Bibliometrics
Monitoring Emerging Fields

In 1958, a young man with a B.S. in chemistry from Columbia University borrowed US-$ 500 from Household Finance to produce an index to the current scientific literature in chemistry and the life sciences. It was Eugene Garfield, who at that time developed what we know today as Science Citation Index (SCI) or Web of Science. 40 years later Garfields company, the Philadelphia-based Institute for Scientific Information (ISI), employes 850 people with offices in 7 countries and sells a variety of library and information science products, indexing more than 8000 leading scientific journals in 35 languages. In 1992, ISI was acquired by Thomson Scientific, a subsidiary of The Thomson Corporation, a leading international business (annual revenues of US-$ 6 billion, common shares listed on stock exchanges). But the history of Garfields idea to set up an index of cited literature is not just a story of economic success (Cronin et al. 2000). Immediately after the SCI appeared on stage, scientists recognized it as a unique source for science studies, namely sociology and history of science. Derek John DeSolla Price was among the first, who discovered the potential of the SCI to give empirical insights into structures and developments of science (Price 1963). Although primarily produced as a tool for searching scientific articles, the SCI provides access also to aggregated data on disciplines, specialities, journals, institutions, countries and other entities. In fact during the past four decades the SCI together with its little 'sisters' SSCI (Social Sciences Citation Index) and A&HCI (Arts & Humanities Citation Index) became the major source for a new scientific field: bibliometrics.

A major product of bibliometric research are indicators, in most cases built from selected and aggregated counts of publications and citations. These indicators turned out to be important not only for studies in history and philosophy of science, but also for purposes of science policy and administration. Since 1972 the US National Science Foundation publishes biannual volumes of 'science indicators' (National Science Board 2000), including publication and citation statistics for international comparisons. Combined with other measures and peer review, bibliometric indicators can be used in the context of research evaluation. Bibliometricians have been heavily offended because of the political consequences which their indicators can have (MacRoberts 1989).

The question 'Which reality do we measure?' (Weingart et al. 1990) still needs to be answered as well.

Although the origin of the SCI is in the United States, there is much more bibliometric research activity in Europe than in the US. The largest group, headed by Anthony van Raan, is affiliated with the University of Leiden in the Netherlands. On the following pages van Raan and his collaborators present a lesson of what can be achieved with modern bibliometric methods – far beyond the pure number-counting of publications and citations. It is a valuable example for the application of sophisticated bibliometric methodology in exploring the interdisciplinary structures of new, unorthodox scientific fields. In fact it shows how such a field can be delineated and how emerging themes as well as the most important groups can be identified and analysed with bibliometric means.

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A Bibliometric Methodology for Exploring Interdisciplinary, 'Unorthodox' Fields of Science. A Case Study of Environmental Medicine

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This article tackles the problem of how to explore a 'not well-defined' or 'unorthodox' field of science. Often, such fields are problem-oriented and interdisciplinary. 'Environmental medicine' is taken as an example, and used to explore two central questions: First, what are the most important groups, for example, in Europe and particularly in Germany, and how do they perform? Second, what themes are possibly emerging in this field of research? Before answering these questions, we have to ask what the field of environmental medicine look likes, how it can be defined, and how it can be 'delineated.' We present a first approach based on several bibliometric techniques, which can be regarded as part of our well-developed practice, in combination with some novel strategies.

First Approach: Definition of the Field on the Basis of Scientific Journals

How to Define 'Environmental Medicine'

The objective of this study is to answer two central questions concerning the interdisciplinary research field 'environmental medicine.' First, what are, worldwide, the most important and/or possibly emerging themes in this field? Second, how well are German research groups and institutes performing in this field, also in relation to possibly emerging themes?

Before we can answer these questions, we have to start by asking what the field of environmental medicine looks like, how it can be defined, and how it can be 'delineated.' This study presents a first approach based on a combination of several techniques that can be regarded as part of our well-developed CWTS practice, along with some novel strategies. Our approach can be seen as a general method for exploring 'unorthodox,' mostly interdisciplinary fields of science. Therefore, it contributes to a much-needed extension of analytical tools in the study of interdisciplinarity (cf. Weingart/Stehr 2000).

'*Umwelt-Medizin*' or 'Environmental Medicine' is not an established, well-categorized research field within the important international databases, neither in the multidisciplinary Science Citation Index nor in the widely used medical database MEDLINE. Therefore, we have to develop a method to define, or to delineate, this 'unorthodox' field as well as possible.

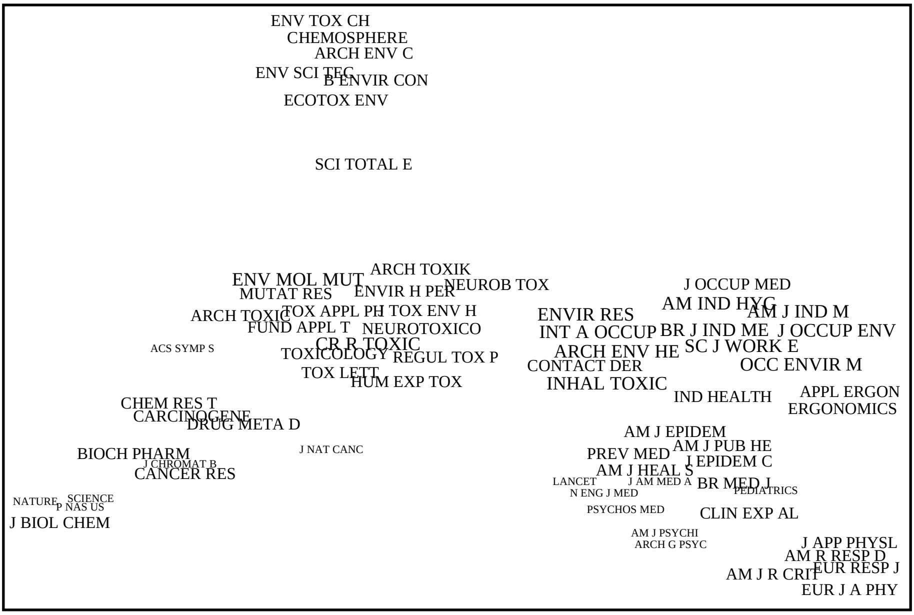
We took the following approach: On the basis of a first survey via *Internet* on environmental medicine (*Umwelt-Medizin*), we identified nine German research centers, mainly university institutes, in Aachen, Bochum, Düsseldorf, Gießen, Göttingen, Mannheim, Marburg, Munich, and Tübingen. We emphasize that this survey was certainly not intended to be exhaustive, and also should not have been, because the idea was to find 'starting points' via the Internet.

The next step was to collect publication data from these institutes. Most institutes make their publication lists over a longer time period (e.g., from 1995) available through their websites. This enabled us to identify the central *international journals* in the field of environmental medicine. Our first round was sufficient for this purpose. It was not necessary to collect a large number of relevant journals, because we developed a specific, iterative procedure to create a large set of environmental-medicine-relevant journals. In fact, five major journals formed the 'seeds' for an advanced journal-to-journal, citation-based analysis that ultimately generated a 'landscape' of about 70 journals grouped into several clusters. These 'seed-journals' are: *Environmental Health Perspectives*, *Journal of Toxicology and Environmental Health*, *International Archives of Occupational Health*, *Archives of Environmental Health*, and *Industrial Health*.

It should be noted that our Internet survey also found more nationally oriented, German-language journals and other periodicals. Although these national communication outlets are certainly important, particularly for daily practice, we did not consider them in this study, because our objective was to position European and particularly German groups on the international map of environmental medicine. We also noticed that several journals with an international status are published in the German language as well. The 'problem' with these journals, however, is that their articles are, on average, cited considerably less frequently in the international literature than those in English-language journals.

As mentioned above, we created a 'landscape' on the basis of *citation relations between journals*, starting with the five 'seed journals.' An extensive description of the journal-to-journal citation cluster analysis is given in Tijssen and van Raan (1994), together with other 'bibliometric mapping' methods. The more closely together journals were positioned on the map, the stronger their citation links. The results of our analysis are presented in Figure 1.

