanities are considered, but without fine differentiation. The database deals above all with English language journals, which is unproblematic for most fields. The German engineering sciences, and to an even greater extent the social sciences and humanities, which mainly publish in the German language, however, are inadequately recorded. Generally, journals are reviewed in the WoS which are frequently cited, i.e. with high visibility, so that primarily higher quality publications are taken into consideration. Thus the fact alone that a paper is recorded in the WoS, respectively, that it appears in journals covered by the WoS, can be considered a first quality indicator.

Besides the absolute number of publications which are available up to the year 2009 citations in particular will be utilised as performance indicators. To estimate the citation rates, citations from the actual year of publication and the two following years are considered, so that a standard time window of three years forms the basis for all years considered. For this reason, citation rates can only be calculated up to the year of publication 2007. As this type of analysis is quite complex, a special preparation of the WoS is necessary. In former years, the data for this report were provided by the Centre of Science and Technology Studies (CWTS) at the University of Leiden, the Netherlands. This year, the analyses were performed by Fraunhofer ISI which has access to the full WoS file as member of the "Competence Centre Bibliometrics". This centre, consisting of four German research institutes, has the task to build up an own version of the WoS data adapted to generate different citation indicators and to analyse the scientific structures in Germany in more detail.

This year, a complete new analysis also of antecedent years was performed, as in the last years, the producer of the WoS, Thomson Reuters, substantially extended the coverage of journals as reaction to the growing competition with the new bibliometric data base Scopus. This enlargement also affects early datasets of the 1990s, so that the referring indicators may change. Furthermore, Fraunhofer ISI now has access to former data for South Korea, and China from the EU12 countries which were included in the former data analysis starting from 2002.

Until 2003, the bibliometric analyses - at that time in the context of the Report on the Technological Competitiveness of Germany – were performed without excluding self-citations. Then the reporting was converted to citations without self-citations following the advice of CWTS. The scientific debate on self-citations does not lead to clear evidence as to whether the exclusion of self-citations is preferable to the analysis of all citations (Aksnes 2003; Glänzel et al. 2004; Glänzel/Thijs 2004; van Raan 1998; van Raan 2008). In any case, self-citations are frequent in the early years of the citation history of a publication. Thus, if short 3years citation windows are used, the share of self-citations is quite high, at a level of about one third of all citations. A major argument for the inclusion of self-citation is that the reference to own publications reflects the emergence of research trajectories which are more important than "isolated" publications without follow-ups. A more detailed analysis of self-citations reveals that the average number of self-citations per publication is quite similar for most countries, whereas the differences between countries with reference to external citations are more spread. In any case, the underlying determinants for self- and external citations appear to be different. Therefore, we decided to exclusively refer to external citations, i. e. citations without self-citations, to avoid a mix of different effects.

For a more exact analysis of the citation quotas, the calculation of two additional indicators has proved to be meaningful, the "journal-specific Scientific Regard" (SR index, in German: *Zeitschriftenspezifische Beachtung*) and the "International Alignment" (IA index, in German: *Internationale Ausrichtung*). The indicator "Scientific Regard" states whether the articles of a country / a region are cited on average more frequently or more seldom than the articles in the journals in which they appeared. Positive indexes point to an above-average citation rate; values of zero correspond to the world average. Through reference to the journal in question, the disadvantages of countries which have less than optimum access to big English-language journals are compensated for. Furthermore, the different citation behaviour between disciplines is compensated. The indicator is calculated as follows:

$$SR_k = 100 \tanh \ln (OBS_k/EXP_k)$$

In this equation, OBS_k means the actually observed citation frequency of publications from country k. EXP_k is the expected citation number which results from the average citation frequency of the journals in which the authors of this country have published their articles. Thus the sums of observed and expected citations with reference to a specific country are divided.[1]

1 There is a debate about the appropriate calculation of the relation of observed to expected citations (Leydesdorff/Opthof 2010), but the factual differences at the country level are minimal.

In addition to this, the indicator "International Alignment" shows whether the authors of a country publish in internationally visible or in less visible journals, judged against the world average. Through a high quota of publications in internationally visible journals, an intensive participation in the international scientific discussion is documented. Similar to the SR index, positive values in the IA index signify an above-average international orientation. The IA index is calculated as follows:

$$IA_k = 100 \tanh \ln (EXP_k/OBS_w)$$

The same conventions apply as for the SR index. The index w stands for the world as a whole.

In order to compensate for the possible distortions through database coverage in the analysis of absolute publication numbers, the specialisation index RLA (Relative Literature Advantage) is calculated. The corresponding equation is:

$$RLA_{ij} = 100 \tanh \ln [(Publ_{ij} / \sum_i Publ_{ij}) / (\sum_j Publ_{ij} / \sum_{ij} Publ_{ij})]$$

Here i stands for the country and j for the field. The RLA index is so constructed that its scale of values encompasses ± 100 with the neutral value 0. Positive values indicate an above-average specialisation, negative values a below-average one, whereby the world average serves as a reference.

2.2 Scientific Publications from Germany in an International Comparison

The journals covered by the WoS steadily change, in particular, the number of journals covered is increasing. Therefore it is not meaningful to consider absolute numbers of publications, but rather the shares of the selected countries in all WoS publications (Table 1).

A long-term inspection of the data series show that the share of Germany increased between 1990 and 2000 from 7.0 to 8.2% at the end of the 1990s, and since then decreased and now has a level of 7.3%. This gradually decreasing share of Germany since the year 2001 was already observed in former years of this report; it also applies to other large industrialised countries such as the USA, Japan, Great Britain or France. In particular, the USA substantially lost already since the beginning of the 1990s from a level of about 36% to presently 28%. This phenomenon can be explained by the growth of publications from catching-up countries like China, India, South Korea, Taiwan or Brazil. As the number of journals in the WoS is limited and thus the number of publications which WoS covers, the growing strengths of the catching-up countries lead to a visible displacement effect at the expense of established actors. In 2009, this general trend was even more accentuated. In particular, the shares of Japan, Great Britain and Sweden sharply decreased, whereas the German reduction remains comparatively moderate.

Table 1: Shares of Selected Countries and Regions in all Publications in the WoS

*Data till 2005 refer to the EU-10, from 2006 to EU-12; **Data till 2005 refer to EU-25, from 2006 to EU-27.

Country	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
US	35.8	36.1	35.8	35.7	34.7	34.3	33.4	32.8	32.8	32.2	32.1	31.9	31.7	31.5	31.4	30.9	30.3	29.4	28.6	28.0
JP	6.8	7.1	7.4	7.6	7.7	7.7	8.0	8.2	8.5	8.6	8.7	8.6	8.6	8.5	8.2	7.8	7.4	7.0	6.6	6.3
DE	7.0	6.9	6.8	7.0	6.9	7.1	7.4	7.8	8.2	8.2	8.1	8.2	8.1	7.8	7.8	7.8	7.6	7.4	7.2	7.3
GB	8.2	8.3	8.6	8.7	8.8	9.0	9.0	8.9	9.1	9.1	9.3	9.0	8.7	8.6	8.5	8.3	8.3	8.2	7.8	7.8
FR	5.0	5.1	5.4	5.5	5.5	5.6	5.7	5.9	6.1	6.0	5.9	5.9	5.8	5.7	5.5	5.5	5.4	5.3	5.4	5.3
CH	1.3	1.3	1.4	1.5	1.5	1.5	1.5	1.6	1.7	1.7	1.7	1.7	1.7	1.7	1.8	1.7	1.8	1.8	1.7	1.8
CA	4.6	4.6	4.8	4.7	4.6	4.5	4.4	4.3	4.2	4.1	4.2	4.1	4.2	4.3	4.3	4.5	4.6	4.5	4.5	4.5
SE	1.6	1.6	1.6	1.6	1.7	1.7	1.8	1.8	1.8	1.8	1.8	1.9	1.8	1.8	1.8	1.7	1.7	1.7	1.6	1.6
IT	2.7	2.9	3.1	3.2	3.3	3.4	3.6	3.7	3.8	3.8	3.9	4.0	4.0	4.2	4.2	4.2	4.2	4.3	4.3	4.3
NL	2.0	2.0	2.1	2.2	2.2	2.2	2.3	2.3	2.4	2.3	2.3	2.3	2.4	2.4	2.4	2.5	2.4	2.4	2.4	2.5
FI	0.6	0.6	0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.8	0.9	0.8	0.8	0.8
KR	0.2	0.3	0.3	0.4	0.5	0.7	0.9	1.1	1.3	1.5	1.6	1.9	2.0	2.3	2.6	2.6	2.7	2.7	2.9	3.1
CN	1.1	1.2	1.2	1.3	1.3	1.6	1.8	2.0	2.4	2.8	3.5	4.1	4.5	5.2	6.1	7.1	8.1	8.6	9.2	10.3
EU15	29.7	30.2	31.1	31.8	32.1	32.7	33.5	34.3	35.1	35.1	35.0	35.0	34.8	34.3	34.0	33.8	33.6	33.1	32.6	32.5
EU12	2.3	2.3	2.4	2.5	2.5	2.6	2.7	2.8	2.9	3.0	3.1	3.3	3.3	3.4	3.5	3.4	3.5	3.9	4.1	4.1
EU27	31.7	32.1	33.1	33.8	34.0	34.7	35.5	36.3	37.2	37.2	37.2	37.4	37.2	36.8	36.5	36.3	36.1	36.0	35.7	35.6
WORLD	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Sources: WoS, searches and calculations by Fraunhofer ISI.

If the publication share of the year 2000 is indexed to the level 100, then the index for Germany in the year 2009 lies at 90% (Table 2). Among the industrialised countries only Switzerland, Canada, Italy and the Netherlands still have an index above 100 in 2009.

In contrast to the industrialised countries, South Korea reached an index of 194 and China of even 296. The long-term series shows that China started at a very low level of 1.1% of the worldwide publications and the take-up in terms of publication numbers began at the end of the 1990s. At present, China has a level of 10.3%. In the case of South Korea, the share increased from 0.2% in 1990 to 3.1% in 2009. The take-up started already in the first half of 1990s, thus earlier than in China.

