France Universités

Supporting France Universités's reflections on the state of biomedical research in France

January 2023

Acknowledgments

This report presents the findings of an independent study commissioned by France Universités to SIRIS Academic to analyse the current state of biomedical research in France, using a bibliometric in-depth analysis.

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Context and aims of the study

The state of biomedical research in France has been debated repeatedly over the last decade. It has been examined, its difficulties exposed and recommendations for change advanced, most recently in the context of the preparation of the law for multiannual programmation of research (LPR) in 2019[1].

In the wake of the COVID-19 pandemic that exposed further weaknesses in the system, the performance and organisation of the French biomedical research have been placed under even higher scrutiny, pushing discussions further. As a result, the Academie of Medicine and Pharmacy published in 2021 a two-volume report[2] summing up the state of the debate along two main lines:

1) there is a **decline of French biomedical research in volume and visibility leading to a lower positioning in the world;**

> ***"Notre pays est devenu une puissance moyenne dans le domaine de la recherche scientifique et de l'innovation en passant en 15 ans de 4,5% des publications mondiales à 3%,*** *reculant de la 6ème à la 9ème place, encadré par l'Italie et le Canada dont on peut remarquer que le pourcentage par rapport au PIB des crédits publics de R&D, est très inférieur au nôtre.* ***La recherche médicale a reculé dans les mêmes proportions****, bien qu'il y ait une grande disparité suivant les disciplines."*

2) this decline is mainly attributable to:

i) the proportionally **lower share of research funding to biomedical research** in France with respect to other fields and in comparison to international peers, as well as to outdated and inflexible methods (e.g. SIGAPS) by which the funding is allocated;

> ***"Ce budget en Biologie-Santé n'a cessé de décroître en euros constants, avec une diminution estimée à 25% entre 2008 et 2020****. Le ratio actualisé de 17,2% est loin de celui des 25% habituellement avancés, pourtant déjà faibles comparativement aux pays voisins."*

ii) the state of **fragmentation of actors** in charge of financing, performing and steering biomedical research and to the inefficient organisation and execution of research that ensues;

> ***"L'origine de cette dégradation continue de la recherche en biologie-santé dans notre pays a été analysée et découle en grande partie d'un émiettement et d'une superposition des structures publiques*** *qui ne font que s'accroitre depuis plus d'une vingtaine d'années, chaque nouvelle maladie conduisant à créer en réaction une agence ou structure autonome*

[1] C. Boitard, B. Clément, P. Debré, L. Degos, D. Houssin, P. Netter, au nom d'un groupe de travail, « Rapport 19-05. Contribution au projet d'une loi de programmation pluriannuelle de la recherche », *Bull. Acad. Natl. Med.* 2019, 203, 394

[2] A. Migus, R. Ardaillou, P. Berche, C. Boitard, B. Clément, P. Couvreur, P. Debré, P. Netter, au nom d'un groupe de travail bi-académique de l'Académie nationale de pharmacie et de l'Académie nationale de médecine, *Rapport 21-06. Réformer la recherche en sciences biologiques et en santé: partie I, le financement*; A. Migus, R. Ardaillou, P. Berche, C. Boitard, B. Clément, P. Couvreur, P. Debré, P. Netter, au nom d'un groupe de travail bi-académique de l'Académie nationale de pharmacie et de l'Académie nationale de médecine, *Rapport 21-07. Réformer la recherche en sciences biologiques et en santé: partie II, l'organisation.*

spécialisée (INCa, ANRS, bientôt peut-être sur les coronavirus) accroissant à chaque fois les incohérences et gaspillages du dispositif."

iii) Finally, the decline in biomedical research, which requires a cross-talk between fundamental and applied research, is also attributable to a **lack of integration of Universities in University Hospitals (CHUs)** at the level of governance and research.

*"La faiblesse de coordination locale entre les différents partenaires est un frein à la recherche en biologie-santé. **Une raison en est l'absence d'intégration à la gouvernance hospitalière des volets universitaire et de recherche** qui ont fait l'originalité des CHU à leur création."*

This fragmentation and multitude of structures and funding, as well as the misalignment between Universities and CHUs[3], is perceived as having a strong negative impact on the ability to do translational research and engage in multidisciplinary and interdisciplinary research, with consequences on advanced patient care and therapeutic innovation. **Although this perception is strongly supported by experts from the sector, there was a lack of evidence that could substantiate it**, due to the difficulty in addressing quantitatively and robustly issues such as interdisciplinarity, or the separate contributions of the different actors.

In light of this reality, France Universités commissioned an independent study aimed at bringing additional arguments and evidence to this debate, based on a bibliometric analysis of publications. The study, conducted during 2022, shed light on two main aspects:

1. Through original bibliometric analyses, it refined the view of the production, scientific impact, thematic specialisation and interdisciplinarity of French biomedical research in an international comparison (Part 1).

2. It provided an understanding of the respective weight of the main types of institutional actors in the French ecosystem, with a special focus on the Universities and CHUs (Part 2).

The report is intended to further inform ongoing discussions among all relevant stakeholders over the current state of biomedical research in France and possible future actions to take at national level, namely on a reflection on the role and expected contribution of the universities and CHUs as well as more broadly on the setting of a biomedical research national strategy. It assesses the validity of some of the existing assumptions and perceptions and provides additional evidence-based insights on where the issues may be arising.

[3] In France, with the *Loi Debré* of 1958, hospitals became legally joined to the universities of their region, through the medical faculties, officially leading to the creation of the Centre Hospitalier Universitaires (CHUs), university hospitals tasked with delivering teaching, research and patient care.

Executive Summary

The question of France's overall performance and positioning in biomedical research has been discussed and analysed multiple times, most recently by Terra Nova and Alain Fischer[4], whose conclusions are in line with previous reports. The present study aims at refining and completing this discussion, by providing precise data and analysis to validate or inform key assumptions and hypotheses. This section provides an overview of the main conclusions and identifies discussion points that arise from them.

Both the proportion and the growth of biomedical research in France are lower than in other comparable countries. If France does not prioritise biomedical research by increasing investment to the levels of competing countries, then it is crucial to rethink French biomedical research policy by better aligning decisions and priorities with those taken at a European level by other EU27 countries.

- Compared with the UK, the Netherlands, Sweden, Germany, Italy, Spain and Canada, overall, **measures of biomedical research production in France fare poorly**. France has the lowest growth rate from 2010 to 2020, and is the only country below EU27+UK average of growth for the most part of the last decade. It also has the lowest overall production per capita.
- Although growth in overall production is not the only relevant measure of the health of research in a given country, **this suggests that biomedical research in France has plateaued below its potential**.
- **Most European countries, including France and most of the benchmarks analysed, have not increased their contribution to the world's share of biomedical research in the last decade**, which has remained largely stable. This is likely the result of the emergence and expansion of very large contributors to this field (and arguably not only to this field) such as China, India and Brazil. **However, France's share of the world's publications is below countries such as Germany and the UK, not only in biomedical research but also in other types of research**.
- **Compared to other countries, research in France is proportionally more concentrated in Physical Sciences**, with lower dedication to Health and Life Sciences as well as very low dedication to Social Sciences. This is linked to long-term science policy choices and investment in other fields, specifically in the Physical Sciences and Mathematics.

Since research thematic specialisation is obviously a zero-sum game (France is less specialised in biomedical research with respect to the UK, and the UK is less specialised in physics than France), this brings up the question of **whether this choice is a good long-term strategy and what the consequences are for the country**. More widely, it underlines the fact that it probably makes sense to consider Europe as a whole and explore intra-European complementary areas of specialisation.

[4] La recherche médicale en France, bilan et propositions | Terra Nova

Research is concentrated in classical fields rather than in cutting-edge areas. This increases the risk that French biomedical research will fall further behind competing countries, especially in emerging fields with strong input from the social sciences such as public health and applied sciences such as bioengineering. Furthermore, French research appears to be more uneven than elsewhere in terms of scientific impact.

It is useful to explore the topics and areas of specialisation and multidisciplinarity within a given country's portfolio[5], since it shows where it may have a competitive edge at a European or global level and where it stands to contribute and impact the most. In this regard:

- One of the **main issues for biomedical research in France appears to be the specialisation in classical fields rather than in cutting edge or emergent fields**. This is true of French research in the Physical Sciences, Social Sciences and Health and Life Sciences, but, arguably, is felt most strongly in the Health and Life Sciences where new diagnostic tools and treatments, such as vaccines, require more advanced, innovative approaches.
- **Biomedical research in France is dedicated to traditional areas** such as Cancer, Cardiovascular Diseases, Infectious Diseases, Neuroscience, Immunology, Surgery and Genetics, **in a pattern mostly shared amongst the benchmark countries.**
- The **areas of Cancer, Infectious diseases and Immunology are those where France is more specialised in comparison with benchmarks**; this is not surprising considering the existence and success of specialised and/or research intensive centres on these topics (e.g. Institut Gustave Roussy, Institut Curie or Institut Pasteur). In line with this, France also shows significant dedication and high specialisation in haematology and virology.
- However, **France is clearly not specialised in other fields, such as those of Public Health and Policy, and Psychiatry and Mental Health**. These are fields that have garnered increased attention in the last years and in which countries such as the UK and the Netherlands (and Spain in the case of Public Health and Policy) have higher contributions.
- France's biomedical research shows a **degree of multidisciplinarity[6] similar to the benchmark countries**.
- Overall, the **level of interdisciplinarity[7] is similar between France and benchmarks, albeit with different patterns.** Interdisciplinarity in Biomedical research in France has contributions mainly from the Physical Sciences, and, in contrast to the Netherlands or the UK, **interdisciplinary research with the Social Sciences is low**.
- Interestingly, and most likely linked to the known strengths in Physical Sciences,

[5] High dedication means a high volume of research on a certain topic(s); while specialisation indicates research for which the country produces more in comparison to other comparators (a defined baseline).
[6] Research with contribution of topics in fields within Health and Life Sciences
[7] Research with contribution of topics in fields outside of Health and Life Sciences

interdisciplinary biomedical research in France is more specialised in Environmental Sciences and Physics, rather than in biomedical applied fields such as Biomedical Engineering, Bioengineering or Biomaterials.