Figure 1: Bibliometric map of environmental medicine and related fields. This map is based on citation relations between journals (iteration procedure starting with 'seed journals' indicated by boxes; cf. main text).



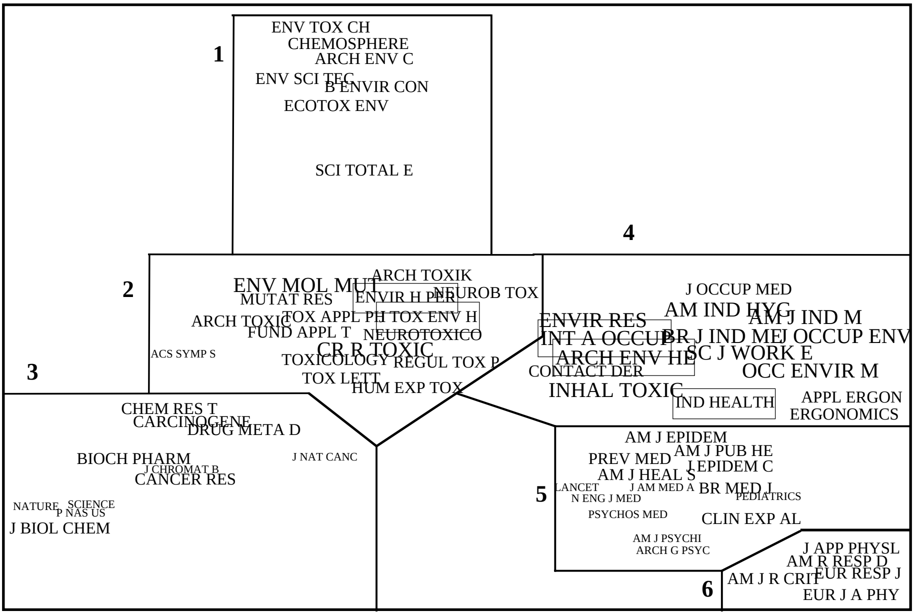
We view this landscape as a preliminary but good approximation of the research field 'environmental medicine.' Because this landscape was based on journal-to-journal citation relations, it contained only journals covered by the Science Citation Index. Therefore, it was not a 'perfect' representation of the field. Nonetheless, it certainly yielded a very useful *map* to guide the further steps in the analysis. SCI-covered journals represent the better and best international journals in most scientific fields, and thus SCI-covered journals form the 'hard core' of most natural science and medical fields.

As discussed above, the more nationally oriented (German-language) journals were not entered into our analysis because they were not covered adequately by the SCI. This made some subfields or specialties, particularly those with a typical national focus (and [parts of] the research groups concerned), 'invisible' on our map. Nonetheless, once scientific work had been published in the international, mostly SCI-covered literature, it would appear in our analysis.

The following *clusters* can be seen in Figure 1: Environmental toxicology and chemistry ('north' side of the map, 1), applied toxicology (center-left, 2), carcinogenesis research ('south-west', 3), environmental and in particular occupational health ('east', 4), epidemiology ('south-east', 5), and allergies and respiratory diseases ('far south east', 6). General journals such as *Nature*, the *Journal of Biological Chemistry* are included in the 'nearest' cluster. These clusters can be regarded as subfields of environmental medicine. Figure 2 is the same as Figure 1, but now these six clusters are indicated. Thus we have found a first thematic division of environmental medicine. We consider Clusters 1, 2, and 4 as the most central subfields, and the journals in these clusters as the *core journals of environmental medicine*. These journals, such as *Environmental Toxicology & Chemistry*, *Chemosphere*, *Archives of Environmental Contamination and Toxicology*, and *Environmental Science & Technology*, are given in Appendix 1.

These journals, however, also belong to 'already established' fields within the Science Citation Index. These fields (first 10) are environmental science, toxicology, public health, pharmacology and pharmaceutics, environmental engineering, allergy, dermatology, chemistry, genetics and heredity, and neurosciences. This clearly shows the 'interdisciplinary composition' or 'interdisciplinary profile' of environmental medicine. Later, we will compare the profile of the field *as a whole* ('the main stream profile') with that of outstanding groups or institutes within the field. Significant 'deviations' of these outstanding groups from the main stream may indicate important developments.

Figure 2: Bibliometric maps of environmental medicine and related fields. Same as Figure 1, now the six clusters as discussed in the main text are indicated.



The total number (worldwide) of core-journal publications in the period 1995–1998 was 24,714 of which 1,569 came from Germany. Table 1 shows the division of publications over the most active countries.

The German 'share' in environmental medicine research was 6.4 percent compared with 7.4 percent for science as a whole (1995). We conclude from these figures that Germany is internationally somewhat underrepresented in environmental medicine as far as our set of core journals defined above is concerned. Sweden, the Netherlands, and particularly Finland are quite 'over-active' in environmental medicine. However, we stress again that environmental medicine is mainly an applied research field. Therefore part of the German contribution will be in German-language journals that are *not* covered by the SCI, or in SCI-covered journals that do not belong to the clusters identified in Figure 1. A similar situation probably applies to France.

Table 1: Numbers of Environmental Medicine Publications 1995–1998

Country	Number	Percent
US	9,765	39.5
UK	1,673	6.8
Germany	1,569	6.4
Canada	1,469	5.9
Japan	1,147	4.6
Italy	861	3.5
Sweden	818	3.3
France	797	3.2
Netherlands	782	3.2
Spain	583	2.4
Finland	556	2.3
All other	4,694	19.0
Total	24,714	100.0

It is interesting to analyze which journals other than the core journals themselves frequently *cited* the core journals. These citing journals represent the 'direct periphery' of environmental medicine. Their names in conjunction with those of the above core journals reveal the *mainstream themes* of environmental medicine. Most of them addressed occupational / industrial / working environment and health, microbiology in relation to environmental contamination, and xenobiotica. Furthermore, we found several major environment-related themes within toxicology: eco-toxicology, genetic toxicology, neuro-toxicology, inhalation-related toxicology, and food toxicology; water-related themes such as aquatic toxicology and marine pollution; drug-related themes such as applied pharmacology, drug metabolism, and regulatory toxicology; plus a major allergy theme of contact dermatitis. Analytical chemistry proved to be very important as the 'instrumental' part of environmental medicine. The first 10 of these citing journals, such as *Water Environment Research*, *Analytical Chemistry*, *Drug Metabolism and Disposition*, and *Environmental Pollution* are given in Appendix 2. The list of these citing journals shows the strong links between the set of environmental medicine core journals and, above all, water-related problems, analytical methods, and cancer research.

Most Prominent European Research Groups

The approach described in the foregoing section provides us with a *journal-based* delineation of the field. This could be used as the basis for a further bibliometric analysis. Within the set of core journals as defined in the foregoing section, we identified the *most prominent research groups/institutes* on the basis of the articles published in 1995–1998 in all journals from the three clusters. We distinguished between two types of 'prominence' in this analysis: the most *active* groups in terms of number of publications and the most *influential* groups in terms of number of citations received (high 'impact'). It has to be pointed out that the 'most active' groups are often the large institutes (and have a large publication output for this reason). Nonetheless, it is clear that very good research work can be done in smaller groups as well. Therefore, we decided that the best way to identify prominent groups was to look for the most influential groups; that is, groups with a high impact in the first place, *plus* a publication output above a specific threshold.

First, Table 2 presents the European (31) groups belonging to the 100 most active groups worldwide, ranked according to number of publications in 1995–1998. All these groups/institutes had 50 or more publications (P^3 50), hence, a minimum of circa 12 publications per year. In order to assess the scientific influence of these groups, we measured the 'impact' of each group or institute. This was done by counting all citations received by these 1995–1998 publications *from 1995 up till mid-1999*, and calculating the average number of citations per publication (*CPP*). This is our first impact indicator. The next section presents a detailed discussion of the methodology and a more extensive set of indicators. Within these 31 most publishing European groups (P^3 50), we selected the best 10 percent (in terms of high impact) by taking CPP^3 3.0. These groups/institutes are marked in bold.