A further interesting case is the EU-12 countries, the new member states of the European Union. They had a share of 2.3% in 1990 and have achieved a level of 4.1% in 2009. Their index between 2000 and 2009 increased to 133. Thus the EU-12 countries steadily increased their publication activities, but at a lower rate than the countries from South East Asia.

Table 2: Shares of Selected Countries and Regions in all Publications in the WoS in the Period 2000 to 2009 indicated to the Year 2000 (Index = 100)

Country	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
US	100	99	99	98	98	96	94	92	89	87
JP	100	99	99	98	94	90	86	81	76	73
DE	100	100	100	97	96	95	93	91	89	90
GB	100	97	94	93	91	90	90	89	85	84
FR	100	99	98	96	93	93	92	89	90	90
CH	100	97	97	99	102	101	104	103	102	105
CA	100	99	100	103	104	108	109	108	108	108
SE	100	103	102	98	97	96	94	92	88	89
IT	100	104	105	109	110	110	109	112	111	112
NL	100	100	103	103	103	106	105	104	104	107
FI	100	104	101	100	99	95	97	94	92	91
KR	100	117	126	142	159	165	170	167	182	194
CN	100	118	129	150	176	203	233	247	264	296
EU15	100	100	99	98	97	97	96	95	93	93
EU12	100	106	108	110	113	112	115	125	133	133
EU27	100	100	100	99	98	97	97	97	96	96
WORLD	100	100	100	100	100	100	100	100	100	100

Sources: WoS, searches and calculations by Fraunhofer ISI.

The comparison of the shares according to the old dataset and the new WoS version used by the Competence Centre Bibliometrics shows slight, but not substantial differences. For instance, the share of the USA in 2008 according to the old set was 28.3%, according to the new set 28.6%. In the case of Germany, the share in the old dataset was 7.7% and in the new 7.2%. The share of China according to the old dataset was 9.9%, compared to 9.2% in the present set. In particular, the order between the countries did not change and the time trends are equivalent. The differences are primarily due to the inclusion of the social sciences and the humanities in WoS.

When the citation rates are scrutinised, the particularly good positions of Switzerland, the United States and the Netherlands appear (Table 3). All three countries were able to strengthen their already good position further. Germany was able to improve its citation rate continuously, which however had no impact on its relative positioning in comparison to other countries, as in recent years the citation quotas improved for almost all investigated countries.

Table 3: Citation Rates (3 year window) of Selected Countries and Regions in Publications in WoS (without self-citations)

Country	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
US	4.9	4.0	4.2	4.4	4.5	4.6	4.8	5.0	5.1	5.3	5.4	5.4	5.5
JP	3.2	2.1	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.2	3.3	3.4	3.5
DE	4.0	2.9	3.0	3.2	3.4	3.6	3.8	4.0	4.1	4.3	4.6	4.6	4.8
GB	3.9	3.0	3.3	3.5	3.6	3.8	3.9	4.3	4.4	4.6	4.9	4.9	5.1
FR	3.7	2.7	2.9	3.1	3.1	3.3	3.5	3.6	3.7	3.9	4.1	4.2	4.5
CH	5.9	4.7	4.9	4.9	4.9	5.2	5.4	5.6	5.4	5.9	6.3	6.1	6.2
CA	3.7	3.0	3.2	3.5	3.5	3.8	3.8	4.0	4.2	4.4	4.5	4.7	4.8
SE	4.4	3.3	3.5	3.7	3.7	3.9	4.1	4.3	4.5	4.8	5.0	5.1	5.2
IT	3.6	2.6	2.8	3.1	3.2	3.3	3.3	3.7	3.6	3.9	4.2	4.2	4.4
NL	4.6	3.3	3.9	3.9	4.2	4.2	4.4	4.6	5.1	5.2	5.4	5.5	5.8
FI	4.2	3.0	3.3	3.5	3.5	3.9	3.7	4.2	4.0	4.2	4.4	4.6	4.8
KR	2.0	1.2	1.4	1.5	1.8	2.0	2.1	2.2	2.4	2.6	2.7	2.8	3.0
CN	1.3	0.7	0.9	1.0	1.1	1.3	1.5	1.7	2.0	2.2	2.4	2.5	2.8
EU15	3.6	2.6	2.8	3.0	3.1	3.2	3.3	3.5	3.7	3.9	4.1	4.1	4.3
EU12	2.0	1.1	1.2	1.4	1.5	1.6	1.8	1.9	2.0	2.2	2.3	2.5	2.5
EU27	3.5	2.5	2.7	2.8	3.0	3.1	3.2	3.4	3.5	3.7	3.9	4.0	4.1
WORLD	3.2	2.4	2.6	2.7	2.8	2.9	3.0	3.1	3.3	3.4	3.5	3.6	3.6

Sources: WoS, searches and calculations by Fraunhofer ISI.

Table 4 reports the result for the indicator journal-specific Scientific Regard (SR index). For Germany, this index has been rather stable in the last decade. On the whole, the German value is comparable with that of other leading industrialized countries like Great Britain, Sweden, the United States or Finland. Switzerland holds by far the leading position with regards to the SR index. For China, a steady improvement and since 2004 a stable level slightly above average can be observed. The South Korean value also increased, but the value is still slightly below average.

Table 4: Scientific Regard (SR Index) of Selected Countries and Regions in Publication in WoS (without self-citations)

Country	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
US	6	8	8	9	8	9	9	9	8	8	8	7	7
JP	-3	-7	-7	-5	-6	-6	-5	-8	-9	-7	-8	-7	-7
DE	10	7	6	7	7	7	9	8	7	8	8	6	8
GB	10	8	10	9	8	9	8	10	8	9	8	9	8
FR	6	3	2	4	3	3	3	3	2	2	2	3	4
CH	17	20	19	17	15	17	16	16	14	15	17	16	14
CA	4	5	3	8	5	9	3	5	7	5	5	6	6
SE	11	8	10	11	9	9	9	11	10	11	10	11	8
IT	2	-3	-3	1	-2	-1	-2	3	-4	0	1	1	3
NL	9	8	14	10	11	7	10	8	13	10	9	9	10
FI	10	10	6	11	3	9	8	13	4	5	5	10	9
KR	-17	-25	-19	-17	-12	-9	-9	-7	-4	-1	-3	-2	-3
CN	-31	-41	-34	-29	-23	-21	-10	-9	-1	1	3	2	5
EU15	5	2	2	2	2	2	2	2	2	2	2	2	2
EU12	-10	-26	-24	-19	-16	-16	-11	-13	-11	-8	-9	-7	-3
EU27	4	1	1	1	1	1	1	1	1	1	1	1	1
WORLD	0	0	0	0	0	0	0	0	0	0	0	0	0

Sources: WoS, searches and calculations by Fraunhofer ISI.

The minor differences of the SR indices compared to the version of last year's report (see Schmoch/Schulze 2010, p. 7) are due to the inclusion of the social sciences and humanities, whereas the former calculation for the Science Citation Index only covered the natural, life, and medical sciences, as well as engineering.

In the German perspective, the development of the International Alignment (IA index) has been positive for many years (Table 5). Here a positive trend can be observed since the beginning of the 1990s, i.e. the efforts of a broad integration in the international scientific discussion are being successfully continued. On the whole, German authors are increasingly successful in placing their articles in reputed international journals.

Similar upwards trends in international alignment can be observed for other countries like Great Britain, France or the Netherlands. This general trend can be interpreted against the background of an increasing use of bibliometric indicators for the assessment of scientific performance, in particular, in the selection of candidates for higher academic positions. Now the most effective method for increasing citation rates is to publish articles in internationally visible journals, in particular in American, instead of less visible ones. Obviously, many authors follow this strategy which is apparent as a wide-spread behaviour influencing the increasing IA indexes of whole countries.

Table 5: International Orientation (IA Index) of Selected Countries and Regions in Publications WoS (without self-citations)

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
US	35	38	37	37	37	36	36	36	35	34	33	33	34
JP	2	-6	-2	-2	-1	-1	0	-1	-1	1	0	0	2
DE	13	11	9	10	12	14	13	14	16	16	18	19	21
GB	11	14	15	16	15	18	18	21	21	21	23	22	25
FR	9	9	9	8	7	11	12	10	11	12	14	13	17
CH	41	43	42	40	39	39	40	38	35	38	38	36	38
CA	11	16	18	18	18	18	20	19	19	19	18	20	22
SE	21	21	20	19	19	22	21	20	22	23	23	24	27
IT	10	9	11	12	16	14	12	13	13	14	15	15	15
NL	27	23	26	26	29	30	27	28	30	31	32	33	35
FI	16	13	19	15	18	21	14	16	16	16	16	14	18
KR	-32	-42	-41	-38	-33	-26	-28	-27	-27	-28	-25	-24	-17
CN	-51	-63	-63	-62	-61	-54	-52	-48	-44	-43	-40	-37	-29
EU15	7	6	7	7	8	9	9	10	10	10	12	12	13
EU12	-36	-45	-46	-44	-42	-38	-40	-37	-34	-34	-31	-29	-33
EU27	4	3	3	3	5	6	5	6	7	7	9	9	9
WORLD	0	0	0	0	0	0	0	0	0	0	0	0	0

Sources: WoS, searches and calculations by Fraunhofer ISI.

In absolute terms, the leading countries in the International Alignment index are the United States, Switzerland, the Netherlands and Sweden.

An interesting development has to be stated for South Korea and China. Here the IA indexes are steadily improving as well, but are still substantially below average. China appears to be above South Korea in terms of Scientific Regard, but it is distinctly lower in terms of International Alignment. An obvious interpretation of this finding may be that Chinese authors primarily publish in less visible journals of lower quality and that their slightly positive Scientific Regards only refers to these journals, whereas the negative in South Korea's SR index is realised in journals of higher visibility and quality.