- It has been argued that weaknesses of the system, such as a lack of funding and evaluation structures specific for translational research, have a negative impact on the ability to do this type of research. The analysis shows that **the share of basic and translational research in France is similar to other countries such as Spain and Germany, and its performance** (at least measured through the ability to publish in Nature Index journals) **is on par to countries such as the Netherlands, and only slightly lower than the UK[8].**
- **Despite lower production, France's biomedical research has a similar scientific impact to countries such as Spain and the UK**, with a similar percentage of its publications in top tier journals (all around 50%)[9],Top 1-10% Scimago journals[10]).
- **However, France also has a proportionally higher number of publications in lowest tier journals** (30-100% Scimago journals), compared to benchmarks**.**

The organisational complexity of the French biomedical research system appears to have a negative impact on the capacity at steering research policy and addressing major national priorities. This seems, at least in part, linked to a difficulty in aligning CHU research priorities with that of universities and a broader issue in terms of primary affiliation identity of joint CHU-University academic staff, as well as the scientific impact of the research performed at the CHUs.

The dichotomy in the impact of research just mentioned[11] could be the result of the diversity of practices and types of research being developed in Universities and CHUs, and across the different sites. Several factors can influence this: the different practices normally seen in fundamental vs clinical research, and specifically within clinical research, factors such as the type of clinical research taking place (e.g clinical case studies) or the prioritisation of excellent research by institutions. The higher proportion of publications in lower tiers could be indicative of a low or/and uneven focus on (excellent) research.

Biomedical research that originates from both clinical and fundamental research functions in a continuum, requires coordination and exchange between all the institutions/groups that perform these types of research, which is naturally complex. In

[8] However, it should be noted that 1) this conclusion is based on a whole country analysis and does not give higher granularity and 2) this analysis does not assess production and performance of *specifically and only* translational research, for methodological reasons.

[9] As reference, the Netherlands distinguishes itself as the most competitive country of the benchmarks, and has 55.7% of its publications in Top 1-10% Scimago journals.

[10]A further step forward in measuring journals' scientific prestige: The SJR2 indicator (https://www.scimagojr.com/files/SJR2.pdf)

[11] As measured by the capability to publish in top tier journals (Scimago journals). It should be noted that this is only *one* measure of impact (does not give the full picture of the impact of research in a country) and particularly dependent on research´s global visibility and recognition. It was chosen in this analysis as it permitted a robust and accurate comparison at an international level.

France, this relies on a triad of actors: Universities - CHUs - Research organisations (such as Inserm).

One of the main intuitions of the actors is that France's under-performance is largely due to organisational complexity, which dilutes efforts and diminishes efficiency. **There is also the idea that the CHU model, once quite successful, is in need of revision to allow higher quality research,** namely translational clinical research.

By analysing the institutions behind French biomedical research publications, with a special focus on the Universities-CHUs relation, this study **attempted to see whether evidence supports these perceptions**:

- By identifying the research produced by the different types of institutions through the affiliations that are indicated by each last author on a publication (research group or leader of the research) **we confirmed a clear problem of feeling of belonging to the universities which appear through the affiliation practices of CHU authors**.
- Nearly all authors mentioning a CHU affiliation should also indicate a university affiliation, since most are employed by a university. However, this is far from the case, as we found that a considerable percentage of all publications of CHU´s last authors did not mention the university affiliation. To be able to have an approximation of reality, we have "reconstructed" the Higher Education Institutions (HEI) affiliations to include the CHUs, and considered this as well as research conducted exclusively at universities (hereinafter called Universities) and research conducted at CHUs regardless of University relation being made explicit or not, (hereinafter called CHUs) as our predominant categories in the analyses.
- **Higher education institutions (and associated CHUs) contribute to more than 60% of all biomedical research in France** (33% and 29%, in Universities and CHUs respectively)
- **The contribution of most institutions by research type is as expected**, such as with CNRS publishing substantially more in basic and translational research; CHUs and Hospitals in public health, epidemiology and clinical research and university groups without CHU affiliation publishing more in basic and translational research. **Cancer centres dedicate most (around ⅔) of their research to public health, epidemiology and clinical research.**
- Citation behaviours are distinct for basic & translational research vs the clinical research domain, in which the latter generally has a dichotomy of highly cited studies (e.g. big clinical collaborative studies on major diseases) and very low cited research (e.g. clinical case studies or regional public health studies); while research categorised as basic research tends to have a more uniform type of studies. This pattern is reflected in the citation metrics we see for Fundamental and Clinical research in Universities and CHUs.
- **CHUs do not fare well in the scientific impact of their publications,** and especially so in basic and translational research, **with citation metrics below Universities and Inserm in both research types.** The low citation metrics in basic and translational research suggests that there is not a focus on excellent translational research in the CHUs, even if the dedication to this research type

is expected to be low.

- Despite an overall lower scientific impact in both fundamental and clinical research, **in research on these major disease groups, CHUs actually have a higher share of their publications in the Top 1-10%, when compared to Universities**.
- CHUs and Inserm display the highest proportion of publications in Top 2-10% Scimago in Cardiovascular Diseases and Infections; while Inserm publications have the highest scientific impact in the fields of Neoplasms and Nervous System Diseases.
- In fields of higher research dedication (larger fields in volume of publications), **nearly all research in Life Sciences is published by Universities and nearly all research in Health Sciences by CHUs**. There is however an interesting exception: **Public Health is in fact a specialisation of Universities.**
- In fields of higher research dedication, **Universities are more prone to interdisciplinarity**.
- **There are no substantial differences between Universities, Inserm and CHUs in the dedication pattern of research to the main areas of high production and specialisation in France**: Neoplasms, Infections, Infectious Diseases, Cardiovascular Diseases and Hemic and Lymphatic diseases. Although, and as expected, CHUs have a proportionally higher volume of research per disease group than other organisations. It is interesting to note that although producing more in basic and translational research, university groups have a reasonable percentage of research in diseases; likely in fields such as molecular basis of disease or disease models.
- **The national specialisation in infectious diseases and cancer is distributed through all institution types** (CHUs, Universities, Inserm and others), with all having a reasonable contribution in publications in Top 1-10%.
- **CHUs and Hospitals display the lowest share of publications with international partners** (around 45%, while all other actors show >50% share).
- **Of all types of institution analysed, CHUs, together with HE Institutions, have the highest share of publications led as first or last author**. An increased capacity to lead, although in itself good, is also often a trade-off of reduced collaborative work, which may decrease international visibility, peer recognition and research excellence[12].
- Inserm, CNRS and IHUs show a fairly balanced distribution of leadership and internationalisation, showcasing the capacity to collaborate internationally, without losing the capacity to lead.
- The patterns of internationalisation and leadership do not change substantially when just basic & translational or public health, epidemiology & clinical research are considered.

[12] It should be noted, however, that both CHUs and Universities are much larger contributors of research and therefore there may be very different practices taking place within each of the " institutions".

Overall, this study tested one main assumption and raised one additional main question (that can be subdivided in two more specific questions):

1) Is there a decline of biomedical research in France?
2) Where is research produced and what is the weight of the different actors?
3) And, is the current CHU model allowing high quality research, namely translational clinical research?

Three broad conclusions can be reached:

1. Biomedical research is not declining per se (although it is declining relative to other countries here analysed), but its growth is plateauing below its potential and has been doing so in the last decade, in contrast to other European countries. Considering the intense competition from large emerging countries, this is a major cause for concern. Moreover, and beyond specialisation in large areas such as cancer and infectious diseases, France appears to be specialised in classical fields rather than in cutting edge or emergent fields.

   It would be important to ask what are the biomedical research priorities at the national level, and is, overall, biomedical research a priority? And if not, what would be the effect for the country?

2. More than 60% of the research produced in France originates from the combined Universities and CHUs. However the pattern of research that is being performed is distinct; with Universities carrying nearly all specialisations in Life Sciences and CHUs nearly all the research in Health Sciences, with little overlap. Universities are also more interdisciplinary.

3. CHUs are also not faring well in terms of scientific impact of publications; with the lowest rate of citations when compared to Universities and Inserm in both basic & translational but also, importantly, in public health, epidemiology and clinical research. Although this could indicate that different types of studies carrying different citation behaviours are occurring in CHUs vs Inserm/University groups, it nonetheless indicates a lower impact and/or lower interest from the global community. It also suggests that there may not exist a focus on excellent translational research in the CHUs.

   Although CHUs have a lower research impact than what would/could be expected or desirable, further comparative studies with international institutions with a similar model to the CHUs would allow a deeper understanding of how the CHUs, and integration with the Universities to which they are associated, are truly faring.

Challenges, Solutions and Definitions

Any attempt to understand a national research ecosystem is bound to face methodological issues. This report relies exclusively on bibliometric data as information, which theoretically enables an unbiased and robust comparison of the research outputs of a whole country with other countries. However, such a comparison relies on the capacity to address two main difficulties: i) the correct identification of institutional affiliations in a given country ii) the correct identification of topics and disciplinary fields.

This section discusses these main challenges and the methodological solutions that were used. It further clarifies what definitions were used for concepts such as *translational research, biomedical research* or *interdisciplinarity*, that can be "fuzzy" and perceived differently by different people.

The correct identification of institutional affiliations

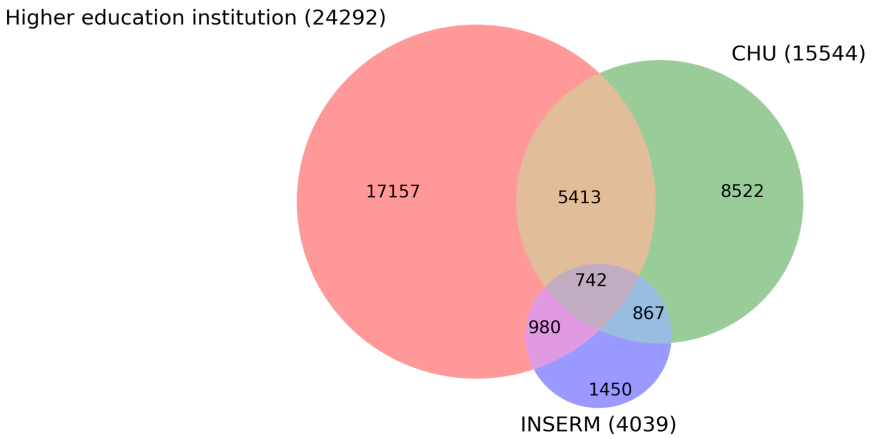
Identifying correct research authors affiliation is key for any bibliometric study which wishes to attribute work to specific institutions. However, the authorship of researchers in publications are very often multiple and written in various formats (ie. the same institution may appear written in a variety of forms because each affiliation is manually added by the author). This often leads to significant distortion in results.