We wish to emphasize that this exploratory study pinpointed groups/institutes by their main organization (e.g., university) only. It is possible that several groups within one university or large institute published in our set of core journals. Because this study regarded them as one 'group,' in such cases, we were actually dealing with all the environmental research activities of that university or large institute as a whole. A more detailed study would be necessary to focus on specific departments.

Table 2: European groups with the most publications. Ranked according to numbers of publications 1995–1998

	P	CPP
Karolinska Institute Stockholm	*226*	*3.64*
University London	186	2.75
ETH Zurich	*154*	*7.14*
Finnish Institute of Occupational Health	146	2.83
University of Lund	*122*	*4.15*
RIVM, Bilthoven (Utrecht)	*116*	*3.23*
Agricultural University of Wageningen	*115*	*5.79*
University of Utrecht	*107*	*4.20*
University of Amsterdam	*94*	*3.33*
University of Milan	91	2.52
University of Birmingham	83	2.49
University of Umea	*81*	*3.41*
University of Uppsala	*78*	*3.27*
Zeneca, Macclesfield (UK)	*76*	*4.28*
Free University of Amsterdam	*74*	*3.86*
National Institute of Working Life, Stockholm	73	1.99
University of Leuven	*65*	*3.12*
University of Kuopio	63	1.87
University of Stockholm	*62*	*5.53*
University of Lancester	*59*	*5.85*
University of Helsinki	*58*	*3.48*
Natiotanl Public Health Institute, Kuopio	56	2.66
University of Munich	56	2.14
University of Lyons	*56*	*3.00*
University of Jyvaskyla	*55*	*3.49*
University of Göteborg	55	2.95
University of Odense	*53*	*4.64*
TNO Zeist (Utrecht)	53	1.91
University of Düsseldorf	52	2.44
University of Bayreuth	*50*	*6.82*
CSIC Barcelona	*50*	*6.18*

Three German universities were present in this list: Munich, Düsseldorf, and Bayreuth. Only Bayreuth was above the *CPP*[3] 3.0 threshold. The impact of Bayreuth was by far the largest, and in fact one of the highest on the list. Therefore, we may conclude already that this is a *prominent German research group* in environmental medicine, at least according to our definition of this field given above. We emphasize however that a more detailed assessment of research performance will be presented in later on in this article. It should also be noted that we did not find the Bayreuth group in our Internet survey. The reason for this will be discussed below.

Table 3 reports the 15 German groups with the most publications (groups marked in italics are among the European groups given in Table 1; i. e., groups with $P > 50$), again ranked according to number of publications in 1995–1998. *CPP* (1995-mid-1999) is also indicated. We have already noted the high impact of the University of Bayreuth.

Table 3: German groups with the most publications. Ranked according to numbers of publications 1995–1998

	P	CPP
University of Munich	56	2.14
University of Düsseldorf	52	2.44
University of Bayreuth	50	6.82
University of Würzburg	47	3.70
University of Mainz	46	2.67
University of Hamburg	43	2.58
Free University of Berlin	42	3.02
Free University of Berlin	42	3.02
University of Erlangen-Nuremberg	42	3.17
University of Tübingen	42	2.95
University of Göttingen	41	2.78
GSF München	41	2.58
University of Dortmund	38	3.26
BASF Ludwigshafen	32	1.61
University of Ulm	33	3.88
Fraunhofer Institute Schmallenberg	32	1.63

Very high-impact (*CPP* ≥ 10.0) groups in Europe that are not reported in Table 2 because their number of publications was lower (i. e., 10 < *P* < 50) are:

University of Granada	32	10.78
Brunel University	*21*	*35.43*
University of Helsinki	*12*	*10.08*

The *extremely high impact* of the group at Brunel University, Uxbridge, UK is immediately apparent. This can be explained only by some very frequently cited publications. The next section will discuss highly cited publications as indicators of 'hot topics,' and come back to the performance of the Brunel group.

We emphasize that the above figures are a *first indication* of research output and impact. A more detailed analysis of selected groups / institutes is presented in Section 3. We also emphasize that German research groups, in general, may score lower than, for example, UK groups because of the relatively low impact of German-language papers *in journals covered by the SCI*. This may have quite a dramatic influence on a SCI-based performance assessment of Germany compared with other countries (particularly the commotion around the article by the UK Chief Scientist Robert May in Science, May 1997). This will be discussed extensively in a forthcoming paper (cf. van Leeuwen / van Raan 2000).

We conclude from the above that our bibliometric analysis permits a preliminary identification of European groups or institutes that can be characterized as highly active and / or highly influential. Prominent European groups can act as 'benchmark' institutes for comparisons with German institutes. As indicated above, this is particularly the case for highly productive, high-impact groups such as at the Karolinska Institute in Stockholm, ETH Zurich, University of Lund, and the Agricultural University of Wageningen.

We stress that the numbers of publications given in Tables 2 and 3 may differ considerably from the numbers derived from publications lists in, for example, the annual research reports of the groups or institutes concerned. Our analysis considers only those publications that meet the following two selection criteria: (1) *general*, for example, only publications covered by the Science Citation Index and related indexes, as well as only publications of a special 'article type' (cf.

methodology discussion in the appendix), and (2) *specific*: a further selection by the set of journals described above.

Important Themes Identified on the Basis of Frequently Cited Publications

We applied a third bibliometric analysis to our journal-based definition of environmental medicine: most cited papers in the period 1995–1998. The importance of such an analysis is twofold. First, it reveals the groups / institutes with publications of the highest impact, which is an indication of the quality of the research groups concerned. Second, we consider the topics of these high-impact publications as important themes, *hot topics*. Not necessarily all of them will be breakthroughs or new developments (review publications with an extensive state of the art of a research field can also be cited very frequently!). In most cases, however, high-impact papers will be *nonmainstream* contributions.

On the basis of the titles of the top-100 most cited publications, List 1 presents a number of 'hot topics.' In the case of frequently cited *review* papers, however, it is mostly not a 'hot topic' but an important though 'classic' theme. Therefore, it is crucial to distinguish between types of articles in this analysis. Frequently cited review topics are given in italics.

List 1: Important research themes

Cytochrome-P450 Inhibitors
Estrogenic environmental pollutants
Male reproductive health and xeno-estrogens
Biodegradability and aging of chemicals
Endocrine disrupters
Phyto-estrogens and cancer
Estrogens and dentistry
Aquatic colloids
Sorption by soil models
Antrazine in surface water
Oxidative damage to DNA
Particulate / ultra-fine particle air pollution
Phytoremediation of contaminants

Metal-ion binding to humic substances
Organochlorine compounds and cancer
Harbor contaminants
Ion-trap mass-spectrometry
PCB's
Plants to remove heavy-metals from soils and aquatic streams
Apoptosis
Neuro-toxicity
Pesticides and breast cancer
EDTA in natural water
Mercury in coastal waters and rivers
Land-ocean interaction
Photo-catalytic degradation
Carcinogenicity of diesel exhaust
Fly-ash and acute lung injury

Many of the high-impact publications originated from US groups or institutes. The first 10 US groups within the set of *top-25-cited* publications were: Merck & Co.; Tufts University, Boston (in cooperation with the University of Granada); Connecticut Agricultural Experimental Station, New Haven; Texas A&M University; University of Florida (in cooperation with groups from Denmark, Finland, France, UK, and Tulane University in New Orleans); Cornell University; US Environmental Protection Agency (EPA, in cooperation with Procter & Gamble and the Agency of Toxic Substances and Diseases Registry in Atlanta); College of William & Mary, Williamsburg (in cooperation with several other US groups); University of Missouri; University of Rochester (in cooperation with Tulane University and the University of Florida).

When identifying the European groups contributing to the top-25 impact publications, then the position of Brunel University immediately strikes the eye. This university was involved in 6 of the top-25 publications. We already mentioned the very high impact of the Brunel group in the foregoing section. It is clear that this was based mainly on this remarkably high share of the top-25 cited publications.