2.3 Germany's Profile

In order to arrive at a more disaggregated consideration of Germany, the citation indexes were differentiated into 27 fields; 17 of these fields demonstrate clear connections to technology, further 8 fields have relations to the natural and life sciences, but are rather general. As major difference to the classification of former years, the fields "thermal processes" and "civil engineering" were abandoned and introduced into a new field called "specific engineering". The major reason for this decision was the very small number of publications of these fields in WoS, implying an enormous statistical instability. Furthermore, the sub-field "multidisciplinary engineering" - according to the

WoS terminology - was moved from "mechanical engineering" into "specific engineering", whereby "multidisciplinary engineering" dominates the new field "specific engineering" quantitatively. It comprises to a large extent the application of computer methods on mechanical engineering, that is, the calculation of resistance or vibrations etc. using the improved performance of computers.

Further new fields are "economics", "other social sciences" and "humanities" where the "other social sciences" primarily refer to sociology. However sociology and humanities are not sufficiently represented by articles in journals. Rather, book contributions and monographs should be included to achieve a more appropriate picture of these fields. Furthermore, in the social sciences and humanities, articles in national languages not covered by the WoS are relevant, so that in both fields the findings from the WoS data should be interpreted with caution (Hicks 2004).

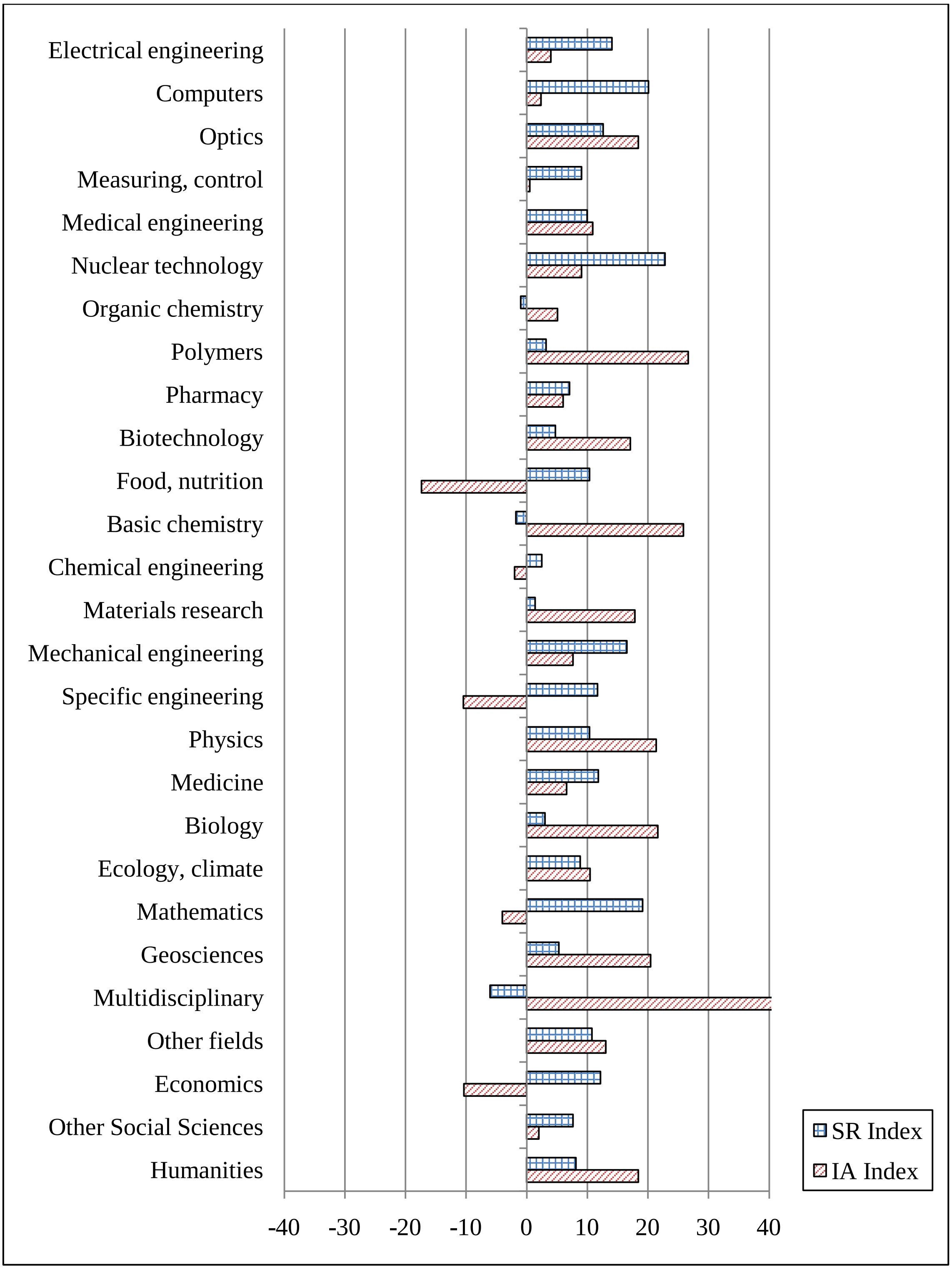
Based on the indexes of Scientific Regard and International Alignment for the individual fields, country-specific broad profiles of strengths and weaknesses in scientific performance can be drawn up. In Figure 1, the SR and IA indexes for Germany are presented conjointly. As first observation, the values of the SR and IA indexes considerably vary; some fields show average values, other fields quite high ones. In earlier reports, for instance Schmoch/Qu (2009), it was demonstrated that a very high average value of Switzerland for both indexes are based on quite uniform high levels in all fields.

As to the comparison of SR and IA indexes for Germany, the values are quite different in many fields. For example, in "electrical engineering", "computers", "nuclear technology", "food & nutrition", "mathematics" or "economics", the SR index is high and the IA index average or even below average. Thus in these cases high SR indexes are achieved in less internationally visible journals. In other cases such as "polymers", "biotechnology", "basic chemistry", "material research" or "biology", the IA index is high, but compared to the level of these highly visible journals, the SR indexes are modest. However, in some fields, in particular "optics" or "ecology & climate", above average values are achieve for both indexes.

The SR and IA indexes reflect the scientific performance with the analysed papers, but not the activity in quantitative terms. In this regard it is more illuminating to consider the German profile with respect to specialisation, i. e. the distribution of the scientific/publication activities by fields in Germany compared to the international distribution. According to such a calculation, depicted in Figure 2, major fields of German scientific activity are "medical engineering", "nuclear technology", "physics" and "geo sciences". Furthermore, a distinctly positive value for "biotechnology" has to be mentioned.

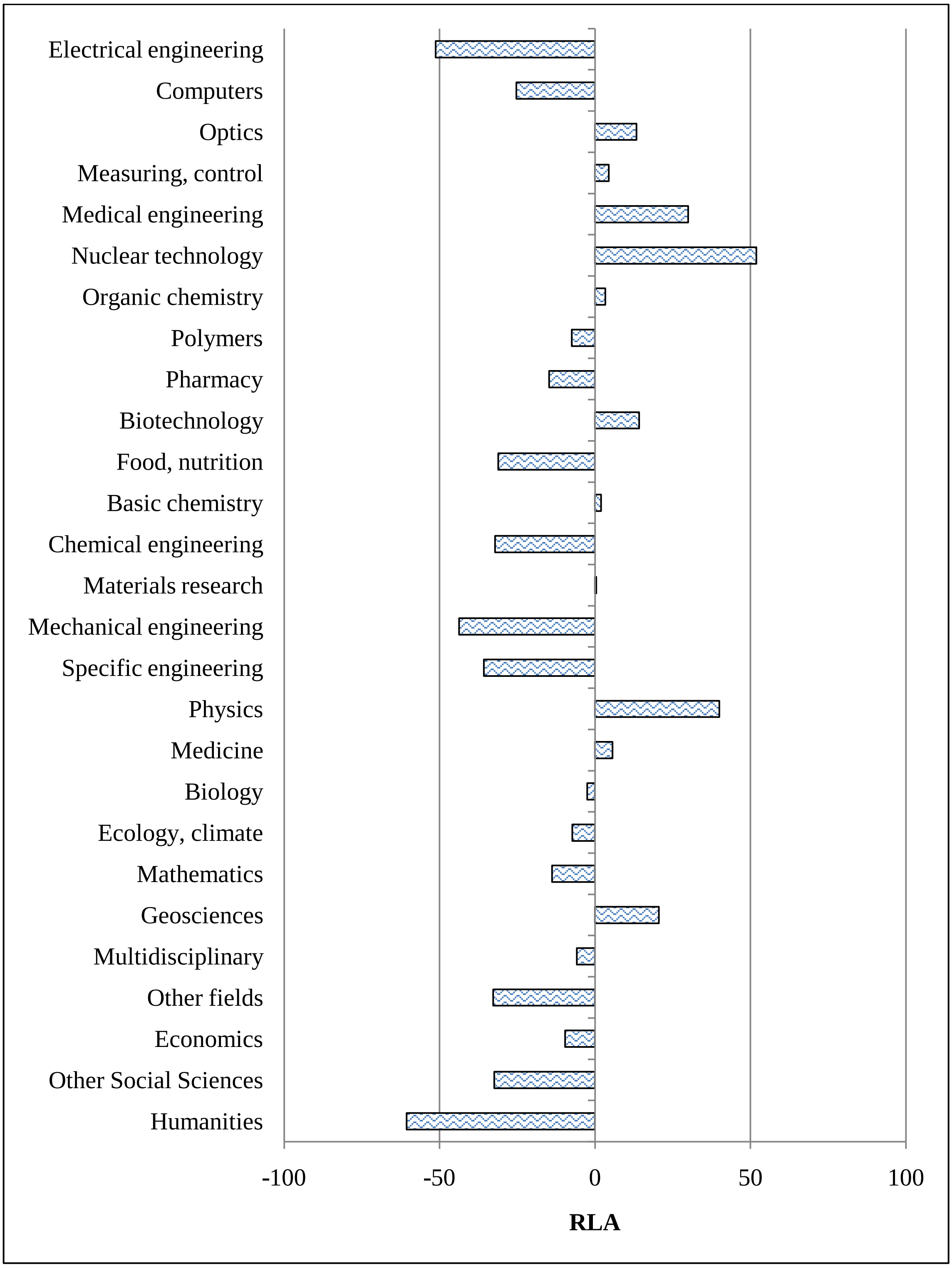
The negative specialisation indexes for "chemical engineering", "mechanical engineering", "specific engineering", "other social sciences" and "humanities" require an annotation. In all these fields the coverage of non-American journals is very weak, and in consequence the indexes for German articles are low. The negative values have to be seen as database artefacts. Against this background, it is interesting to note that the specialisation index in "economics" is less negative and that a high Scientific Regard index is achieved. The slightly negative International Alignment index has to be seen in the context of the weak representation of European journals in WoS in "economics" visible in the slightly negative German specialisation index in this field.