Scopus, contrary to other databases, specifically works to improve affiliation information[13], and was therefore used in this study (in order to use higher quality data possible), in combination with the PubMed database.

A common issue with French affiliations is that (i) typically several institutions contribute to research because they support salary and infrastructure cost; (ii) affiliations are embedded - the more typical example being CHUs, which have a strong institutional identity but as far as research is concerned are *de facto* fully embedded within the respective university.

In that sense, affiliations provided by researchers often inform more about the feeling of belonging of the researcher, than about their correct institutional affiliation. In France, this is particularly important in the case of CHUs: virtually all CHU-affiliated authors are affiliated to a university, but a significant share of those authors do not mention the university in their affiliation (as shown by the Venn diagram below, which is based on how authors have actually signed their publications; Higher Education Institutions corresponding to the Universities).

[13] What is the Scopus Affiliation Identifier? (elsevier.com)



The multi affiliation issue in the French Biomedical Ecosystem between major institutional types (Venn diagram, n= number of publications 2019-2020)

Since one of the main aims of the present study is to understand what is the **weight of the main types of institutional actors in the French ecosystem**; a major difficulty lies in the fact that bibliometric analysis must rely on the affiliation provided by the author when signing a publication. However, in the complex and multi-layered French system, this explicit affiliation might be only part of the story and be more telling to understand the "feeling of belonging" of authors rather than the contribution really supported by different institutions.

For this reason, in this study, in order to get a more correct picture of the research produced, only publications with the last author were considered, and in the case of universities and associated CHUs some "reconstructions" were deemed necessary. Rationale and choices are explained in detail in Part 2 (see Methodological Considerations B).

The correct identification of research areas of interest

Database providers typically offer a categorisation of publications by disciplines, which is mostly applied at the level of journals (rather than single publications) and relies on a pre-established, and rather rigid, taxonomy. In addition, being based on disciplines, they are mostly not aligned with modern multidisciplinary and challenge-based research. While convenient, this approach misses the publication-level detail and does not provide a good vision of topics of specialisation.

To address this difficulty, most of the analyses provided in this study are based on *ad-hoc* semantic approaches, applied at the level of publication and tailored to the biomedical research sector. Such approaches used resources from the NIH bibliometric database PubMed (nih.gov) (see How to Identify the Biomedical domain for more detail.

For this study, the scope of biomedical research was defined in collaboration with France Universités and is based on SIRIS technologies and PubMed Database; when not possible, Scopus Health & Life Sciences selected areas are also utilised as proxy for biomedical research (see How to Identify the Biomedical domain). The NIH-NLM curated Medical Subject Headings (MeSH) Taxonomy and the Elsevier - Scopus ASJC

classification system were also exploited to categorise national research in different sub-topics of biomedicine (see Analysing Biomedical topics).

Defining Biomedical research, Translational research, Multidisciplinarity and Interdisciplinarity

In this study it was important to define and identify biomedical research that goes beyond existing, and more limiting, categorisations and is aligned to the context and aims. **Biomedical research**, thus, **encompasses the whole spectrum of the biomedical field, from fundamental research**, on the cellular basis of health and disease for example, **to the most classical clinical research** such as epidemiology; and excluding some aspects of life sciences such as ecology and evolution studies. This perimeter was also defined and used as such as is the closest related to the field of "*Biologie-Santé*" or "*biomedicale*" (vs "*medicale*") in France.
According to this biomedical perimeter, the areas of health sciences, and most of the life sciences, are part of biomedical research.

To be able to address questions and perceptions regarding the state of **translational research** in France, it was essential to be able to distinguish this type of research. The concept of translational research is often debated and has particularly unclear boundaries. Although there is always a good degree of grey areas in the definition of research "types", **for this work, a simple structure with 2 main groups whose boundaries are less debatable and that can, at this stage, be more accurately separated, was used**. Publications were identified and separated in two sets: those that concern **Public health, Epidemiology and Clinical Research**, and, by exclusion, those that concern **Basic and Translational Research**. The distinction is based on criteria and topics that are shown in more detail in the Methodology section. Importantly, this distinction also enables fairer and more accurate comparisons across the same research "type", as these two types of research have different publishing behaviours and citation metrics.

Finally, Biomedical research that has contributions from categories outside the Health and Life Sciences, i.e in the physical and social sciences, represent **interdisciplinary research**; while the research that is on diverse categories within Health and Life Sciences represents **multidisciplinarity**. These two concepts encompass the broader "recherches pluridisciplinaires" cited in recent reports[14].

[14] A. Migus, R. Ardaillou, P. Berche, C. Boitard, B. Clément, P. Couvreur, P. Debré, P. Netter, au nom d'un groupe de travail bi-académique de l'Académie nationale de pharmacie et de l'Académie nationale de médecine, *Rapport 21-07. Réformer la recherche en sciences biologiques et en santé: partie II, l'organisation*

Part 1. French biomedical research in international comparison

There is currently a feeling shared by many actors of the French system that biomedical research is underperforming and that the country is losing international competitiveness and the ability to innovate (helped by, among other factors, the ability to engage in interdisciplinary and translational research).

This part of the report asks if this feeling is warranted when **comparing French biomedical research production to a set of benchmarked countries**.

More precisely we look at:

- measures of volume
  - the absolute volume of biomedical publications
  - the ratio of biomedical publications per number of inhabitants
  - the share of research devoted to biomedical research
  - the share of world´s publications in biomedical research
  - the ratio of Basic & Translational vs Public Health, Epidemiology and Clinical Research
- measures of scientific impact
- specialisation in topics of relevance within biomedical research;
- level of interdisciplinarity and multidisciplinarity

Methodological Considerations

Choice of benchmark countries

When conducting a comparative study, the choice of benchmarks must be discussed prior to engaging in the analysis, since it needs to be aligned with the main objective of said comparison right from the beginning.

Comparing performance under similar external conditions (economic, social, legal) helps to understand how a certain system is over or underperforming; while comparing radically different systems allows the understanding of the specific conditions that allow them to excel (or negatively, lag behind).

Due to their relevance and different positioning in European Biomedical research, **Germany, Netherlands, Sweden, UK, Italy and Spain** were selected as benchmark countries to compare measures of volume of production and growth. To allow for the comparison with other non European benchmarks used in previous, but relevant, reports[15], and due to its relevance in medical research, **Canada** was also added to most analyses. Common benchmark countries such as the USA and China were mostly excluded due to their much larger size.

Furthermore:

- China, USA and EU27+UK were used as reference points for measures of share of the world's publications, precisely due to their large size and contribution.

[15] Le rôle des CHU dans l'enseignement supérieur et la recherche médicale - Dec 2017, Cour des comptes

- For some in-depth analysis, only Germany, Netherlands, UK and Spain were used as benchmarks. These countries were identified as relevant benchmarks due to either their similar size (UK, Germany), being powerhouses of biomedical research (UK, The Netherlands) or being countries with lower governmental support (Spain).

Analysing biomedical research areas

Dedication refers to the share of research (in this case published work) that relates to a specific category. **Specialisation** implies a comparison with a baseline (of a set of countries, for example EU27); an entity can have a "high" dedication to an area of research, whilst not being highly specialised if their dedication is not above average for their context.

This report uses different hierarchical levels of the Scopus classification in order to understand the research dedication - and specialisation - of France's ecosystem (see visualisation bellow):

- All publications of France and a specific set of most relevant European benchmarks (Germany, UK, The Netherlands, Spain) were classified by Scopus main domains: Health Sciences, Life Sciences, Physical Sciences and Social Sciences. Scopus distinguishes between journals which are more "medical" from those more in the realm of biology (even if biomedical), so both domains of Health Sciences and Life Sciences were analysed (see "Defining biomedical research, multidisciplinarity and interdisciplinarity").
- Furthermore, the set of biomedical research publications that have been identified based on SIRIS Biomedical Research vocabulary (to avoid including in the study veterinary/dentistry/evolution and agricultural sciences, thus having the perimeter of biomedical research aligned to the study question -see How to Identify the Biomedical domain for more detail) was then further analysed. Publications were classified by how the journals they publish in are categorised by Scopus in 2 additional levels (*areas* and *fields* - see infographic in the following page); please bear in mind that one single journal can belong to more than one Scopus Category - see examples below).

journal	Cluster(s)	Areas(s)	Fields(s)
Nature Microbiology	Life Sciences Health Sciences	Immunology and Microbiology Biochemistry, Genetics and Molecular Biology Medicine	Cell Biology Genetics Applied Microbiology and Biotechnology Immunology Microbiology Microbiology (medical)
Mutagenesis	Life Sciences Health Sciences Physical Sciences	Biochemistry Genetics and Molecular Biology Medicine Pharmacology, Toxicology and Pharmaceutics Environmental Science	Genetics Health, Toxicology and Mutagenesis Genetics(clinical) Toxicology
Nanomedicine	Health Sciences Physical Sciences	Chemical Engineering Engineering Materials Science Medicine	Bioengineering Biomedical Engineering General Materials Science Medicine (miscellaneous)

Examples of journals that cross categories in the Scopus Science Journal Classification system (ASJC)

ANALYSING BIOMEDICAL RESEARCH

Identifying Biomedical Research

Source: PubMed Database
Methodology: SIRIS Controlled Vocabulary for Biomedical research, using MeSH Terms

French Biomedical Research Publications (2019-2020)

Categorising publications in different level topics:

Methodology: Scopus Classification System (based on the publication's Journal)*

1st level Cluster:
Health Sciences, Life Sciences, Physical Sciences, Social Sciences

2nd level Areas:

Clusters	Areas
Physical Sciences	Chemical Engineering Chemistry Computer Science Earth and Planetary Sciences Energy Engineering Environmental Science Material Science Mathematics Physics and Astronomy Multidisciplinary
Health Sciences	Medicine Nursing Veterinary Dentistry Health Professions Multidisciplinary
Social Sciences	Arts and Humanities Business, Management and Accounting Decision Sciences Economics, Econometrics and Finance Psychology Social Sciences Multidisciplinary
Life Sciences	Agricultural and Biological Sciences Biochemistry, Genetics and Molecular Biology Immunology and Microbiology Neuroscience Pharmacology, Toxicology and Pharmaceutics Multidisciplinary