Other European groups contributing to the top-25 were: University of Granada (we also mentioned its very high impact) in cooperation with Tufts University, Boston; Imperial Cancer Research Foundation, London, in cooperation with Brunel University; MAFF (UK) also in cooperation with Brunel University; National University Hospital in Copenhagen in cooperation with Brunel University, University of Florida, Tulane University, University of Turku (Finland), National Food Agency in Soborg (DK), University of Odense (DK), INSERM in Rennes (F), University of Paris V, MRC in Edinburgh; University of Helsinki (also mentioned earlier for its very high impact); RIZA in Lelystad (NL) together with two Dutch firms; University of Geneva; Rowett Research Institute (UK) in cooperation with the Institute of Preventive and Clinical Medicine, Bratislava, and the Czech Academy of Sciences.

Second Approach: Definition of the Field on the Basis of Institute Names

Why a Second Approach to Define the Field?

The definition used so far to identify groups and institutes in environmental medicine was based on a *set of core journals*. It is highly possible that these groups and institutes do not 'present' themselves with their institutional names as being 'environmental medicine research groups' (e. g., 'Institute for Environmental and Occupational Medicine'). They may be, for example, departments of epidemiology, departments of allergy research, or institutes of general environmental research.

On the other hand, many groups and institutes indicate specifically that they are working in environmental medicine through their *institutional names*. They 'advertise' themselves, as it were, as environmental research institutes. Given the interdisciplinary nature of the field, it is possible that these research groups publish (substantial parts of their work) in *other* journals than those used in Section 1 to define the field.

Therefore, we have to conclude that, alongside the journal-based definition of the field, we need a *second* definition based on institute names. The second analysis for identifying relevant research groups searched in the entire Science Citation Index (SCI) and Social Science Citation Index (SSCI) in the period 1995–1998 for all institutes or groups worldwide, with the following keywords (abbreviations) in their institute's name (in the address field of the publication record): 'environm…' (or 'Umw…') *or* 'occupat…' (or 'Arb…') *together* with 'med…' or 'hyg…'. For the SCI / SSCI, this analysis is possible only in our CWTS bibliometric data-system. To our knowledge, no other SCI / SSCI based system allows address keyword analysis.

The search yielded a large set of groups and institutes, 15,962 publications worldwide, of which 1,410 came from Germany. Thus the German share in the world total of environmental research defined on the basis of institutional names was 8.8 percent. This differed from the finding in Section 1 that revealed a German share of 6.4 percent with the journal-based definition of environmental medicine. Most of this difference was probably explained by the use of different journals.

Most Prominent European Research Groups

We used a frequency analysis to rank all European groups / institutes (German groups / institutes in italics) with an average of at least five publications per year, that is $P > 20$ (1995–1998), cf. Table 4. In contrast to the journal-based method, the probability of having several groups in one university or larger institute was small, because it would be unlikely to find groups within a university or large institution with similar names. Because we performed a detailed impact analysis on the results of a combination of the journal-based and the name-based methods, we shall present only publication numbers (output).

It would be interesting to see how the groups and institutes identified with the two methods differed; the one based on a selection of environmental medicine journals; the other, on the use of environmental medicine (or related terms) in the name of the group or institute. The most obvious way to do this would be to compare the lists of groups resulting from both analyses. Recall that the journal-based method may reveal more than one research group in a university or larger institute. These comparisons are discussed in the next section.

Again, we stress that the publication numbers given in the above tables may differ considerably from the numbers derived from publications lists in, for example, the annual research reports of the groups or institutes concerned due to general (cf. appendix) and specific (institute name) selection criteria.

Table 4: European groups with the most publications
Ranked according to numbers of publications 1995–1998

	P		P
Karolinska Inst. Stockholm	653	University of Padua	42
GSF München	*411*	*University of Freiburg*	*39*
University of Lund	181	*University of Tübingen*	*39*
University of Düsseldorf	*173*	*University of Erlangen-*	*36*
University of Linköping	142	*Nuremberg*	
University of Birmingham	133	University of Brescia	33
University of London,	86	*Technical University of*	*30*
Imperial College		*Munich*	
University of Aarhus	81	University of Pavia	30
University of Vienna	76	University of Newcastle	29
University of Göteborg	75	University of Wageningen	28
University of Glasgow	70	University of Montpellier	26
University of Umeå	67	University of Milan	25
University of Leuven	66	Finn.Inst.Occup.Health	24
University of Helsinki	63	University of Odense	24
University of Uppsala	60	Swedish University of	23
University of Aberdeen	57	Agricultural Science	22
University of Ulm	*51*	University of Bergen	
University of Bochum	*49*	*University of Aachen*	*21*
University of Göttingen	*47*	University of Florence	21
University of Amsterdam	43	*University of Hohenheim*	*20*
University of Essen	*42*	University of Verona	20

Comparison of First and Second Field Definition

Many of the universities and institutes identified with the name-based definition of environmental medicine had been found already with the journal-based definition. As discussed at the end of the last section, the journal-based definition is *broader* because it also includes groups and institutes that do not name themselves explicitly with environmental medicine. A comparison of both methods reveals that this is particularly the case in Germany for the University of Bayreuth. Another European example is groups / institutes at the ETH Zurich.

On the other hand, groups and institutes that use environmental medicine in their name (or related terms) may use other journals than those in our core set. To study this possible difference, App 3 presents the top-20 journals in 1995–1998 of all groups worldwide with environmental medicine or related terms in their name. It can be seen that more than one-half of these journals belonged to the core journal set used in the first definition of environmental medicine (App 1). This explains the considerable overlap of groups and institutes in environmental medicine found by both methods, as is clear from a comparison of Tables 1 and 2. Similarly, App 4 gives the top-10 journals for German groups with environmental medicine (or related terms) in their name. Here, the picture differed somewhat from the worldwide findings. Only 3 of these 10 journals belonged to the core journal set (see above). There were two German-language journals, one clearly within the field (*Zentralblatt für Hygiene und Umweltmedizin*) and another with a general medical scope (*Deutsche Medizinische Wochenschrift*). Two other journals were in English but devoted mainly to a German audience, and belonged to related fields (*Naunyn-Schmiedesberg Archives of Pharmacology* and *Fresenius Journal of Analytical Chemistry*).

Clearly, the German groups and institutes with environmental medicine and related terms in their name often use journals ‘outside’ the core journal set as defined above. Undoubtedly, the choice of German-language or primarily Germany-oriented (though English-language) journals plays a role here. It explains why both methods will reveal considerable differences in groups and institutes, as was the case with the University of Bayreuth.

Research Performance of Selected German and European Institutes

Research Impact

After identifying European and, in particular, German research groups in environmental medicine on the basis of two different methods, we performed a *standardized bibliometric performance analysis*. We applied our analysis to three selected German institutes / groups: one large organization, GSF München, and groups at two universities, Düsseldorf and Bayreuth. The same analysis was also applied to three selected European institutes: Karolinska Institute in Stockholm as a large (university-related) institution, and groups at two universities: in the Netherlands, Wageningen (agricultural university) and, again in Sweden, Göteborg. Publications were collected on the basis of both methods of field definition *combined*.

The core of our bibliometric approach can be described as follows:

Communication, that is, exchange of research results, is the driving force in science. Publications are not the only, but certainly very important elements in this knowledge-exchange process. High-quality work triggers reactions in fellow scientists. They provide the international forum, the 'invisible college' in which research results are discussed. In most cases, these fellow scientists perform their role as members of the invisible college by referring in their own work to the earlier work of other scientists. We all know that the process of citation is a complex one, and that it certainly does not provide an 'ideal' monitor of scientific performance. However, the same criticism holds for peer reviews as well (cf. Moxham/Anderson 1992). The application of citation analysis at a statistically low aggregation level (e.g., just one publication) is hardly meaningful in terms of performance assessment. However, application to the work of *a group as a whole over a longer period of time* does yield, in many situations, a strong indicator of scientific performance, and, in particular, of scientific quality given the correlation with peer review judgements (cf. Rinia et al. 1998). An important, absolutely necessary condition for the citation analysis is, nonetheless, that it be part of an advanced, technically highly developed bibliometric method.