Figure 1: Scientific Regard (SR) and International Alignment (IA) of Germany in Publications in WoS differentiated by Science Fields, 2007 (without self-citations)



Sources: WoS, searches and calculations by Fraunhofer ISI.

Figure 2: Revealed Literature Advantage (RLA, specialisation) of Germany in Publications in WoS differentiated by Science Fields, 2009



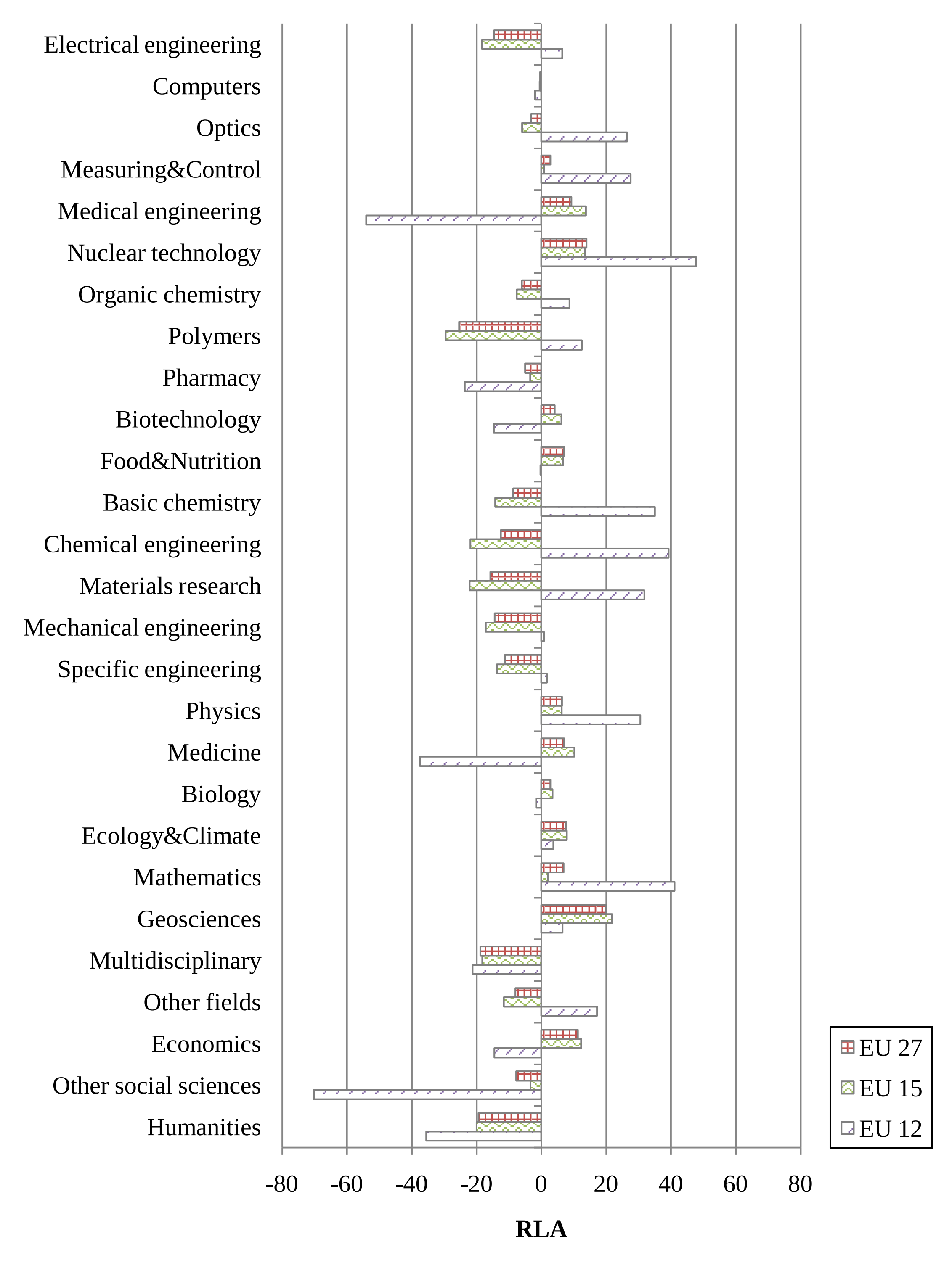
Sources: WoS, searches and calculations by Fraunhofer ISI.

2.4 The New EU Profile

The European Community was founded 1958 and gradually increased in several steps. In 1973 Denmark, Ireland and the United Kingdom became members, in 1986 Spain and Portugal, already in 1981 Greece. Austria entered only in 1995. All these countries constituted the so-called EU-15 countries. Then the European Community, now called European Union, was enlarged in 2004 by Cyprus, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia and Slovenia. In 2007 Bulgaria and Rumania were integrated as well. The latter countries are called EU-12 countries. This chapter examines to what extent the publication profile of the "old" EU-15 countries was changed by the integration of the EU-12 countries.

Looking at the publication shares in the WoS, the EU-15 countries started at a level of 29.7 % in 1990 and reached 42.5 % into 2009 (Table 1). The EU-12 countries began at 2.3 % and recently achieved 4.1 %, thus increasing their share substantially. Despite this tremendous growth, the share of the EU-12 countries within the EU-27 countries is still limited, at 11.4 % into 2009. In comparison, Germany held a share of 20.0 %, and thus the impact of Germany on the profile of the EU-27 is distinctly higher than that of all EU-12 countries combined. Due to the low weight of the EU-12, its impact on the specialisation profile of the EU-27 is finite (Figure 3). Rather, the profile of the EU-15 and EU-27 are largely similar. For instance, in cases of a highly positive specialisation of the EU-12 in "basic chemistry", "chemical engineering" or "materials research", the specialisation index of the EU-27 is only slightly better than that of the EU-15. The main areas of specialisation of the EU-12 are "optics", "measuring & control", "nuclear technology", "basic chemistry", "chemical engineering", "material sciences", "physics" and "mathematics". Looking at the long-term trends of the citations indexes, the performance of the EU-12 countries in Scientific Regard has improved from an originally distinctly below average value to an average one (Table 4). As to International Alignment, the index improved a little bit from a very low level, but is still distinctly negative. In this index the above average value of the EU-15 of 13 is a little bit diminished to the value 10 for the EU-27, due to the inclusion of EU-12.

Figure 3: Revealed Literature Advantage (RLA, specialisation) of the EU in Publications in WoS differentiated by Science Fields, 2009



Sources: WoS, searches and calculations by Fraunhofer ISI.

2.5 Public Non-university Research Institutions in Germany

Among the research institutions with public agencies, the universities are only one of a broad variety of other research organisations in Germany. Among them the most important ones are the Helmholtz Association, the Max Planck Society, the Fraunhofer Society and the Leibniz Association. All these public non-university organisations taken together represent about 80 % of the university research in terms of R&D budget. In consequence, there is also an explicit competition within the public research sector between universities and non-university institutions, as well as between different non-university institutions.

As to their general orientation, the Max Planck institutes are engaged in excellent basic research and primarily rely on institutional funding[2]. The main areas of Max Planck institutions are physics, biology and chemistry, but there is also a relevant share of humanities and social sciences. In general, the mission of Max Planck institutes is to conduct fundamental research in important or strategic fields of science with an adequate concentration of personal and equipment, to quickly enter newly emerging fields, especially those outside the mainstream, or fields that cannot be covered sufficiently at the universities, and to conduct research that requires special or large equipment or research facilities, so that it cannot be undertaken at universities. Some of the leading researchers of Max Planck also teach part-time at universities, but the general focus of the Max Planck Society is on research.

The Fraunhofer Society has a distinct orientation towards applied research and is primarily financed by external funds, in particular from industrial enterprises. The Fraunhofer Society´s mission is the distinct counterpart of the Max Planck Society. Nearly all of the 58 Fraunhofer institutes have a specific technical focus, covering the areas of information and communication technology, life sciences, microelectronics, surface technology, production and materials.

The first Helmholtz Centres were founded in the late 1950s when the allied forces gave Germany the permission to perform nuclear research; at that time, they were called Large Research Centres (*Großforschungseinrichtungen*). Following the pattern of US and British national laboratories, all Helmholtz Centres initially worked in various areas of civil nuclear research. Since the late 1960s, other areas of research have been added, such as aeronautics, computer science or biotechnology. It is not possible to describe the research orientation of Helmholtz in terms of simple categories like basic or applied.

2 The following description of German non-university institutions is largely based on Schmoch (2008).

Their activities include

- basic research requiring large research facilities,
- large projects and programmes of public interest requiring extraordinary financial, technical and interdisciplinary scientific resources and management capabilities, and
- long-term technology development, including pre-industrial fabrication.