3rd level Fields:

Area	Fields
Neuroscience	General Neuroscience Neuroscience (miscellaneous) Behavioral Neuroscience Biological Psychiatry Cellular and Molecular Neuroscience Cognitive Neuroscience Developmental Neuroscience Endocrine and Autonomic Systems Neurology Sensory Systems

Categorising publications in disease groups:

Methodology: MeSH Taxonomy** (based on MeSH terms assigned to each publication in PubMed)
Branch C: Diseases and F03: Mental Disorders

- Anatomy [A]
- Organisms [B]
- Diseases [C]
  - Infections [C01]
  - Neoplasms [C04]
  - Musculoskeletal Diseases [C05]
  - Digestive System Diseases [C06]
  - Stomatognathic Diseases [C07]
  - Respiratory Tract Diseases [C08]
  - Otorhinolaryngologic Diseases [C09]
  - Nervous System Diseases [C10]
  - Eye Diseases [C11]
  - Urogenital Diseases [C12]
  - Cardiovascular Diseases [C14]
  - Hemic and Lymphatic Diseases [C15]
  - Congenital, Hereditary, and Neonatal Diseases and Abnormalities [C16]
  - Skin and Connective Tissue Diseases [C17]
  - Nutritional and Metabolic Diseases [C18]
  - Endocrine System Diseases [C19]
  - Immune System Diseases [C20]
  - Disorders of Environmental Origin [C21]
  - Animal Diseases [C22]
  - Pathological Conditions, Signs and Symptoms [C23]
  - Occupational Diseases [C24]
  - Chemically-Induced Disorders [C25]
  - Wounds and Injuries [C26]
- Chemicals and Drugs [D]
- Analytical, Diagnostic and Therapeutic Techniques, and Equipment [E]
- Psychiatry and Psychology [F]
  - Behavior and Behavior Mechanisms [F01]
  - Psychological Phenomena [F02]
  - Mental Disorders [F03]
  - Behavioral Disciplines and Activities [F04]

MeSH Browser (nih.gov)

** each journal can be classified in more than one category (regardless of the level); Example of 3rd Level: Neurosciences*
*** each publication can relate to more than one Disease Group, resulting in the fact that each publication can be assigned to multiple topics and disease groups. e.g. a Publication in Asthma is both in Immune Disease and Respiratory Disease category; and can also be in a Scopus area of Medicine or Immunology & Microbiology.*

1.1. Growth, positioning and scientific impact

Despite the lower funding for biomedical research in France, which has been highlighted in recent reports[16], research production in this field has increased in the last few years in France (*Fig. 1*).

However, France is clearly growing at a lower rate than the world average (dotted pink line) (*Fig. 1B*) and even if larger consolidated research ecosystems logically grow more slowly[17], this remains true when comparing France to research systems of a similar size like Italy or Canada (*Fig. 1A*), and even to larger consolidated research systems such as the UK or Germany. France is the country with the most modest growth rate from 2010-2020, and the only one below EU27+UK average (dotted black line) in several of those years[18] (*Fig. 1B*).

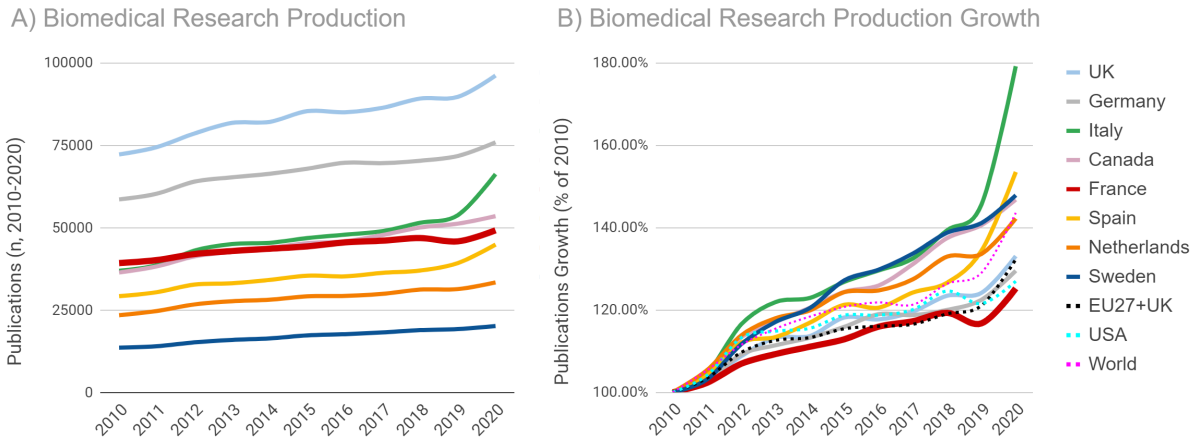


Fig. 1 Biomedical Research growth: *A) number of biomedical research publications in specific Health and Life Sciences Areas of Scopus for each country per year (2010-2020); B) percentage of growth in the number of biomedical publications for each country and worldwide, in respect to 2010 (2010-2020).*
Source: SIRIS Academic, using Scopus biomedical areas in Health Sciences (specifically Medicine, Nursery, Dentistry, Health professions) and in Life (Sciences Biochemistry, Genetics and Molecular Biology, Immunology and Microbiology, Neurosciences and Pharmacology, Toxicology and Pharmaceutics)

Thus, despite a *de facto* increase in the number of publications (*Fig. 1A*), France remains consistently below other countries analysed in dedication to the biomedical field (*Fig. 2A*), alongside Germany and Spain, 10% below the Netherlands and approximately 5% below Sweden and Canada (the Italian case is interesting and presumably to a specific response to the COVID19 pandemic). In addition, France's biomedical research production per capita is the lowest of all benchmarks analysed

[16] A. Migus, R. Ardaillou, P. Berche, C. Boitard, B. Clément, P. Couvreur, P. Debré, P. Netter - groupe de travail bi-académique de l'Académie nationale de pharmacie et de l'Académie nationale de médecine, *Rapport 21-06. Réformer la recherche en sciences biologiques et en santé: partie I, le financement*; A. Migus, R. Ardaillou, P. Berche, C. Boitard, B. Clément, P. Couvreur, P. Debré, P. Netter, au nom d'un groupe de travail bi-académique de l'Académie nationale de pharmacie et de l'Académie nationale de médecine, *Rapport 21-07. Réformer la recherche en sciences biologiques et en santé: partie II, l'organisation*.
[17] Size of research ecosystem as measured by number of publications in the same period
[18] Any "Growth rate", here represented as the percentage of growth of the number of publications relative to 2010, must be considered carefully. In this case, the actual size of the research ecosystem (in number of publications) has a direct effect on the capacity of a given country to double its production (ie. due to its size, USA - even under the same circumstances - will not be able to double the number of publications per year as fast as a smaller system like Sweden). Therefore, the most accurate comparison is to face countries of approximate research production size like France-Canada-Italy, or Spain & The Netherlands.

(*Fig. 2B*).

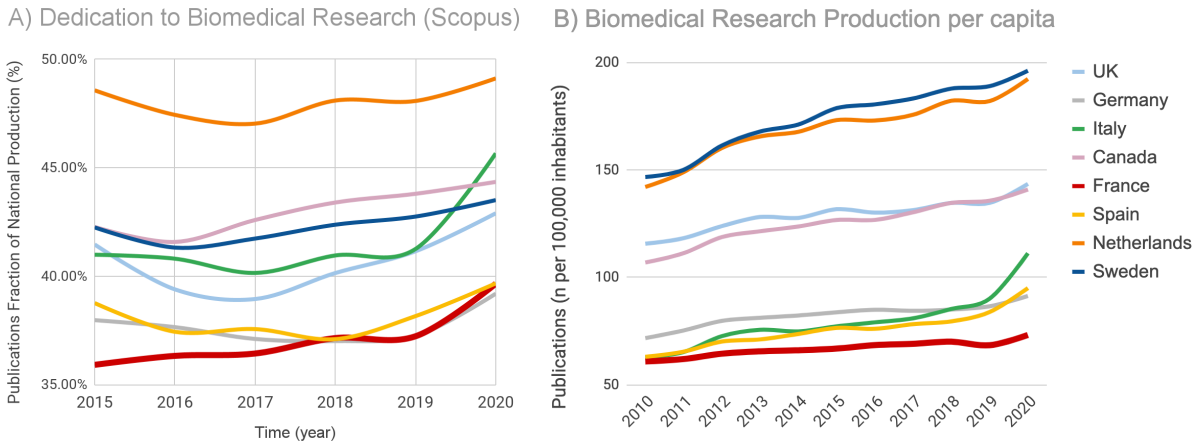


Fig. 2 Biomedical Research dedication and production per capita: *A) Percentage of biomedical research (2015-2020) and B) number of biomedical research publications per 100 000 inhabitants (source Eurostat) in the specific Health and Life Sciences Areas of Scopus for each country per year (2010-2020).*
Source: SIRIS Academic, using Scopus biomedical areas in Health Sciences (specifically Medicine, Nursery, Dentistry, Health professions) and in Life (Sciences Biochemistry, Genetics and Molecular Biology, Immunology and Microbiology, Neurosciences and Pharmacology, Toxicology and Pharmaceutics)

Although all benchmarks, including France, show an increase in the volume of biomedical research publications in the last decade (*Fig. 1A*), their share of the world's research has remained largely stable (*Fig. 3A*). This is, likely, a consequence of the emergence of other larger contributors in Biomedical research, such as China.

France's share of world publications (in all domains) was 3.9% between 2015-2020, below countries such as Germany or the UK (and slightly below Italy), with its share within the field of Biomedical Research only slightly higher at 4% for this period (*Fig. 3B*).