Research output was defined as the number of articles from the institute found in the Science Citation Index (SCI), the Social Science Citation Index (SSCI), or the Arts & Humanities Citation Index (AHCI). We included the following publication types as 'articles': normal articles (including proceedings papers published in journals), letters, notes, and reviews (but not meeting abstracts, obituaries, corrections, editorials, etc.). We developed special software to calculate a set of standardized, basic indicators.

Table 5: Bibliometric Research Performance Indicators 1995–1998

Country; Institution of Group/Institute	P	C	CPP	CPP ex	Pnc	JCSm	FCSm	CPP/ JCSm	CPP/ FCSm	JCSm/ FCSm	% Self Cit.
GSF München	442	809	1,83	1,11	0,48	1,98	1,89	0,92	0,97	1,05	0,39
University of Bayreuth	51	279	5,47	3,57	0,24	2,57	2,06	2,13+	2,66+	1,25	0,35
University of Düsseldorf	131	372	2,84	1,81	0,35	3,15	3,09	0,90	0,92	1,02	0,36
Agricultural University of Wageningen	139	543	3,91	2,40	0,42	2,40	2,01	1,63+	1,94+	1,19	0,38
University of Göteborg	99	225	2,27	1,72	0,46	1,89	2,13	1,20	1,07	0,89	0,24
Karolinska Institute	609	3.737	6,14	4,86	0,34	3,44	3,46	1,78+	1,77+	0,99	0,21

The first column of Table 5 reports the number of papers published (*P*); the second column, the number of citations (*C*) for the time period 1995–1998. The analytic scheme is as follows: For papers published in 1995, citations were counted during the period 1995–1998; for 1996 papers, citations in 1996–1998; and so forth. There is ample empirical evidence that in the natural and life sciences – basic as well as applied – the average 'peak' in the number of citations is to be found in the third or fourth year after publication (Moed et al. 1995). Therefore, a 4-year analysis period is appropriate for impact assessment. The third indicator column reports the average number of citations per publication (*CPP*, calculated by dividing the total *P* of the entire time period by the total *C* in that period counted as reported above). The fourth column presents the same indicator, but now corrected for self-citations, *CPPex*. The fifth column contains the percentage of noncited papers, *Pnc*. It should be emphasized that this percentage of noncited papers covered, like all other indicators, the given time period (4 years). It is highly possible that publications not cited within such a relatively short time period will be cited after a longer period of time.

It is clear that these indicators are not very informative without reference values. How do we know whether a certain volume of citations or a certain citation per publication is low or high? Therefore, it is absolutely crucial to make a comparison with (or normalization to) a well-chosen international reference value, and to establish a reliable measure of *relative, internationally field-normalized impact*. Hence, the problem is to measure impact relative to an international average. We tackled this as follows: We calculated the average citation rate of all papers (worldwide) in the journals in which the institute had published (*JCSm*, the *m*ean *J*ournal *C*itation *S*core of the institute's 'journal set'). Thus, this indicator *JCSm* (sixth column) defined a worldwide reference level for the citation rate of the institute. It was calculated in the same way as *CPP*, but now for all publications in a set of journals instead of all publications of an institute. Details on these calculations are reported in van Raan (1996). By comparing these two indicators, we were able to assess whether the measured impact was *above* or *below* international average. A novel and unique aspect of our comparison with a worldwide reference value was that it took into account not only the type of paper (e.g., normal article, review) *but also* the specific years in which the papers were published. This is absolutely necessary, because the average impact of journals may reveal considerable annual fluctuations and large differences per article type (cf. Moed / van Leeuwen 1995, 1996).

The comparison of the institute's citation rate *(CPP)* with the average citation rate of its journal set (*JCSm*) introduced a specific problem related to journal status. For instance, if one institute publishes in prestigious (high impact) journals and another institute in rather mediocre journals, the citation rate of articles published by both groups may be equal *relative to* the average citation rate of their respective journal sets, even though the first group evidently performs better than the second. Therefore, we developed a second international reference level, a *field*-based world average *FCSm* (seventh column of Table 5). This indicator is based on the citation rate of *all* papers (worldwide) published in *all* journals of the field(s) in which the institute is active and not just the journals in which the institute's researchers publish their papers. Here, we used the definition of fields based on a classification of scientific journals into *categories* developed by ISI. Although this classification is far from perfect, it is currently the only classification available to us in terms of an automated procedure within our data system. We used the same procedure as that applied in the calculation of *JCSm* (cf. van Raan 1996).

Often, an institute is active in more than one field (i. e., journal category). In such cases, we calculated a weighted average value, the weights being determined by the total number of papers published by the institute in each field. For instance, when an institute published in journals belonging to the ISI category 'Environmental research' *and* in journals belonging to the category 'Toxicology,' then the *FCSm* of this institute would be based on both field averages. Thus, the *FCSm* indicator represents a *world average* in a specific (combination of) field(s). About 80 percent of all SCI-covered papers were authored by scientists from the United States, Western Europe, Japan, Canada, and Australia. Therefore, our 'world average' was dominated by the Western world. Again, we observed a general increase of *FCSm* values.

Because worldwide citation rates are increasing, it is essential to normalize the measured impact of an institute (*CPP*) to international reference values. Therefore, we calculated the ratio of *CPP* to the world averages discussed above, *JCSm* and *FCSm*. These ratios are presented in the 8th and 9th columns of Table 5. When the ratio *CPP / JCSm* was above 1.0, the impact of the institute's papers exceeded the journal-based (i.e., the journals used by the group / institute) world average.

A particularly powerful indicator is *CPP/FCSm*. This 'crown' indicator relates the measured impact of a research group or institute to a worldwide, field-specific (i.e., all journals in a field) reference value. It is the *internationally standardized impact indicator*. This indicator enables us to observe immediately whether the performance of a research group or institute is significantly far below (indicator value < 0.5), below (indicator value 0.5–0.8), around (0.8–1.2), above (1.2–2.0), or far above (>2.0) the international (western-world-dominated) impact standard of the field. As shown in Table 1, Wageningen and, in particular, Bayreuth had a very high performance. The other groups / institutes, GSF München, Düsseldorf, and Göteborg performed around world average. We have to emphasize that the extended research performance analysis presented in this section addressed a restricted number of selected groups / institutes, and not all the groups / institutes identified in this study.

An important issue is the level of aggregation or size of the institutions. It is clear that the larger the group or institute, the more difficult it is to maintain a high average performance, because there will often be subunits with lower performance. Therefore, the larger an institute, the more performance will tend to lower average values. In these cases, it is better – and even preferable – to conduct the bibliometric research performance analysis on the level of the smaller subunit as well. Table 5 should also be examined in this light. There were differences in size of about one order of magnitude! For instance, Bayreuth had about 50 publications in the given time period, but GSF München around 400 and Karolinska around 600. Particularly in the latter case, we can speak of an exceptional performance, given the score on the *CPP/FCSm* indicator and the size of the institute. Examples of middle-sized groups / institutes are Düsseldorf, Wageningen, and Göteborg.

The ratio *JCSm/FCSm* (10th column) is the institute's 'journal status' indicator. When it was above 1.0, the mean citation score of the institute's journal set exceeded the mean citation score of all papers published in the field(s) to which the journals belonged. In other words, the institute published in the higher impact journals of the field. This preference for publication in the higher impact journals was particularly strong in Bayreuth and Wageningen.

Research Profiles and Interdisciplinarity

A further important part of our bibliometric analysis was to *break down* the institute's or group's output (publications) into research fields.[1] This 'spectral analysis' of the output is based on the simple fact that researchers generally publish their work in journals belonging to more than just one research field. E. g., researchers at an immunology research institute will publish mainly in the typical immunology journals, but also in journals classified to oncology, haematology, and so forth. In this example, publications in immunology journals will form the largest group, and, consequently, this field will be the largest one in the research profile. Because we ranked fields in the profile according to their size (in terms of numbers of publications), the field immunology would be positioned as number one at the top of the profile. A specific immunology group may have 'genetics' and 'neurosciences' as second and third field in its profile. For another immunology group, 'oncology' and 'dermatology' may take these positions. So this breakdown of the institute's or group's output into research fields provides a clear impression of all the fields involved in the research activities of the institute or group. In other words, it provides us with information about its interdisciplinarity (cf. van Raan 2000), and therefore we can also call such a research profile its 'cognitive orientation.'