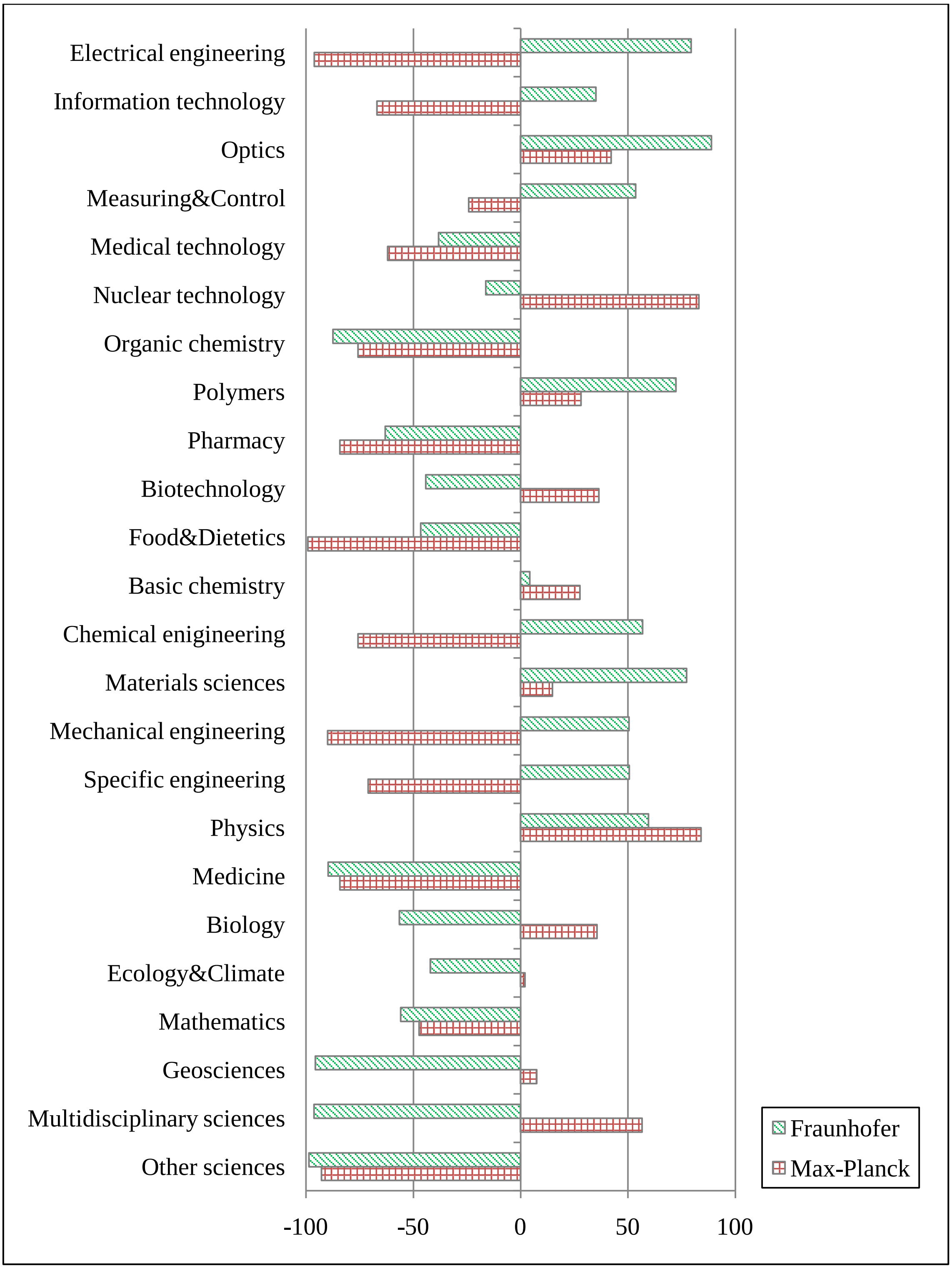
In the 1980s, the focus on civil nuclear research was abandoned, so that at present, only a limited share of Helmholtz activities is still linked to that field. Therefore the mission of the Helmholtz Association is less clear than those of the Max Planck Society and the Fraunhofer Society.

The Leibniz Association (*Wissenschaftsgemeinschaft Gottfried Wilhelm Leibniz*, WGL) is the umbrella organisation for 88 institutions conducting research or providing scientific infrastructure. The institutions included are institutions of specific public interest, supported by the states and central federal government in equal parts. Therefore, the Leibniz Association is characterised by an enormous diversity of themes addressed by the institutions, as well as its decentralised organisational structure: by far the majority of institutes are scientifically and organisationally independent. The Leibniz Institutes can be traced back to the so-called Blue List institutes established in 1992 as a reaction to the new organizational structures after German unification – they were renamed the Leibniz Association in 1997.

The task of this chapter is to depict the different profiles and trajectories of the non-university institutions, primarily referring to publication and patent statistics as proxy for their orientation to basic and applied activities. The specialisation profiles of the four types of non-university institution in publications are presented in Figure 4 and Figure 5. For instance, the Fraunhofer and the Max Planck Society show up largely opposite profiles for example, with a strong focus of Fraunhofer on electrical engineering, information technology and mechanical engineering compared to a negative one of Max Planck in these fields and a positive focus of Max Planck on biotechnology, biology and a respec tively negative one of Fraunhofer.

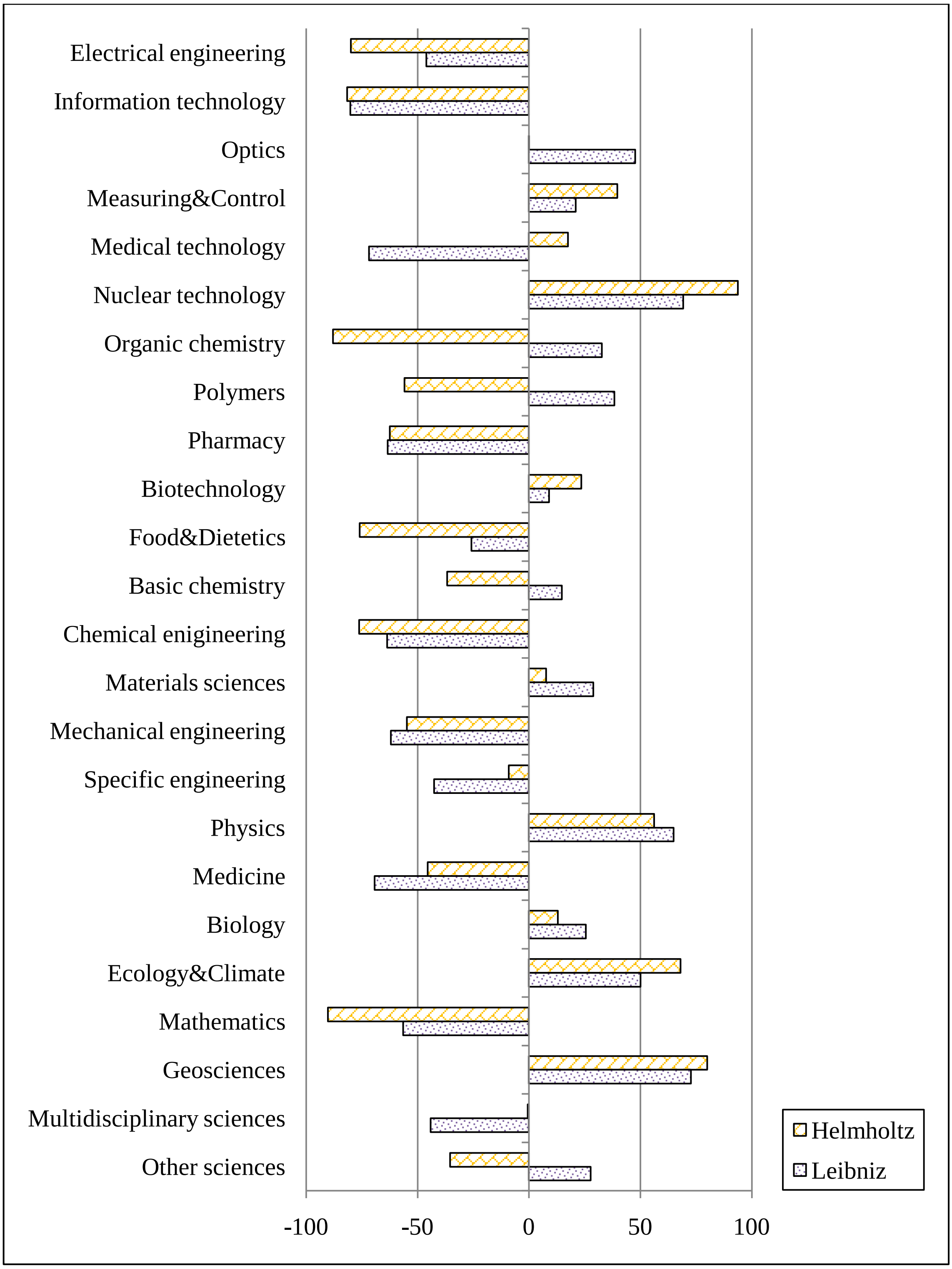
Also in terms of patent applications the four institutions reveal quite different profiles, but a clear concentration of the technological activities on more research-intensive fields like semiconductors, measurement, analysis of biomaterial, biotechnology or surface technology is obvious for all institutions, whereas the less research-intensive areas like textile and paper machines, thermal processes, mechanical engineering or consumer goods are generally out of the focus of these institutions (Figure 6 and Figure 7).