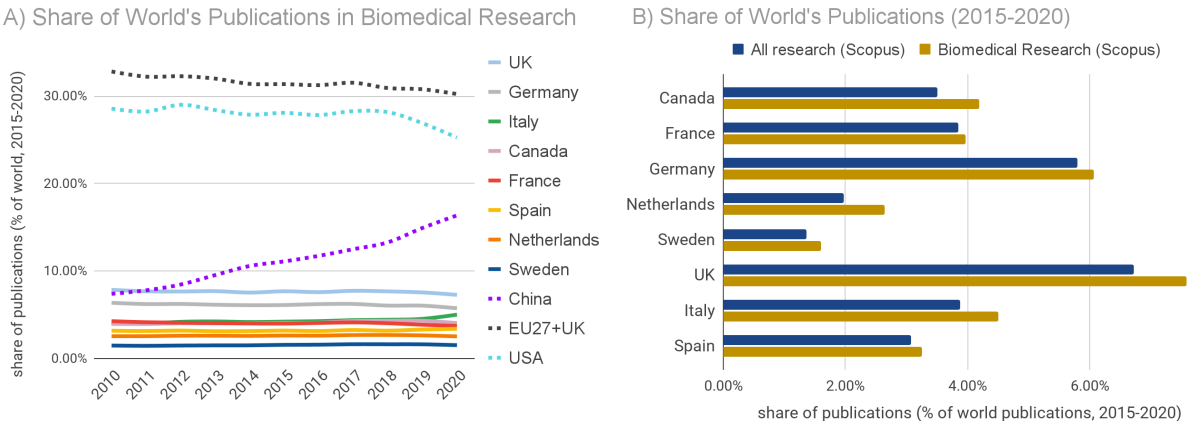


Fig. 3 Biomedical Research share of world's production (2015-2020): *A) percentage of world publications attributed to each country either in biomedical research (as in specific Areas of Health and Life Sciences of Scopus classification) per year (2015-2020); B) percentage of world publications attributed to each country either in total (all areas of research) or biomedical research (as in specific Areas of Health and Life Sciences of Scopus classification).*
Source: SIRIS Academic, using Scopus biomedical areas in Health Sciences (specifically Medicine, Nursery, Dentistry, Health professions) and in Life Sciences (Biochemistry, Genetics and Molecular Biology, Immunology and Microbiology, Neurosciences and Pharmacology, Toxicology and Pharmaceutics).
Despite arguably low volume (*Fig. 2B*), France´s biomedical research has an overall

similar scientific impact to Spain and the UK, with a similar percentage of its publications in Top 1-10% Scimago journals (all around 50%) (*Fig. 4*).

However, France does also show a higher proportion of publications in the lowest tiers (30-100%), with 17.4% in 30-100% Scimago, as compared to 13.6% for Spain and 15.4% for the UK (*Fig. 4*); while The Netherlands distinguishes itself as the most competitive country of the benchmarks.

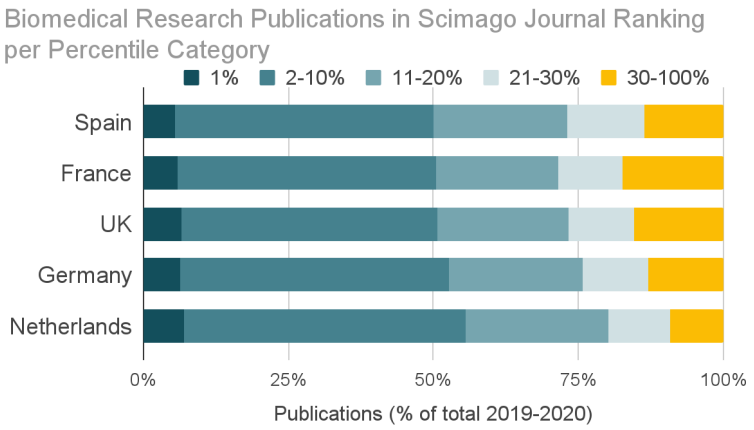


Fig. 4 Biomedical Research Scientific Impact (2019-2020): *Benchmarks share (% of total) publications by percentile category of their journals, according to the Scimago Journals Ranking (SJR) (2019-2020)[19]. Source: SIRIS Academic, using ad-hoc vocabulary for Biomedical research and Scimago SJR.*

Compared with the UK, the Netherlands, Sweden, Germany, Italy, Spain and Canada, overall, **measures of biomedical research production in France fare poorly**. France has the lowest growth rate from 2010 to 2020, and is the only country below EU27+UK average of growth for the most part of the last decade. It also has the lowest overall production per capita.

Many developed countries, including France, have not increased their contribution to the world's share of biomedical research in the last decade due to the emergence of other very large research contributors (such as China). **Nevertheless, France shows a share of the world's publications below countries such as Germany and the UK, due to a particularly low ratio of published biomedical research per capita.**

This **low research production per capita**, together with **low dedication to biomedical research**, and a **modest growth rate - below both World and European averages**, suggests that France is a **system that has plateaued while still having the potential to grow.**

Despite the above, France's biomedical research has a similar scientific impact to Spain and the UK, with an equal percentage of its publications in top tier journals (Top 1-10% Scimago journals; around 50%). Noteworthy however, **France also has a proportionally higher number of publications in lowest tier journals** (30-100% Scimago journals), compared to benchmarks.

[19] For data availability reasons we were not able to analyse cites per paper as a parallel measure of impact when analysing benchmark countries, however it should be noted that other factors influence the capacity to publish in Scimago top ranked journals, including the reputation of researcher/institution, that may be unlinked to the absolute quality of the work.

1.2. Areas of dedication and specialisation in biomedical research

Exploring the topics and areas of specialisation within a given country's portfolio[20] shows where it may have a competitive edge at a European or global level and where it stands to contribute and impact the most.

Firstly, **research in France is more concentrated in Physical Sciences, in a pattern similar to Germany**. **The country's dedication to Health and Life Sciences is slightly below most benchmarks and Social Sciences are clearly underrepresented** (*Fig. 5*). The Netherlands has a clear dedication to Health Sciences, where it also shows high specialisation.

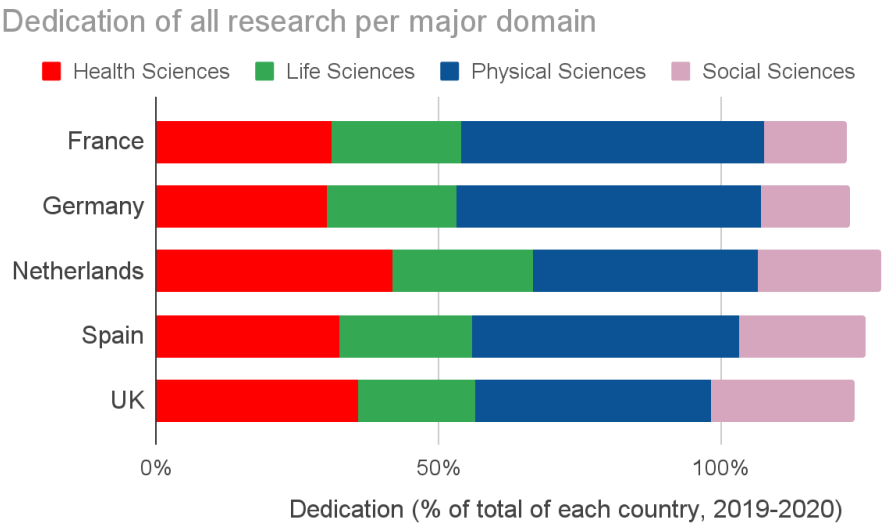


Fig. 5 Overall research dedication (2019-2020): *share of each country's research per Scopus cluster[21]. Source: SIRIS Academic, using all research registered in Scopus database, as well as the 5 main domains existent in Scopus categorization system (Cluster - 1st level of Scopus classification);* the sum for each institutional type is above 100% due to the fact that each journal, and therefore publications, in Scopus database can belong to more than one domain.

Either compared to Europe's baseline (EU27+UK) (*Fig. 6A*) or the set of benchmark countries shown (*Fig. 6B*), counterbalancing a **higher specialisation in Physical Sciences, France shows a modest specialisation in Life Sciences and is not specialised in the Social Sciences**[22]. Its specialisation in the Health Sciences is equivalent to that of Europe's baseline but is not specialised when compared to the selected benchmarks (*Fig. 6*).

France, Germany, The Netherlands, Spain and the UK participate in over 65% of all Health and Life Sciences research in Europe (according to Scopus classification) and

[20] High dedication means a high volume of research on a certain topic(s); while specialisation indicates research for which the country produces more in comparison to other comparators (a defined baseline).
[21] The sum for each institutional type is above 100% due to the fact that each journal, and therefore publications, in Scopus database can belong to more than one domain.
[22] France's seemingly lower dedication and specialisation in Social Sciences could be the result of a lower coverage of this domain by Scopus, as there is a significant share of Humanities and Social Sciences (H&SS) publications in French, and Scopus is strongly skewed to English language publications. However, it is difficult to establish the degree to which this masks French or other countries' reality. The high share of publications in H&SS in French would also highlight a lack of internationalisation of the domain.

will be used as comparators for the following analysis.

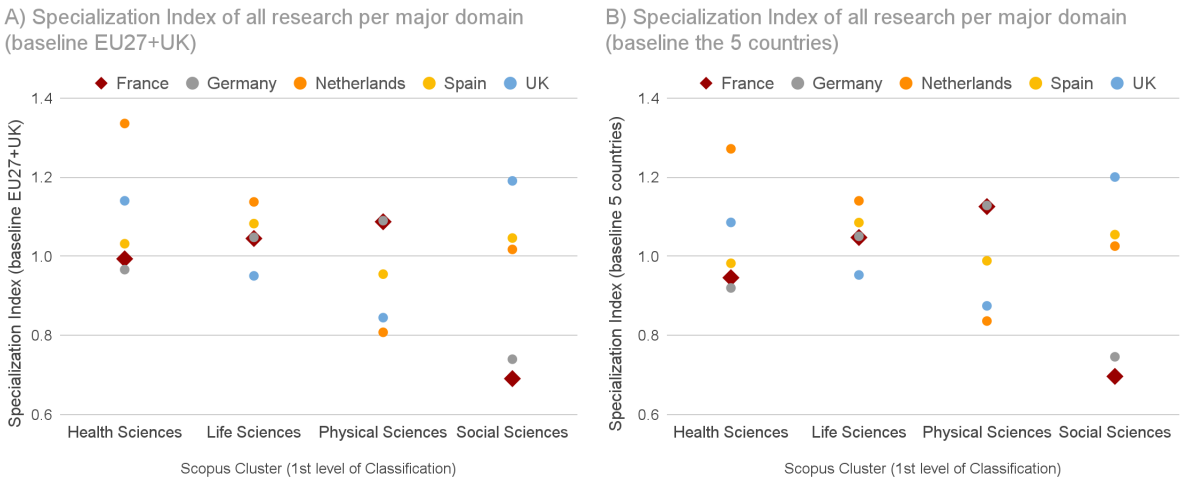


Fig. 6 Overall research specialisation (2019-2020): A) *Specialization Index of all research per Scopus Cluster, baseline: EU27+UK* ***and B)*** *baseline the combination of Germany, UK, France, The Netherlands and Spain.*
Source: SIRIS Academic, using all research registered in Scopus database, as well as the 5 main domains existent in Scopus categorization system (Cluster - 1st level of Scopus classification).