Not only size (number of publications) was given in the profiles. We also determined the indicator *CPP/FCSm* of the articles in these different fields (with international field normalization always to the specific field!), so that the fields within which the interdisciplinary research profile of the institute or group reveals a high (or lower) performance became visible. In our example above, this could mean that we would find that the first immunology group was very strong not only in its 'core' field of immunology but also in neurosciences.

As discussed above, a research profile analysis can also be applied to the field of environmental medicine *as a whole* and can be considered as a characterization of the 'mainstream.' This profile is given in Figure 3. It is based on about 25,000 publications from 1995–1998. It becomes apparent immediately that the field of *environmental science* is the most important in environmental medicine, both in output as well as in impact, followed by toxicology, public health, and pharmacology. Generally, in environmental medicine as a whole, public health publications have a low impact. Figures 4–7 represent the profiles of Düsseldorf, Bayreuth, Wageningen, and Karolinska.

Figure 3: Environmental Medicine Research Profile: 1995–1998

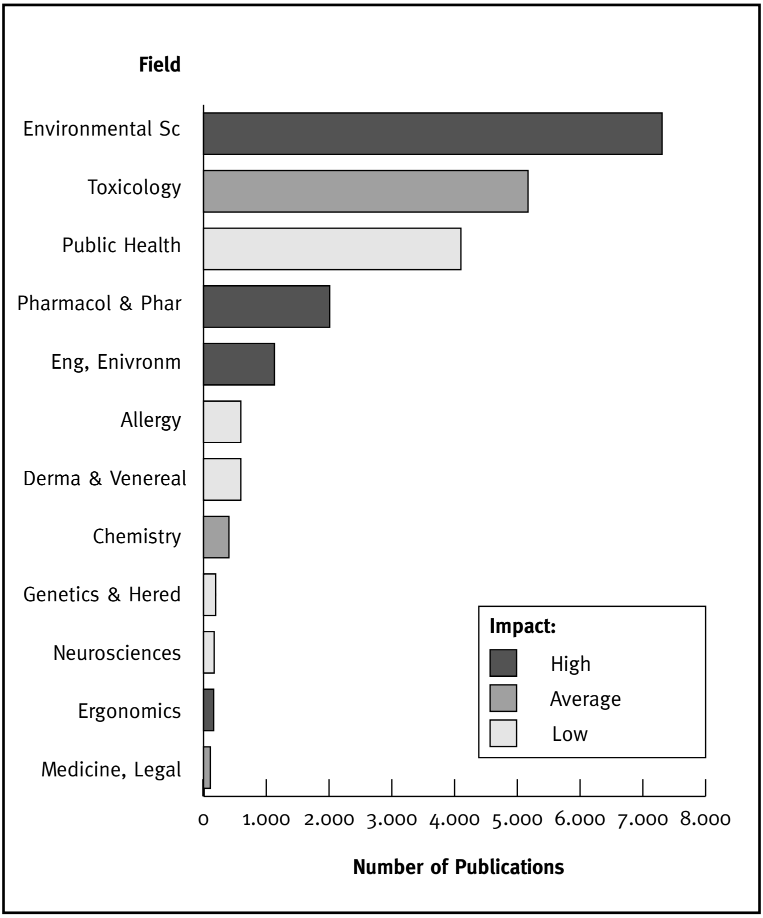


Figure 4: University of Düsseldorf Research Profile: 1995–1998

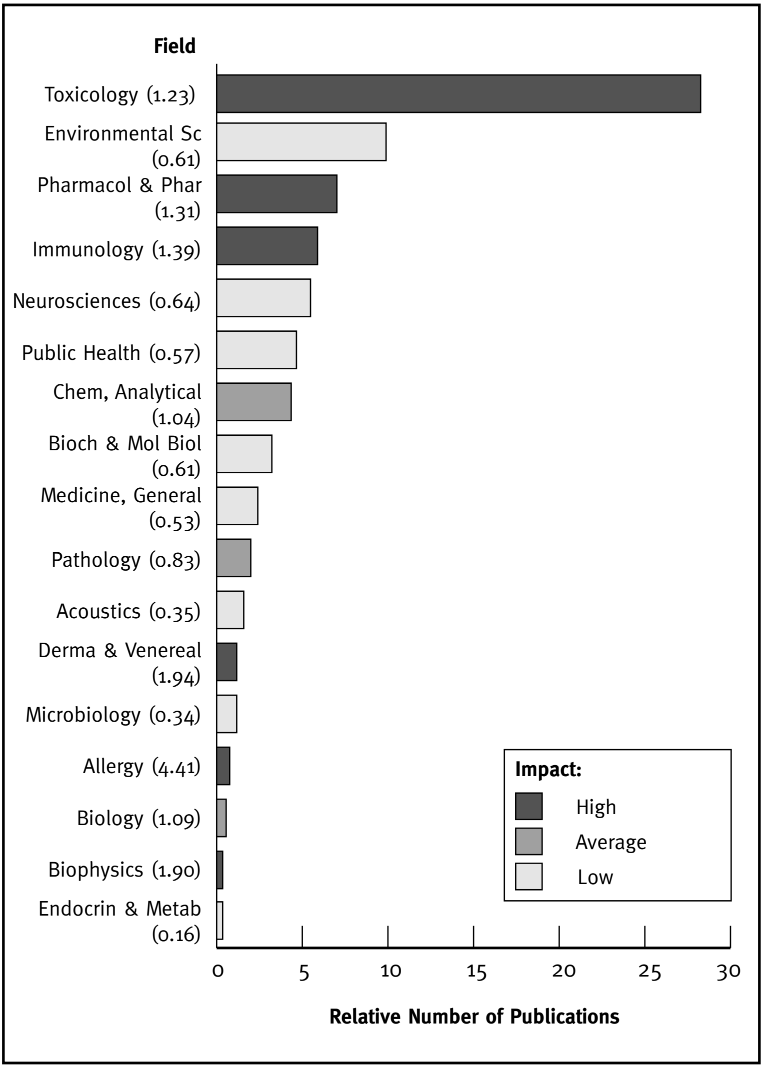


Figure 5: University of Bayreuth Research Profile: 1995–1998

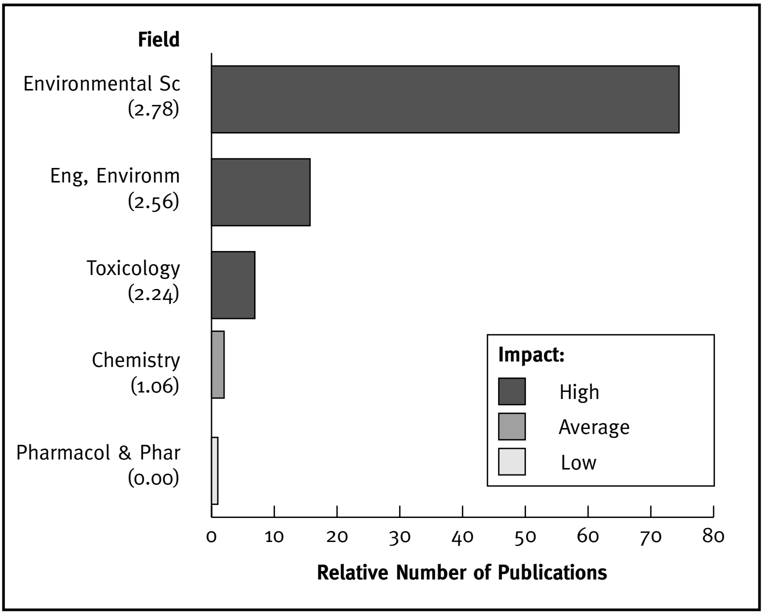


Figure 6: University of Wageningen Research Profile: 1995–1998

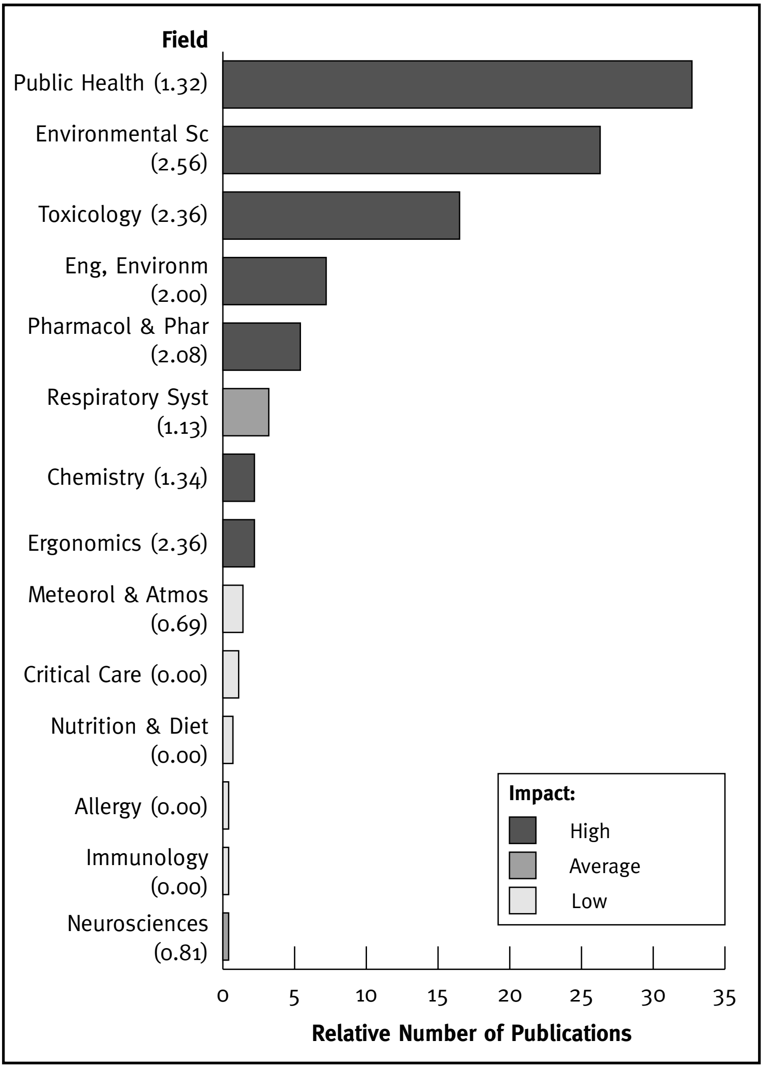
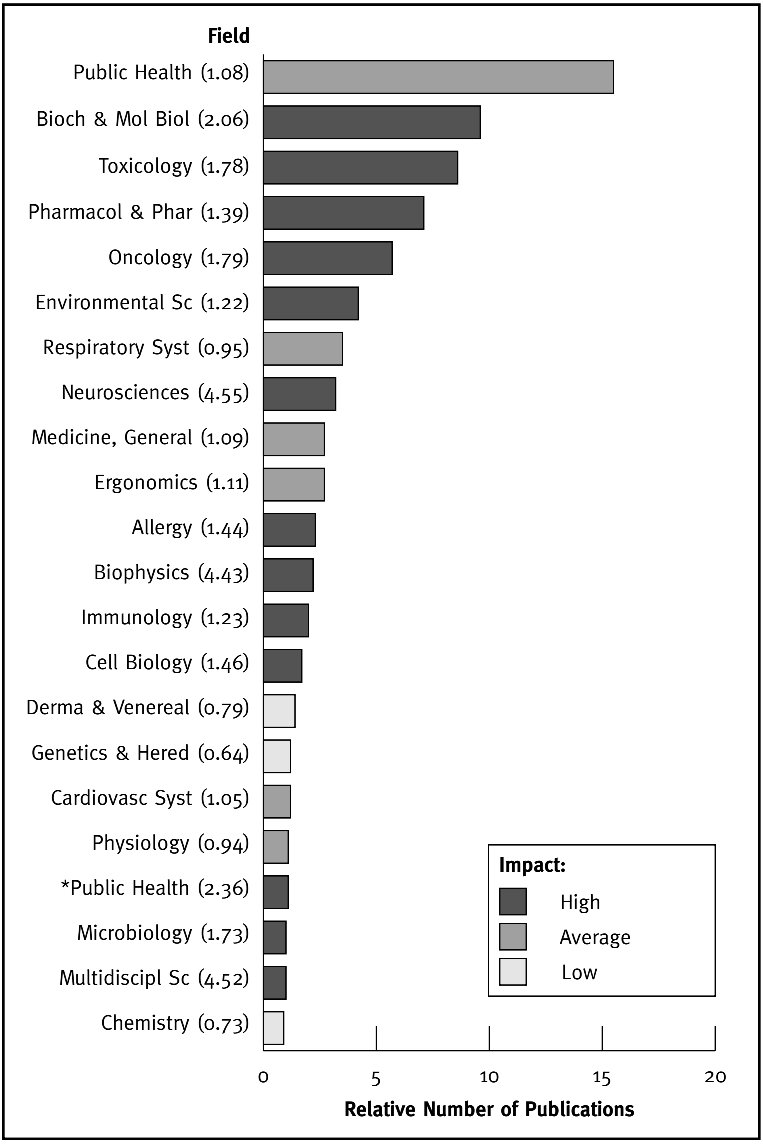


Figure 7: Karolinska Institute Research Profile: 1995–1998



These profiles once again reveal that environmental science, toxicology, and public health were the most important 'component parts' of environmental medicine. However, interesting differences between the various groups and institutes also emerged. Particularly significant 'deviations' in the profile of outstanding groups from the mainstream profile (Figure 3) may indicate important developments.