Figure 4: Revealed Literature Advantage (RLA, Specialisation) of the Max-Planck and the Fraunhofer Society in Publications in WoS differentiated by Science Fields, 2009



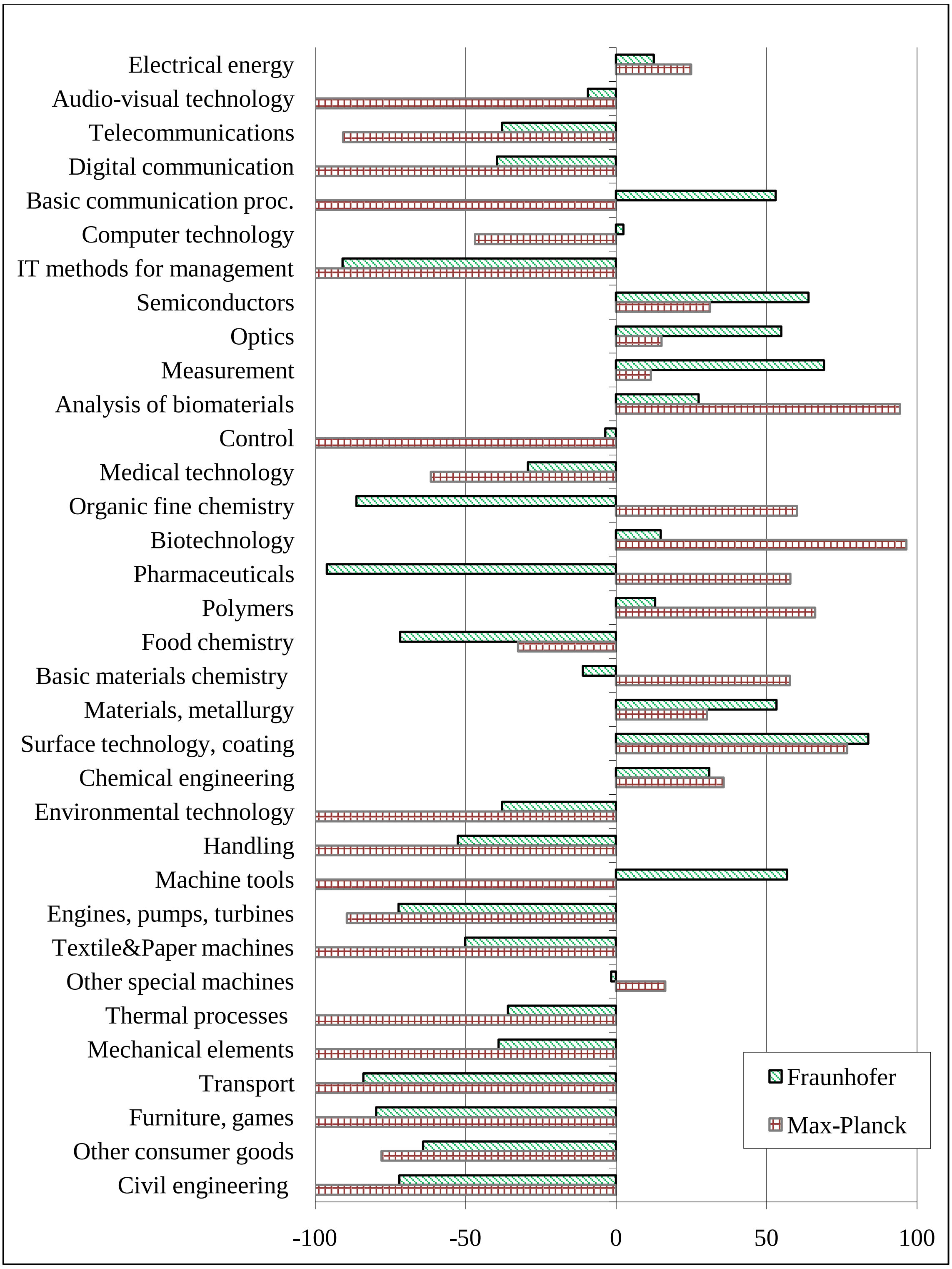
Sources: SCISEARCH (STN), searches and calculations by Fraunhofer ISI.

Figure 5: Revealed Literature Advantage (RLA, Specialisation) of the Helmholtz and Leibniz Association in Publications in WoS differentiated by Science Fields, 2009



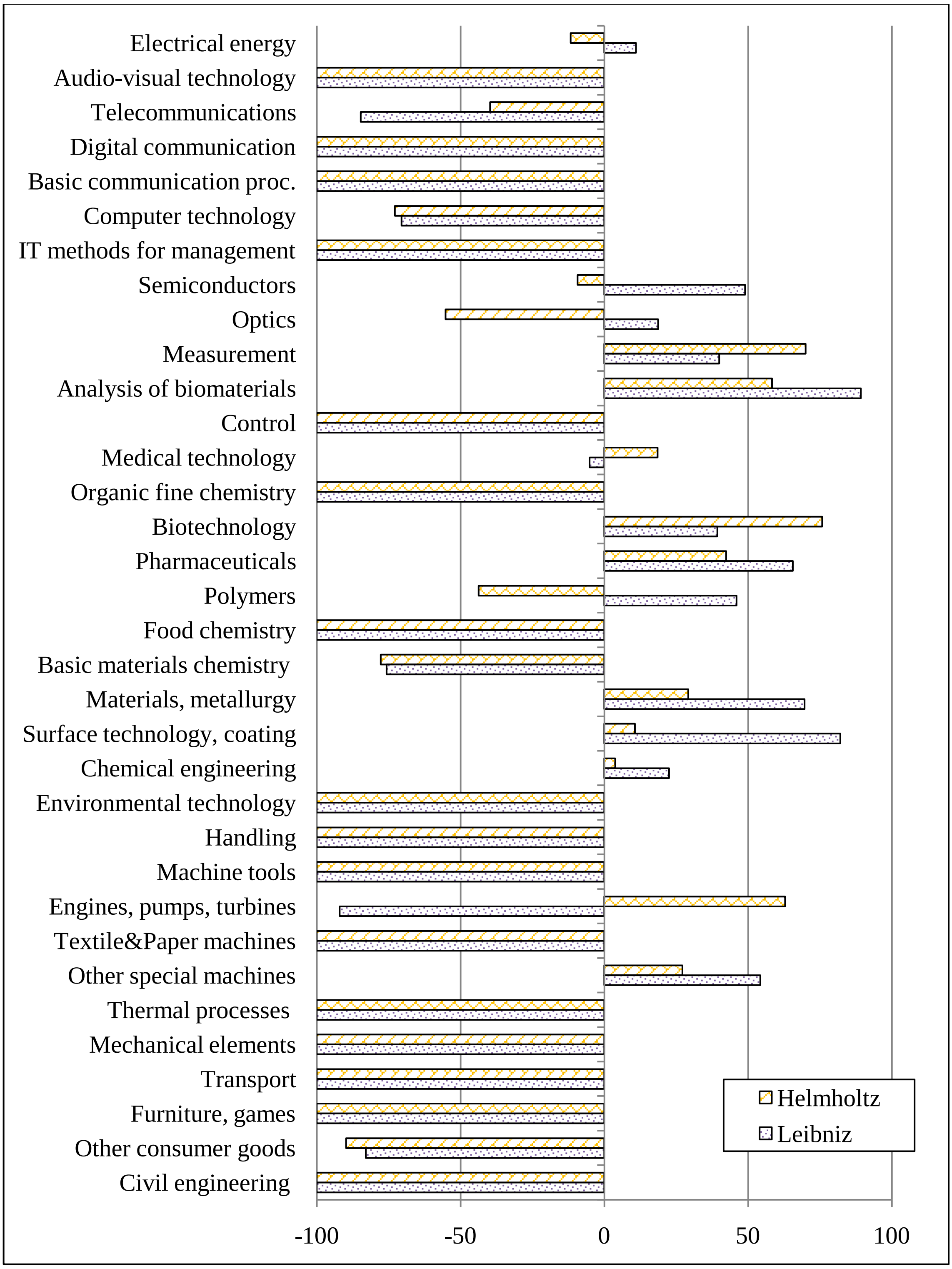
Sources: SCISEARCH (STN), searches and calculations by Fraunhofer ISI.

Figure 6: Revealed Patent Advantage (RPA, Specialisation) of the Max Planck and the Fraunhofer Society in patent applications at the DPMA differentiated by Science Fields, 2008



Sources: PATDPA (STN), searches and calculations by Fraunhofer ISI.

Figure 7: Revealed Patent Advantage (RPA, Specialisation) of the Helmholtz and Leibniz Association in patent applications at the DPMA differentiated by Science Fields, 2008



Sources: PATDPA (STN), searches and calculations by Fraunhofer ISI.

2.5.1 Cluster Analysis and Multidimensional Scaling

2.5.1.1 Method of Hierarchical Clustering

In order to achieve a better understanding of this quite confusing multidimensional picture of the publication and technology specialisation portfolios of the different institutions, a hierarchical cluster analysis was conducted.[3]

Cluster analysis is a term for a variety of different heuristic procedures to assign individual objects to a group, or in other words, for the systematic classification of individual objects from a given pile of objects. The objects which are defined by a fixed set of given attributes are classified into clusters, according to their similarity. Thus, this multivariate statistical procedure divides heterogeneous objects of a given population into relatively homogeneous groups.

Hierarchical clustering methods are characterised by the fact that the number and distribution of groups is reached by stepwise distribution of each single object. The starting point are the smallest possible groups, namely all individual objects, which are distributed bit by bit to larger groups (agglomerative methods). The general approach to these algorithms is repetitive. First, a distance matrix with individual objects is created. Second, the two most similar objects are searched and in a third step they are combined. Afterwards, based on the preceding results, a new distance matrix is created. Those steps are repeated until all objects, in the present case research institutions, are assigned to a group.

If all variables used for the analysis have a metric or quasi-metric scale level, a distance measure is needed to calculate the distances, or similarities, between the objects of groups.[4] For the present analysis, different distance measures revealed the same or at least similar results. One of the most common distance measures is the squared Euclidian distance, which also serves as a basis for most of the more advanced distance measures.

For the derivation of the squared Euclidian distance (SED) between two data points, the sum of the squared differences between the corresponding values is calculated:

$$D^2 = \sum_{i=1}^{V} (X_i - Y_i)^2$$

where V is the number of variables used to calculate the distances.

---

3 (the following methodological explanations are based on the works by Aldenderfer/Blashfield 1984; Backhaus et al. 2005; Bortz 1999; Kruskal/Wish 1977).

4 For dichotomous variables usually proximity measures are used. Proximity measures describe similarities between objects whereas distance measures describe distances. However, every proximity measure can easily be transformed into a distance measure and vice versa.

Following the procedure described above, in the first pass the two most similar objects are combined into a first cluster.

As a result, for this newly formed cluster, the distance to all remaining objects has to be calculated. Several fusion criteria exist which differ in the way of calculating distances between objects aggregated into clusters. Again, several algorithms were tested, all of them yielding similar results. For that reason, the analysis concentrates on the widely used single linkage method. It combines clusters to decrease the average distance between all item pairs, in which one part of the pair stems from its respective cluster.