Looking specifically at Health and Life Sciences, **France shows a high dedication in traditional biomedical main areas**: Cancer, Cardiovascular Diseases, Infectious Diseases, Neuroscience, as well as Immunology, Surgery and Genetics (as observed by the size of the dots in the plots below - *Fig. 7*, where larger dots correspond to higher research volume). Nevertheless, amongst these large areas**, Cancer, Infectious diseases and Immunology are those where France is more specialised, when compared to the European benchmarks** (a specialisation index above 1 in *Fig. 7*); this is not surprising considering the existence and success of dedicated research intensive centres on these topics (e.g. Institut Gustave Roussy, Institut Curie or Institut Pasteur). In line with this, France also shows significant dedication and high specialisation in haematology and virology (*Fig. 7*); in addition, to significant specialisation in other clinical areas like Reproductive Medicine and Critical care (*Fig. 7A*).

On the other hand, **France is clearly not specialised in fields such as Public Health and Policy, Psychiatry and Mental Health** (*Fig. 7A - 8*), fields that have garnered increased attention in the last years, notably in countries such as the UK .

When looking specifically at disease groups, France shows a **clear specialisation in the smaller field of Hemic and Lymphatic Diseases** (*Fig. 8*), with higher research production in this field in comparison to other European countries; but a lower specialisation in Mental Disorders (which is consistent with what was observed above, within the Health and Life Sciences categories of Scopus classification).

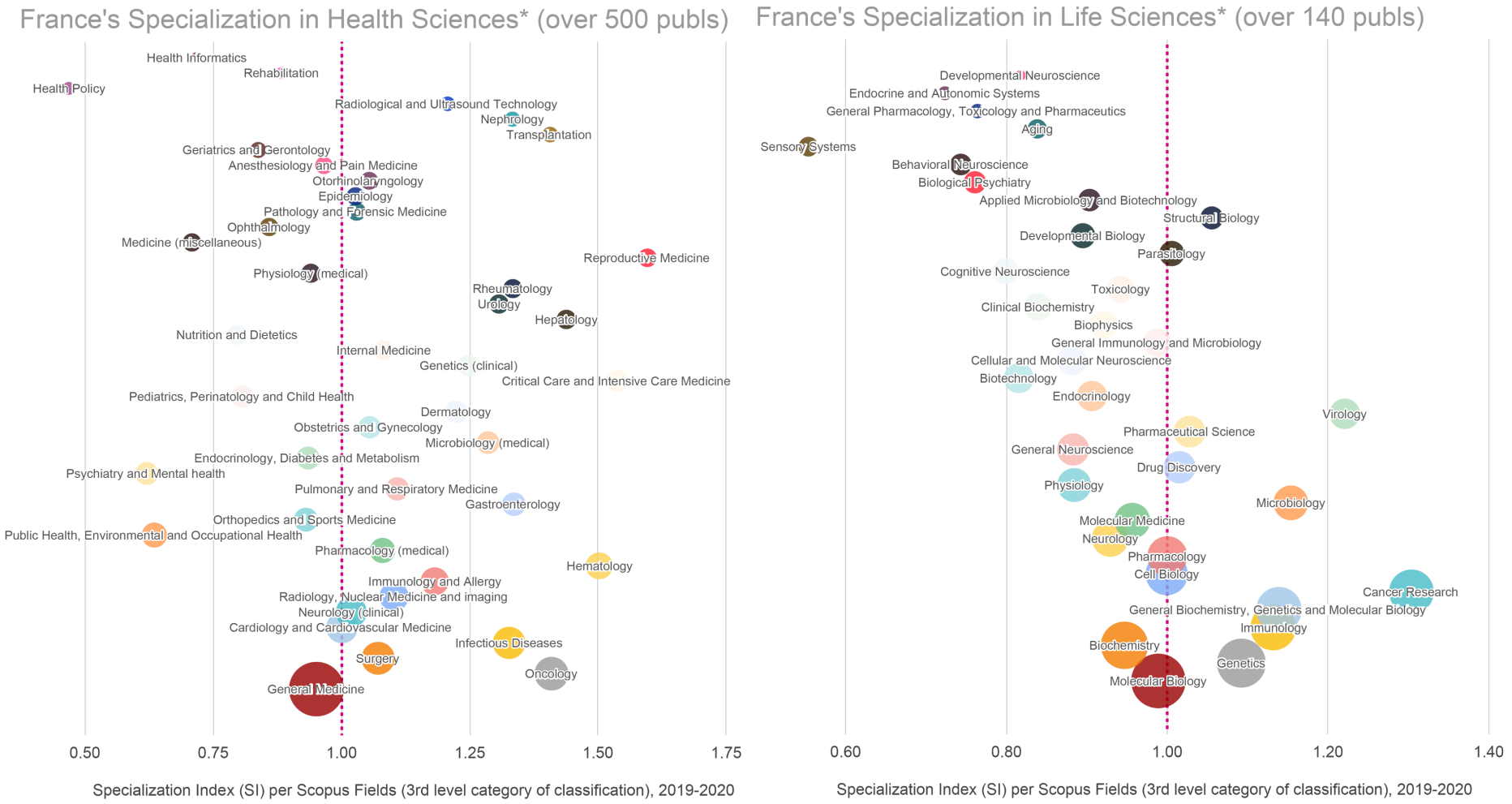


Fig. 7 Specialization Index of French biomedical research in A) selected Scopus Health Sciences areas and B) selected Scopus Life Sciences areas: *baseline:* ***Germany, UK, France, The Netherlands and Spain****, size of dots relates to the number of publications in France (2019-2020); (only Fields with more than 500 publications for Health Sciences and 140 publications for Life Sciences were plotted - i.e. significant representation).*
Source: SIRIS Academic, using ad-hoc vocabulary for Biomedical research and Scopus categorization system (Fields - 3nd level of Scopus classification in Health Sciences areas of Medicine, Nursery, Dentistry and Health professions; and in Life Sciences areas of (Biochemistry, Genetics and Molecular Biology, Immunology and Microbiology, Neurosciences and Pharmacology, Toxicology and Pharmaceutics). A SI=1 means that France is specialised on the same as the baseline.

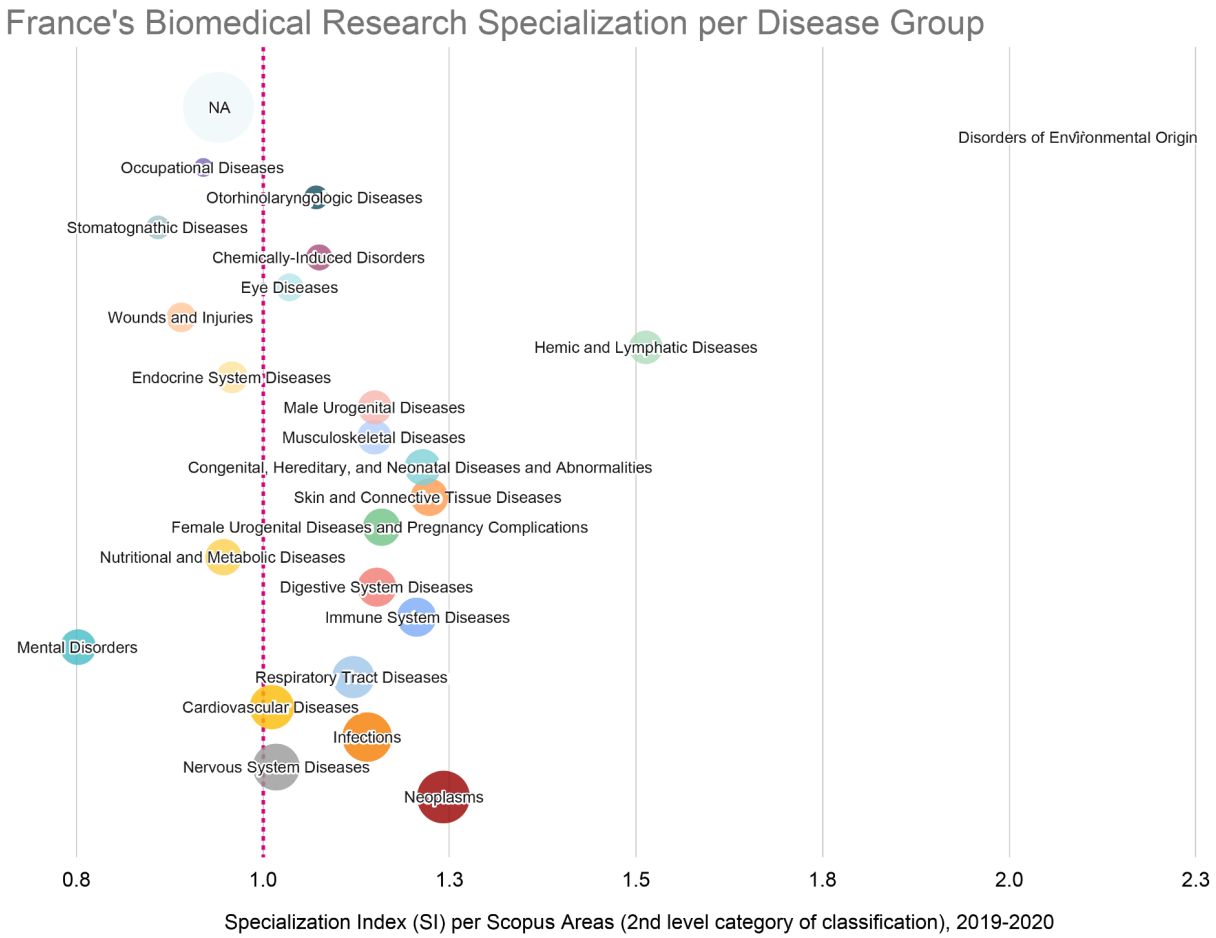


Fig. 8 France's Specialization Index of French biomedical research production by disease group area (2019-2020): *baseline:* ***Germany, UK, France, The Netherlands and Spain****, size of dots relates to the number of publications in France (2019-2020); using publications that have MeSh terms that can be found in the C-Diseases and F03-Mental Disorders branch of the MeSH NIH-NLM taxonomy). Documents can be classified in several disease groups (e.g. research in Asthma will classify as an immune and respiratory disease).*
Source: SIRIS Academic, using ad-hoc vocabulary for Biomedical research and NIH-NLM MeSh Taxonomy. A SI=1 means that France is specialised on, on average, the same as the baseline; A SI around 2 would mean that they are twice more specialised than the baseline.