The *Düsseldorf* group (Figure 4) has a good (above international average) performance in its major field of output, toxicology. Its typical environmental science work showed a lower impact. Work in pharmacology and pharmaceutics, as well as in immunology was above international level. The profile shows that Düsseldorf was characterized by considerably more neuroscience-related activities (in terms of publication output) compared with the mainstream. The international impact of the neuroscience work was, however, lower than in that of other fields.

Bayreuth (Figure 5) was a relatively small group (in terms of number of publications) and therefore its profile was rather narrow. As already noted above, this group showed a very good performance, particularly in its major field, environmental science. *Wageningen* (Figure 6) clearly showed a strong profile. Its most important fields were public health, environmental science, and toxicology – all with a high to very high impact. In particular, the public health work at Wageningen was much stronger than in the mainstream of environmental medicine (Figure 3).

The *Karolinska* Institute in Stockholm (Figure 7) showed a strong and also very broad profile, which was to be expected given its very large size (particularly in terms of publications). The largest field was, similar to Wageningen, public health, with an impact around international level. The most striking observation for Karolinska, however, concerned its neuroscience work. This field took a much more prominent place in the institute's profile compared with the mainstream. But even more important was the extremely high impact of its neuroscience publications. This finding was a strong indication that neuroscience-related research is a theme of growing importance and, most of all, scientific influence in environmental medicine. As already noted above, a large institution such as Karolinska should be split up into different departments. In such cases, it is most appropriate to conduct a more extensive research performance measurement, as we do on a regular basis at our Center.[2]

International Scientific Cooperation

A further part of the analysis was to break down research performance into *types of cooperation*. We distinguished between articles originating from the group or institute only ('no cooperation'), from the group or institute with another group in the same country ('national cooperation'), and from the group or institute with a group outside its own country ('international cooperation). Results are reported in Table 4 for the groups at Düsseldorf, Bayreuth, Karolinska, and Wageningen.