2.5.1.2 Application of the Cluster Analysis on Publication and Patent Profiles

For the ensuing analyses, a cluster analysis is calculated for the patent and the publication specialisation portfolio of the research institutions. In this investigation, universities were also included as fifth element.

Concerning patents, Table 6 shows the distance matrix for the research institutes and universities. In the first step of the cluster analysis, the two institutions with the smallest differences are chosen and combined into one cluster. In the next step, the institute with the second smallest difference is added to the cluster, and so on.

Table 6: Distance Matrix for the Patent Specialisation Portfolios of German Research Institutes, 2008

	FHG	MPG	HGF	WGL	Uni
FHG	0				
MPG	166.455	0			
HGF	172.190	112.557	0		
WGL	138.727	60.149	55.603	0	
Uni	151.258	67.111	31.801	24.929	0

For a better understanding, Figure 8 shows the cluster analysis graphically, using a so-called dendrogram. A dendrogram is a tree diagram frequently applied to illustrate the arrangement of the clusters produced by hierarchical clustering. Reading it from left to right, it shows at which step objects were unified into one cluster and which level the distance between the unified clusters has.

In the first step, the Leibniz Association and the universities show the highest similarity of their patent profiles, at the second level the Helmholtz Association is included, and then the Max Planck Society follows. In any case, the distance of the Fraunhofer profile to those of the other institutions proves to be quite distinct.

Figure 8: Dendrogram for the Patent Specialisation Portfolios of German Research Institutes, 2008

```
        0         5         10        15        20        25
        +---------+---------+---------+---------+---------+

WGL     -+-----+
Uni     -+     +-------------+
HGF     -------+             +---------------------------+
MPG     ---------------------+                           I
FHG     -------------------------------------------------+
```

The same analysis can now be repeated for the publication specialisations of the research institutes. Table 7 shows the distance matrix and Figure 9 the respective dendrogram.

Table 7: Distance Matrix for the Publication Specialisation Portfolios of German Research Institutes, 2009

	FHG	MPG	HGF	WGL	Uni
FHG	0				
MPG	173392	0			
HGF	187260	51204	0		
WGL	160078	57530	51168	0	
Uni	150076	70798	61042	52832	0

Figure 9: Dendrogram for the Publication Specialisation Portfolios of German Research Institutes, 2009

```
        0         5         10        15        20        25
        +---------+---------+---------+---------+---------+

HGF     -+
WGL     -+---+
MPG     -+   +-------------------------------------------+
Uni     -----+                                           I
FHG     -------------------------------------------------+
```

In the case of publications, the profiles of the Helmholtz and Leibniz Association as well as that of the Max Planck Society have the highest similarity, as depicted in the first step. Again, the profile of the Fraunhofer Society is quite distinct.

For a better visualisation of the data, in addition multi-dimensional scaling (MDS) is used. Multi-dimensional scaling describes a set of exploratory statistical techniques used to find proximities and visualise them. Starting with a matrix of item to item similarities, the algorithm assigns a location to each item in an N-dimensional space. As a distance measure, again the squared Euclidian distance was chosen. For our purpose, N is chosen to be 2, so similarities can be visualised and interpreted easily via a Euclidian distance model. The results of the MDS analysis are sometimes less clear than those of a cluster analysis, as a multi-dimensional structure has to be projected on a two-dimensional plane and compromises have to be made.

Figure 10 and Figure 11 show the Euclidian distance models for patents and publications, respectively where the clusters of the first step are encircled.

Figure 10: Euclidian Distance Model for the Patent Specialisation Portfolios of German Research Institutes, 2008

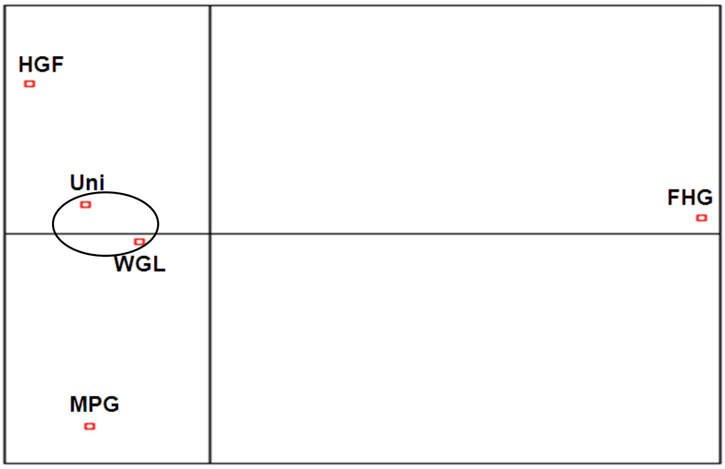
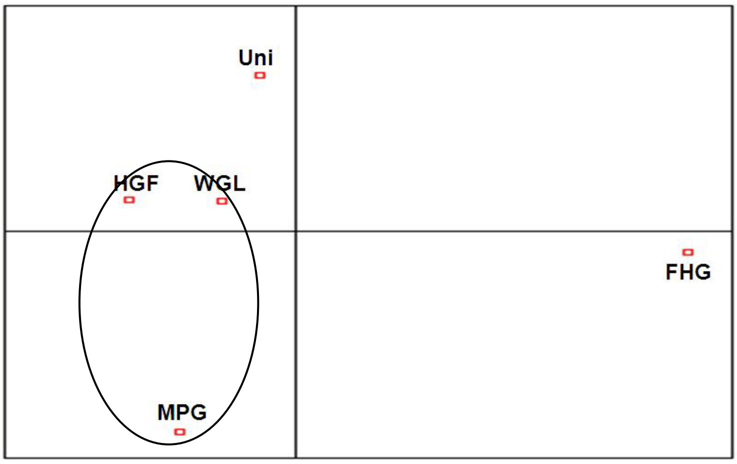


Figure 11: Euclidian Distance Model for the Publication Specialisation Portfolios of German Research Institutes, 2009



The cluster and the MDS analysis for publications show a quite distinct profile of the Fraunhofer Society. The profiles of the Helmholtz and the Leibniz Associations appeared to be quite similar, but also the Max Planck Society exhibits a similar profile, according to the cluster analysis. In terms of patent applications, the Max Planck and the Fraunhofer Society appear to be quite different. Also the Helmholtz Association exhibits a rather unique profile. This time, the portfolios of the universities and the

Leibniz institutions appear to be similar. To conclude, the clear distinct missions of the Fraunhofer Society and the Max Planck Society are also visible in their publication and their patent profiles. The publication profiles of the Helmholtz and the Leibniz Associations appeared to be less unique. However, in terms of patent applications, the profile of the Helmholtz Association appears to be clearly distinct.

Beyond the detailed patent and publication profiles, it is illuminating to examine the total patent and publication numbers and the referring patent and publication intensities. In this context, it is helpful to focus the analysis on the natural, engineering and medical sciences and to exclude the social sciences and humanities, as the latter are not covered by patent applications, and in the publication database WoS, the social sciences and humanities are insufficiently covered. In addition, the publication intensity in the social sciences and humanities, calculated as the number of publications per researcher, is much lower than in the natural, engineering and medical sciences, so that a realistic comparison is not possible. In this context, the following considerations do not refer to the total research work, but to that excluding the social sciences and humanities.

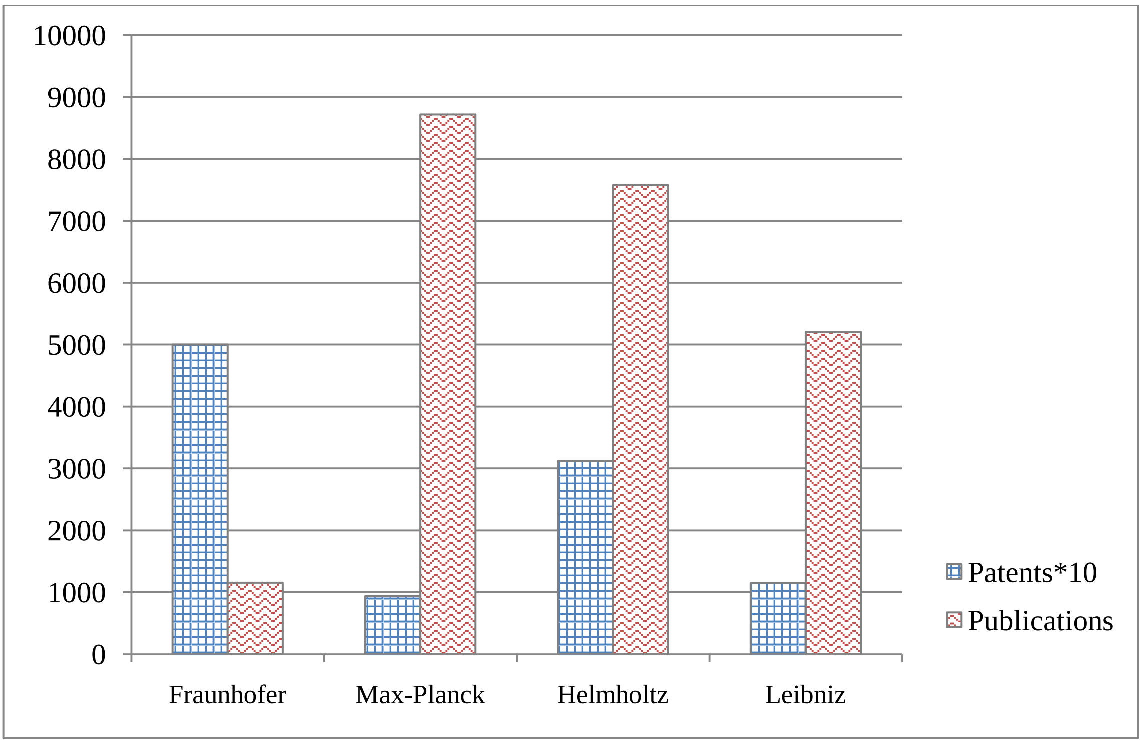
Analysing the patent and publication activities in absolute terms, the number of publications of the Max Planck Society is the highest and that of the Fraunhofer Society the lowest (Figure 12). In contrast, the number of patent applications of the Fraunhofer Society is distinctly higher than that of the other non-university institutions.[5] To make the patent and publication later comparable, the publications of the year 2009 were analysed for the year 2008. The underlying assumption is that it takes about one year between the submission and publication of a paper, and the analysis in publication databases are made on the basis of publication years.