Research in France remains specialised in Physical Sciences, with lower dedication to Health and Life Sciences and even lower to Social Sciences. This proportionally lower dedication and specialisation in biomedical research is linked to long-term science policy choices and investment in other fields, specifically in the Physical Sciences and Mathematics.

Biomedical research in France is significantly dedicated to large traditional areas, in a pattern mostly shared amongst the European countries. **France is, however, specialised in the areas of Cancer, Infectious Diseases, Immunology as well as Hemic and Lymphatic Diseases**, with higher research production in these fields in comparison to the benchmark countries. On the other hand France is clearly **not specialised in the Public Health and Policy and Psychiatry and Mental Health fields**.

1.3. Multidisciplinarity and interdisciplinarity

The ability to carry out multidisciplinarity and interdisciplinarity research is often linked in current discourses to the ability to carry out high quality translational research. However, it is also crucial to be able to develop innovative approaches to complex biomedical problems independently of research "type". Interdisciplinary and cross-sectorial research is also important to address specific public health problems that often use solutions using research in fields that fall out of the classical biomedical fields (e.g. economics, environmental science, psychology and broader social sciences).

France's biomedical research shows a **degree of multidisciplinarity[23] similar to the benchmark countries** (*Table 1, Fig. 9*); as well as a similar **level of interdisciplinarity[24]** (*Fig. 10*)**, albeit with different patterns.** Both France, Spain and Germany appear to have a **higher involvement of physical sciences in biomedical research, in detriment to social sciences**; while the UK and Netherlands have a more balanced contribution from these two domains (*Fig. 9-10*).

France's level of multidisciplinarity and interdisciplinarity in biomedical research is overall similar to what is seen for the benchmark countries, in which almost 80 fields[25] contribute to 99% of the French biomedical research[26] (*Table 1*).

Multidisciplinarity in France shows a share of research published in different topics of Health and Life Sciences similar to other countries (*Fig. 9*). Interdisciplinarity in France, i.e the share of biomedical publications in journals that are outside Health and Life Sciences, is slightly lower than Germany and Spain (16% vs 20 and 22%, respectively) and similar to the UK and the Netherlands (*Fig. 10*). However, the pattern is distinct with a lower volume of research in fields within the Social Sciences (*Fig. 9-10*). The fact that interdisciplinary research with Physical Sciences is more prevalent may be a spill over of the national overall specialisation of France in Physical sciences.

2019-2020	France	Germany	Netherlands	Spain	UK
Total number of fields with >1% of country's research	78	73	69	77	71
number of publications of the first field with >1% of country's research	*821*	*1152*	*583*	*639*	*1729*
Total number of fields with >0.25% of country's research	126	134	129	133	139
number of publications of the first field with >0.25% of country's research[27]	*213*	*304*	*144*	*162*	*441*

Table 1. Biomedical research in number of Scopus Fields, per benchmark country (2019-2020): *number of Scopus fields that are >1% and >0.25% of all biomedical research publications.*
Source: SIRIS Academic, using ad-hoc vocabulary for Biomedical research and Scopus categorization

[23] Research with contribution of topics in fields within Health and Life Sciences
[24] Research with contribution of topics in fields outside of Health and Life Sciences
[25] Here Scopus classification system 3rd Level - Fields, was used (see Analysing Biomedical Research))
[26] Two thresholds for counting the different fields in Biomedical research were defined during the analysis. Since it was key to guarantee that conclusions were gathered using only fields that had a significant number of publications, the threshold of 1% and 0,25% of Biomedical research were chosen (after evaluating other thresholds)- see table. Only fields that included at least more than 0.25% and 1% of all biomedical research of France were therefore analysed.
[27] This information helps understand what the 1% and 0.25% threshold means, and guarantees that there is a robust number of publications. The fields that represent 1% and 0.25% of French Biomedical research includes around 400 and 100 publications per year respectively (821 and 2013 i n 2019-2020).

system (Clusters - 1st level of Scopus classification; Fields - 3rd level of Scopus classification).

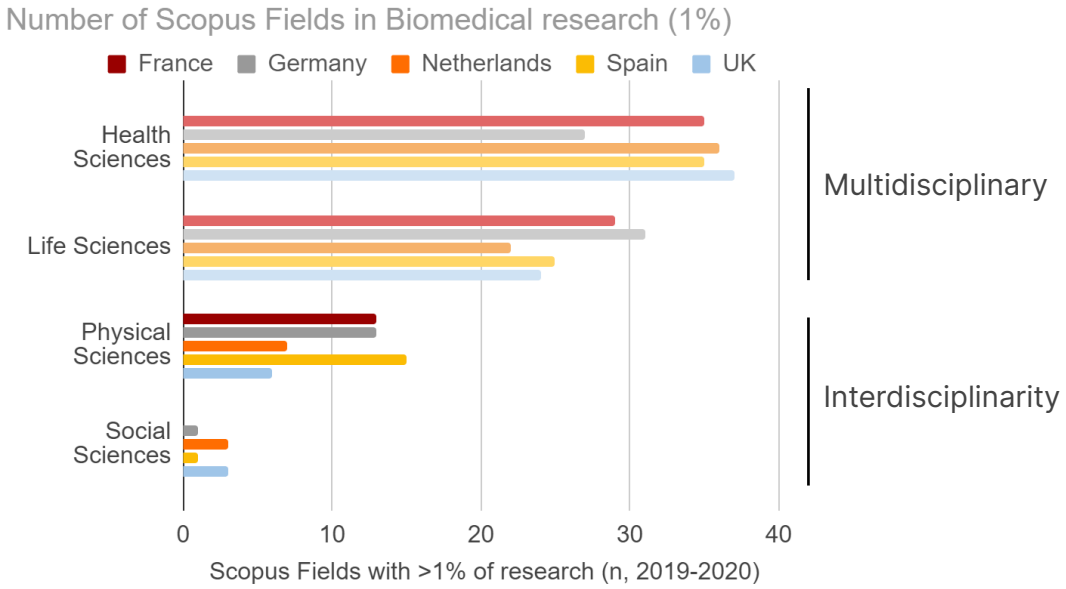


Fig. 9 Biomedical research in number of Scopus Fields, per benchmark country (2019-2020): *number of Scopus fields that are >1% of all biomedical research publications.*
Source: SIRIS Academic, using ad-hoc vocabulary for Biomedical research and Scopus categorization system (Clusters - 1st level of Scopus classification; Fields - 3rd level of Scopus classification).

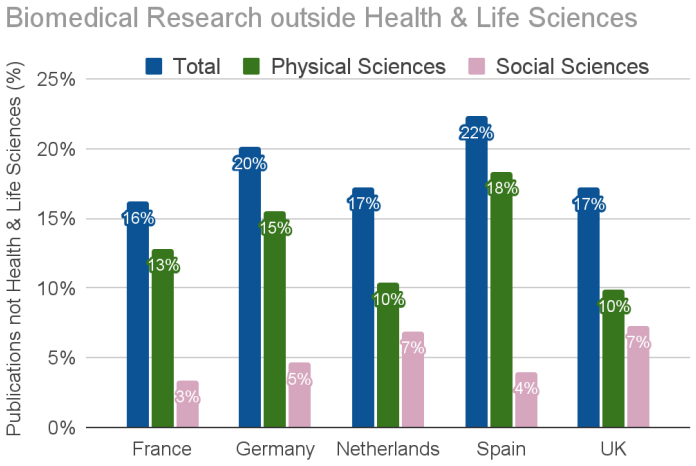


Fig. 10 Dedication of Biomedical research into other Scopus clusters (not Health and Life Sciences): *percentage of Biomedical research in each country (2019-2020).*
Source: SIRIS Academic, using ad-hoc vocabulary for Biomedical research and Scopus categorization system (Clusters - 1st level of Scopus classification).

Interdisciplinary Biomedical research in France with specific contributions from the Physical sciences is strong, in particular several topics of Chemistry, as well as subfields of Computer Science (*Fig. 11*).

Interestingly, and most likely linked to the known strengths in Physical Sciences, **interdisciplinary biomedical research in France is more specialised in Environmental Sciences and Physics, rather than in biomedical applied fields such as Biomedical Engineering, Bioengineering or Biomaterials** (*Fig. 11*).