Table 6: Bibliometric scientific cooperation data, institutes active in environmental medicine, 1995–1998

Country; Institution of Group/Institute	P	C	CPP	CPP ex	%	Pnc	CPP/ JCSm	CPP/ FCSm	JCSm FCSm	JCSm/ FCSm	% Self Cit.
University of Düsseldorf											
Institute only	50	133	2.66	1.70	0.36	2.43	2.78	1.10	0.96	0.87	0.36
National	60	135	2.25	1.43	0.37	2.70	2.80	0.83	0.80	0.96	0.36
International	21	104	4.95	3.14	0.29	6.13	4.67	0.81	1.06	1.31	0.37
University of Bayreuth											
Institute only	27	172	6.37	4.22	0.15	2.91	2.09	2.19	3.05	1.40	0.34
National	9	41	4.56	3.22	0.22	1.86	2.12	2.45	2.15	0.87	0.29
International	15	66	4.40	2.60	0.40	2.39	1.98	1.84	2.23	1.21	0.41
Karolinska Institute											
Institute only	114	859	7.54	6.27	0.25	3.68	4.02	2.05	1.88	0.91	0.17
National	250	842	3.37	2.37	0.41	2.94	3.03	1.14	1.11	0.97	0.30
International	245	2,036	8.31	6.74	0.31	3.84	3.63	2.17	2.29	1.06	0.19
Agricaltural University of Wageningen											
Institute only	29	51	1.76	0.93	0.48	1.70	1.36	1.03	1.29	1.25	0.47
National	57	150	2.63	1.56	0.47	2.06	2.06	1.28	1.28	1.00	0.41
International	53	342	6.45	4.11	0.32	3.14	2.32	2.05	2.79	1.36	0.36

A general phenomenon was that publications involving international cooperation revealed a higher impact than publications from the group or institute only, or in national collaboration (cf. Narin/Withlow 1990). Indeed, for Düsseldorf, publications based on international cooperation attained a relatively high impact. It was strikingly visible with the indicators *JCSm* and *FCSm* that the journals (and the fields) involved in international cooperation had a considerably higher level of impact. For Wageningen, the international publications showed a very high impact. For the Karolinska Institute in Stockholm as well, international co-publications were the ones with the highest impact. Remarkably, this was not the case for Bayreuth. Here the publications of the group 'on its own' showed the highest impact, at an excellent level. This is often proof of a strong and very successful focus on the development of an own, important specialty.

Concluding Remarks

We have tackled the problem of what the field of environmental medicine looks like, how it can be defined, and how it can be delineated by combining two approaches based on bibliometric methods, that is, methods exploring in an advanced way data originating from the scientific literature. The first approach is based on identifying the most important international journals for publications in environmental medicine. The second one is based on identifying institutes with names in which environmental medicine and directly related fields are mentioned. This procedure appears to be successful: Once the field is defined, we are able to analyze it and to discover its main characteristics and, in particular, its main 'players.'

Environmental medicine appears to be a typical interdisciplinary field, 'composed' of quite a broad spectrum of established fields such as environmental science, toxicology, public health, pharmacology and pharmaceutics, environmental engineering, allergy, dermatology, chemistry, genetics and heredity, and neurosciences. Looking at the level of activity in different countries, we find that German activity in environmental medicine is comparable to the average German share in science as a whole. Hence, there is no strong 'over-activity' or 'under-activity' of Germany in environmental medicine. In contrast, countries such as Sweden, the Netherlands, and Finland are significantly 'overactive' in environmental medicine. We stress, however, that the larger a country, the less it will show typical 'over'- or 'under-activity,' because activities in most fields tend increasingly toward average values.

Our analysis reveals the most prominent European groups and institutes, both in terms of publication output as well as scientific influence, measured in terms of their 'impact' revealed by bibliometric performance analysis. This identification of most prominent groups and institutes is a crucial part of the study: First, it allows us to find 'benchmark' groups or institutes; and second, it allows us to find significant 'deviations' from the 'mainstream' in the research themes of excellent groups. Benchmark groups or institutes are important for comparisons with German groups. Because these benchmarks are outstanding groups, they can be drawn on as examples when considering how a specific group or institute could be restructured or reorganized.

The identification of research themes that deviate considerably from the mainstream is essential for monitoring important, and possibly emerging 'hot' research topics. As indicated above, environmental medicine is an interdisciplinary field composed of many different basic fields. The interesting point here is that our bibliometric methods allow us to establish what basic fields are the most important 'components' of environmental medicine as a whole. We have mentioned these fields already, for instance, toxicology, public health, and allergy. This may be called the 'research profile' of environmental medicine mainstream research. Using the same analytical instrument, we can also construct a research profile for each of the most prominent European group or institutes, and see whether a group's research profile deviates significantly from that of the mainstream. For the Karolinska Institute, we find that neuroscience research with very high impact is part of the environmental medicine research profile.

Another 'deviation' from the mainstream is given by very frequently cited publications. These are generally the publications that attract exceptional attention in the research community. Therefore, careful identification of, for instance, the 100 most cited publications in environmental medicine is an interesting method for ascertaining which topics and themes are regarded as very important.

We have not investigated the performance of all European groups in an extensive way, because this would be far beyond the scope of the present study. We have compared research performance in a few selected groups / institutes with a field-specific international standard impact level and focused on performance in more detail through research profiles.

Finally, we have investigated scientific cooperation. A general phenomenon is that publications based on international cooperation show a considerably higher impact than publications from the group or institute 'alone' or in national collaboration. Remarkably, this is not the case for Bayreuth. Here the publications of the group 'on its own' show the highest impact at an excellent level. This is often proof of a strong and very successful focus on the development of one's own, important specialty. Once again, we have to emphasize that these findings are the outcome of a still preliminary survey. In particular, conclusions on research performance must be supported by further findings from more detailed studies.

Notes

1 In research profiles, fields were defined on the basis of standardized sets of journals; discussed on p. 105.
2 Cf., for example, van Leeuwen et al. 1996, available via our website http://www.cwts.leidenuniv.nl

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Appendices

Appendix 1: Core journals of environmental medicine
Environmental Toxicology and Chemistry
Chemosphere
Archives of Environmental Contamination and Toxicology
Environmental Science & Technology
Bulletin of Environmental Contamination and Toxicology
Ecotoxicology and Environmental Science
Science of the Total Environment
Archiv für Toxikologie
Environmental and Molecular Mutagenesis
Mutation Research – Fundamental / Genetic Toxicology
Environmental Health Perspectives
Neurobehavioral Toxicology and Teratology
Toxicology and Applied Pharmacology
Archives of Toxicology
Journal of Toxicology and Environmental Health A
Fundamental and Applied Toxicology
Neurotoxicology
Critical Reviews in Toxicology
Toxicology
Regulatory Toxicology and Pharmacology
Toxicology Letters
Human & Experimental Toxicology
Journal of Occupational Medicine
American Industrial Hygiene Association Journal
Environmental Research
American Journal of Industrial Medicine
International Archives of Occupational and Environmental Health
British Journal of Industrial Medicine
Journal of Occupational and Environmental Medicine
Scandinavian Journal of Work Environment & Health
Archives of Environmental Health
Contact Dermatitis
Inhalation Toxicology
Occupational and Environmental Medicine
Industrial Health

Appendix 2: Journals that frequently cite environmental medicine core journals (1995–1998)
Water Environment Research
Analytical Chemistry
Drug Metabolism and Disposition
Environmental Pollution
Carcinogenesis
Journal of Chromatography A
Ecotoxicology and Environmental Safety
Environmental and Molecular Mutagenesis
Atmospheric Environment
Toxicological Sciences

Appendix 3: Top-20 journals for all groups worldwide (1995–1998) with environmental medicine or related terms in their name
Environmental Health Perspectives
American Journal of Industrial Medicine
Occupational and Environmental Medicine
Journal of Occupational and Environmental Medicine
Toxicology and Applied Pharmacology
International Archives of Occupational and Environmental Health
American Journal of Respiratory and Critical Care Medicine
FASEB Journal
Carcinogenesis
American Journal of Occupational Therapy
American Industrial Hygiene Association Journal
Journal of Applied Physiology
Scandinavian Journal of Work Environment & Health
American Journal of Epidemiology
Toxicology
Toxicology Letters
Chemosphere
Archives of Environmental Health
American Journal of Physiology-Lung Cellular and Molecular Physiology
Science of the Total Environment

Appendix 4: Top-10 journals in 1995–1998 for German groups with environmental medicine (or related terms) in their name

Naunyn-Schmiedesberg Archives of Pharmacology
Zentralblatt für Hygiene und Umweltmedizin
Int. Archives of Occupational and Environmental Health
Chemosphere
Toxicology Letters
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