When the number of patent applications and publications is related with the research staff in the natural, engineering and medical sciences, the differences between the institutions become even more distinct (Figure 13). The Max Planck Society appears to be clearly the most productive institution in terms of publications, the Fraunhofer Society in terms of patent applications. Thus the clear missions of these institutions in terms of basic and applied research are reflected in the patent and publication statistics. The Leibniz Association proves to achieve a high publication intensity, also less elevated than that of the Max Planck Society. The publication intensity of the Helmholtz Association turns out to be distinctly lower than that of Leibniz and Max Planck, but higher than that of the Fraunhofer Society. The patent intensities of Helmholtz and Leibniz are higher than that of Max Planck. In the comparison of patent and publication intensities,

5 In the diagram, the number of patent applications is multiplied by 10 for illustrative purposes, as in scientific institutions the number of patent applications is generally substantially lower than that of publications.

it is revealing to look at those of the universities, again in the natural, engineering and medical sciences. In this perspective, the publication intensity of the universities emerges at between the level of Leibniz and Max Planck, thus it is fairly high. At the same time, the patent intensity is distinctly higher than that of the Max Planck Society, the Helmholtz Association and the Leibniz Association. The transfer orientation of the universities turns out to be distinctly higher than that of the non-university institutions – with the exception of the Fraunhofer Society.

Figure 12: Number of Publications and Patent Applications of German Public Research Institutions, 2008[6]

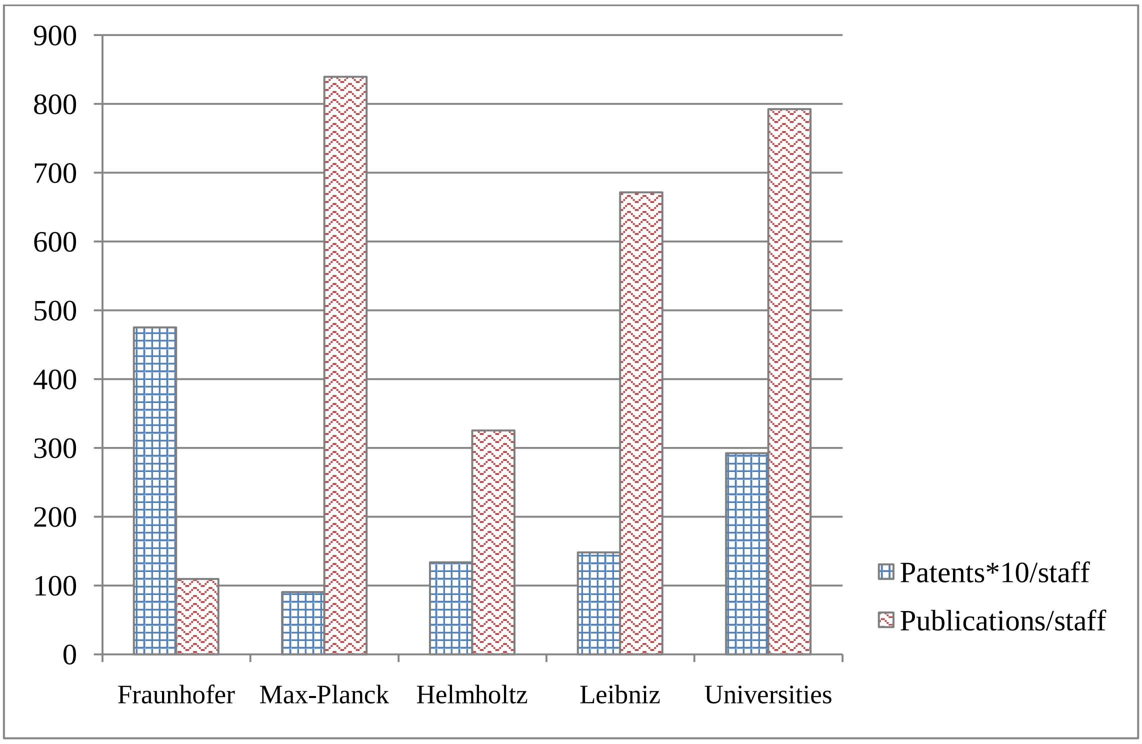


Sources: PATDPA (STN), SCISEARCH (STN), searches and calculations by Fraunhofer ISI.

Figure 13 shows the present situation in terms of patent and publication intensities. It is insightful to consider the change of these structures in time. For that purpose, the patent and publication intensities are depicted in the two-dimensional way in Figure 14 and the position of the research institutions in 2000 and 2008 are shown. In this representation, the situation of the Max Planck and the Fraunhofer Societies are rather stable, thus the dedicated orientation of Max Planck on publications is visible in its position at the upper left corner of the diagram and of top position of Fraunhofer in patents in the position at the lower right end side.

6 Application or submission year.

Figure 13: Publication and Patent Application Intensities (reference to staff) of German Public Research Institutions, 2008[7]



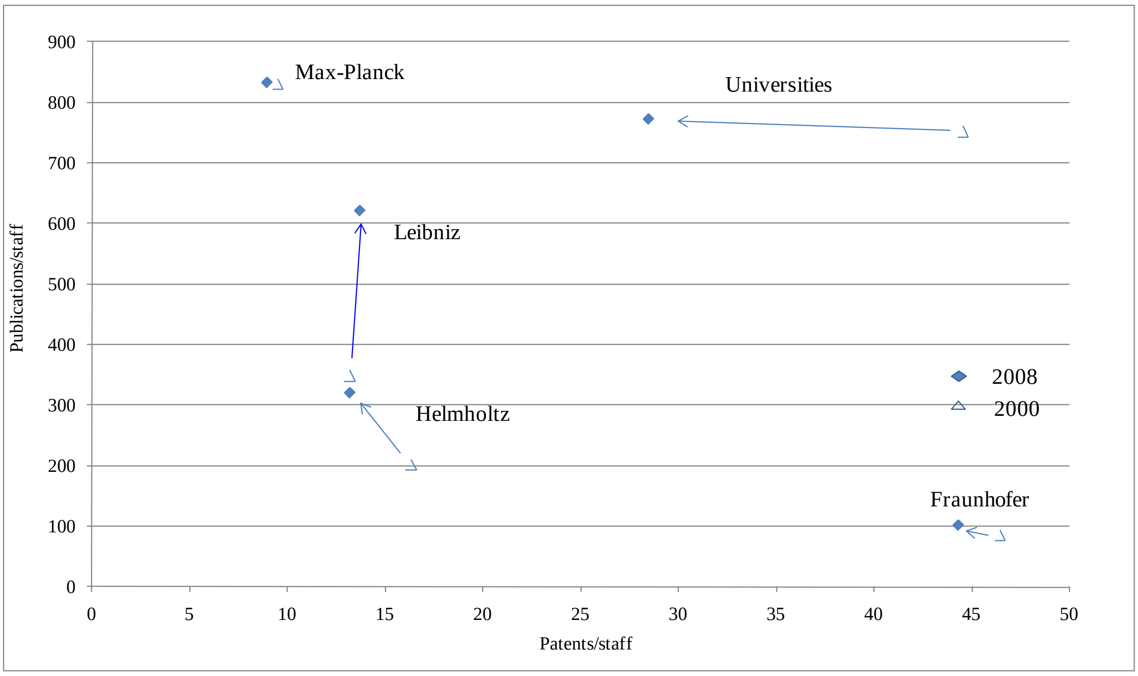
Sources: PATDPA (STN), SCISEARCH (STN), Statistisches Bundesamt, searches and calculations by Fraunhofer ISI.

The Leibniz Association and the Helmholtz Association hold intermediate positions, whereby the Leibniz Association obviously follows a strategy of an increasing orientation towards pure science, illustrated in steeply increasing publication intensity. In this context, it has to be noted that the searches for patents and publications of the Leibniz Association proved to be quite demanding. In 2008, 88 institutes belonged to the Leibniz Association, whereof 47 are active in research in the natural, engineering or medical sciences and thus potentially produce patent applications and publications. For all these 47 institutes, the number of patent applications and publications were searched for. In particular, the publication analysis was fairly difficult, as in WoS the same institute can appear in different name variations and, in addition, the name variance often substantially changes between 2000 and 2008.

The publication intensity of the Helmholtz Association is lower than that of the Leibniz Association. It also increased since 2000, but to a lower extent.

7 Application or submission year.

Figure 14: Publication and Patent Application Intensities (reference to staff) of German Public Research Institutions, 2000 and 2008[8]



Sources: PATDPA (STN), SCISEARCH (STN), Statistisches Bundesamt, searches and calculations by Fraunhofer ISI.

The position of the universities in Figure 14 is rather unique. In terms of publication intensity, the universities appeared to be high already in 2000. The most remarkable point is the considerable reduction of the patent intensity in this period. The reasons for this change are discussed in Frietsch et.al (2010) in more detail.

To summarise, the Max Planck Society and the Leibniz Association exhibit a clear focus on publications in the present situation. Also, in the perspective of publication profiles, the Leibniz Association and the Max Planck Society are similar. In terms of patent applications, the profile of the Leibniz Association is similar to that of universities and not to the Helmholtz Association. The Fraunhofer Society and the Max Planck Society have unique profiles in terms of patent applications and publications, so that a clear division of labour can be stated. As to the Helmholtz and the Leibniz Associations, the orientations are less clear. In this regard, the enforced focus of the Leibniz Association on publication has to be interpreted as a strategy to achieve a more distinct profile. All in all, the German landscape of public research institutions has experienced substantial changes in the last years and it can be assumed that this change is not terminated yet.

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8 Application or submission year.

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