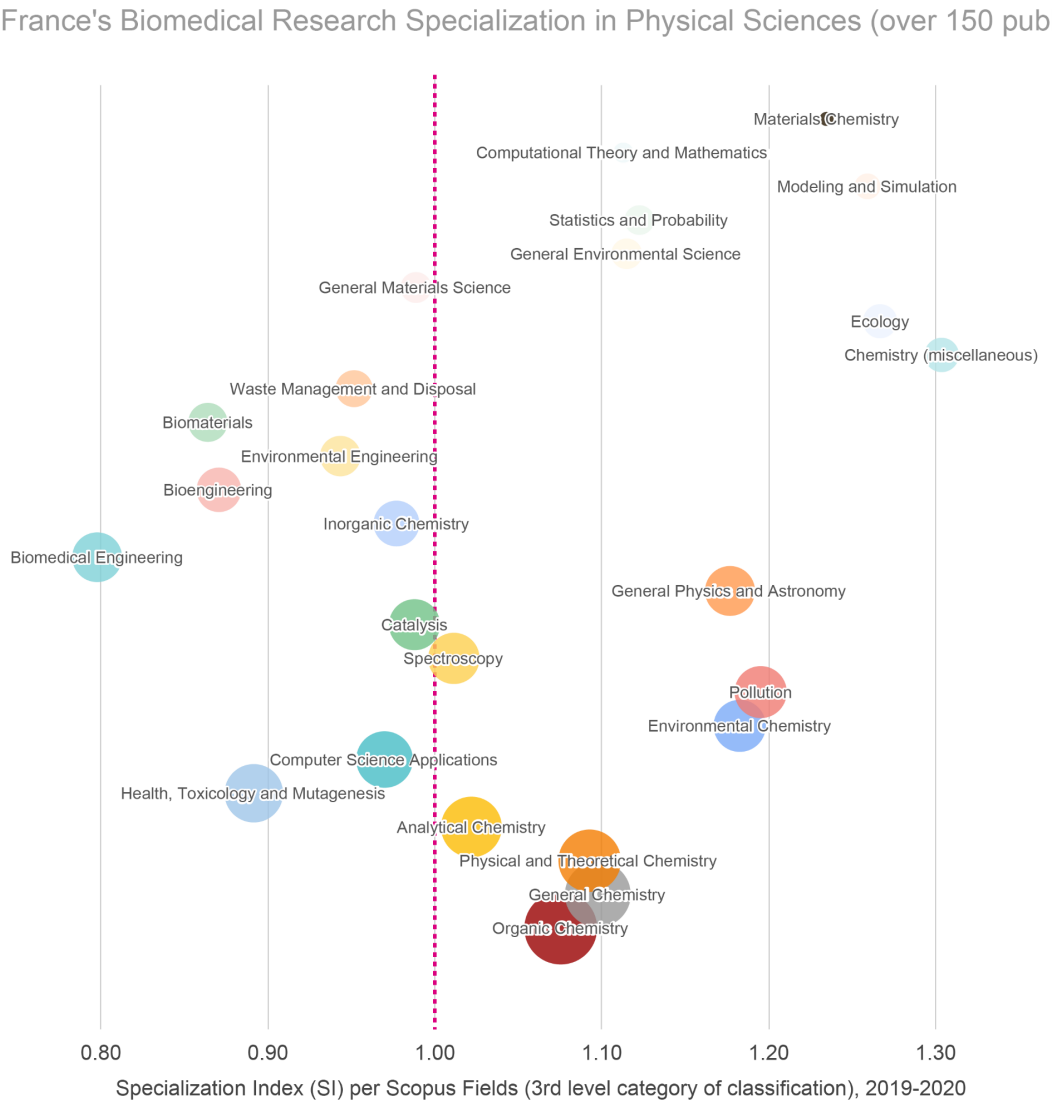


***Fig. 11 Specialization Index of French biomedical research in Scopus Physical Sciences Fields**: baseline: **Germany, UK, France, The Netherlands and Spain**, size of dots relates to the number of publications in France (2019-2020); (only Fields with more than 150 publications - i.e. significant representation).*
Source: SIRIS Academic, using ad-hoc vocabulary for Biomedical research and Scopus categorization system (Areas - 3rd level of Scopus classification for all domains). A SI=1 means that France is specialised on, on average, the same as the baseline; A SI around 2 would mean that they are twice more specialised than the baseline.

France´s biomedical research shows a **degree of multidisciplinarity similar to the benchmark countries**, **as well as a similar level of interdisciplinarity, albeit with different patterns**. France, Spain and Germany appear to have a **higher involvement of physical sciences in biomedical research, in detriment to social sciences**; while the UK and Netherlands have a more balanced contribution from these two domains. Interestingly, **interdisciplinary biomedical research in France is more specialised in Environmental Sciences and Physics**, **rather than in biomedical applied fields such as Biomedical Engineering, Bioengineering or Biomaterials**.

1.4 Production in Basic and Translational Research vs Clinical Research

The difficulty of implementing translational research through the full continuum from biology to health, as well as the difficulty in carrying out multidisciplinary research, although not exclusive to France, is also present in France. This has been attributed, at least partly, to a lack of funding and evaluation structures specific for this type of research (and arguably not only for this type of research but for research in general that is outside narrow and contained thematics)[28].

When analysing the production in basic & translational research vs more clinical research in France, it can be observed that, as a whole, the country presents a fairly balanced research ecosystem by research "type", with 51% of basic & translational research and 49% of public health, epidemiology and clinical research (*Fig. 12A*). This pattern is similar to Spain and Germany but different to that of Netherlands (and, to a lesser extent, to the UK) that presents an increased dedication to public health, epidemiology and clinical research (*Fig. 12*).

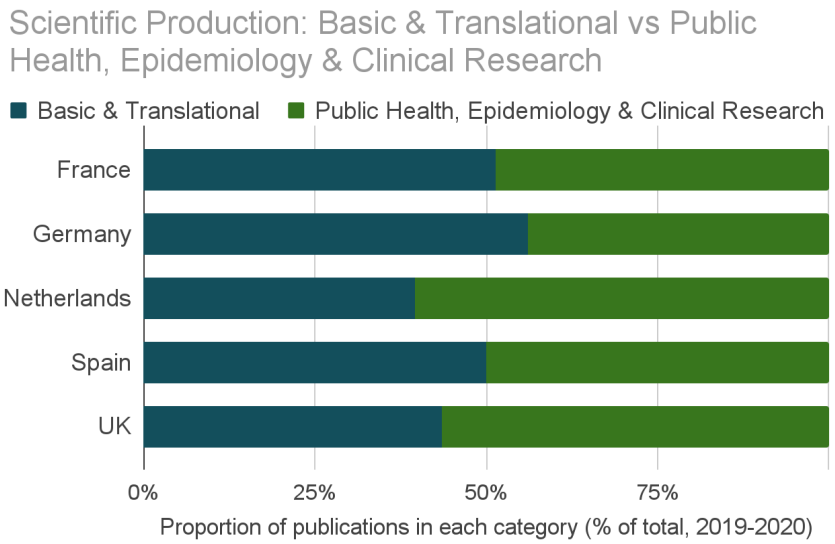


Fig. 12 Share of biomedical research publications by research type, per country (2019-2020): *percentage of basic & translational publications versus public health, epidemiology & clinical publications, data as percentage of total publications from each country in biomedical research; Source: SIRIS Academic, using ad-hoc vocabulary for Biomedical research and type of research (see Methodology section for more details on the Controlled Vocabularies used in this study).*

As an indicator of France's biomedical research impact, the analysis measured the capacity to publish in high prestige journals, like those used to calculate the Nature Index, often associated to higher visibility and peer recognition[29]. Using this metric,

[28] A. Migus, R. Ardaillou, P. Berche, C. Boitard, B. Clément, P. Couvreur, P. Debré, P. Netter, au nom d'un groupe de travail bi-académique de l'Académie nationale de pharmacie et de l'Académie nationale de médecine, Rapport 21-07. Réformer la recherche en sciences biologiques et en santé: partie II, l'organisation; Le rôle des CHU dans l'enseignement supérieur et la recherche médicale - Dec 2017, Cour des comptes

[29] Since the journals selected for the Nature Index mainly represent fundamental research, this metric was only used to evaluate Basic & Translational Research. The *share of publications in the Nature Index* is the percentage of publications from an institution that were published in the journals considered for this index. The Nature Index defines itself as an indicator of research performance, and is based on the output of 82 natural-science journals, selected on reputation by an independent panel of leading scientists.

France's research in basic & translational research seems to achieve similar recognition to benchmarks, as measured by the share of publications in journals considered for the Nature Index (NI), and in line with systems such as the Netherlands (1.21% in France and 1.2% in the Netherlands) and only slightly lower than the UK and Germany (1.3% and 1.4%, respectively).

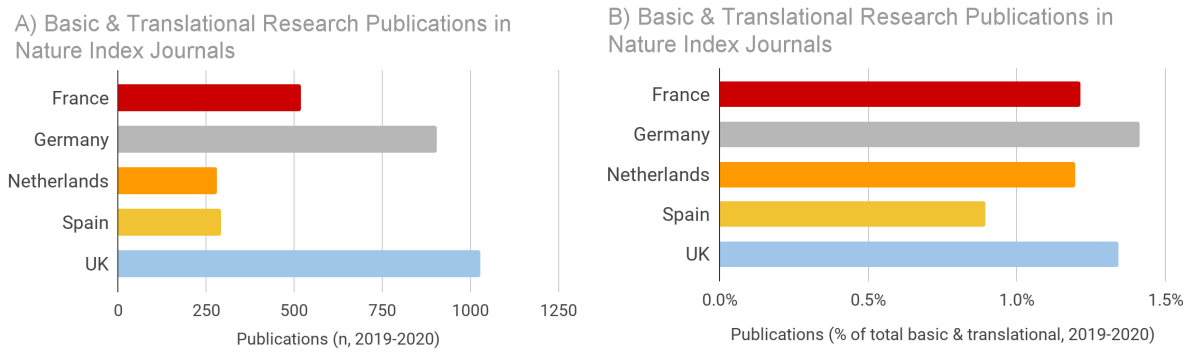


Fig. 13 Nature Index of biomedical publications by research type and its impact, per country (2019-2020): A) *number of basic & translational publications in NI journals;* ***B)*** *percentage of publications, from total number of basic & translational production, in NI journals.*
Source: SIRIS Academic, using ad-hoc vocabulary for Biomedical research and type of research (see Methodology section for more details on the Controlled Vocabularies used in this study).

It has been argued that the different weaknesses of the system, such as lack of specific funding and evaluation structures, have a negative impact on the ability to do translational research. **The share of basic and translational research in France is similar to Spain and Germany, and its performance** (at least measured through the ability to publish in Nature Index journals) **is on par to countries such as the Netherlands, and only slightly lower than the UK.** However, it should be noted that the analysis does not permit an assessment of production and performance of specifically and only translational research.

The COVID19 Response of the French Biomedical Research

As an iconic scenario, it has been argued that France's poor response to the COVID19 pandemic was a sign of the fragmentation of actors, lack of coordination and absence of a global strategy of biomedical research[30].

"La pandémie de la COVID19 a été un puissant révélateur de l'état inquiétant de cette dispersion des moyens et de la complexité de l'organisation et du financement de la recherche en biologie-santé. ***La cacophonie des appels à projets de recherche et la multiplication anarchique du nombre d'essais cliniques engagés le démontrent, 365 pour la France seule soit presqu'autant que les 415 des Etats-Unis (415) ou des 404 de la Grande Bretagne et l'Allemagne réunies (4), mais sans aucune chance d'aboutir à des conclusions fiables en raison des nombreux biais méthodologiques****, en particulier un nombre trop restreint de patients. L'absence de stratégie globale a*

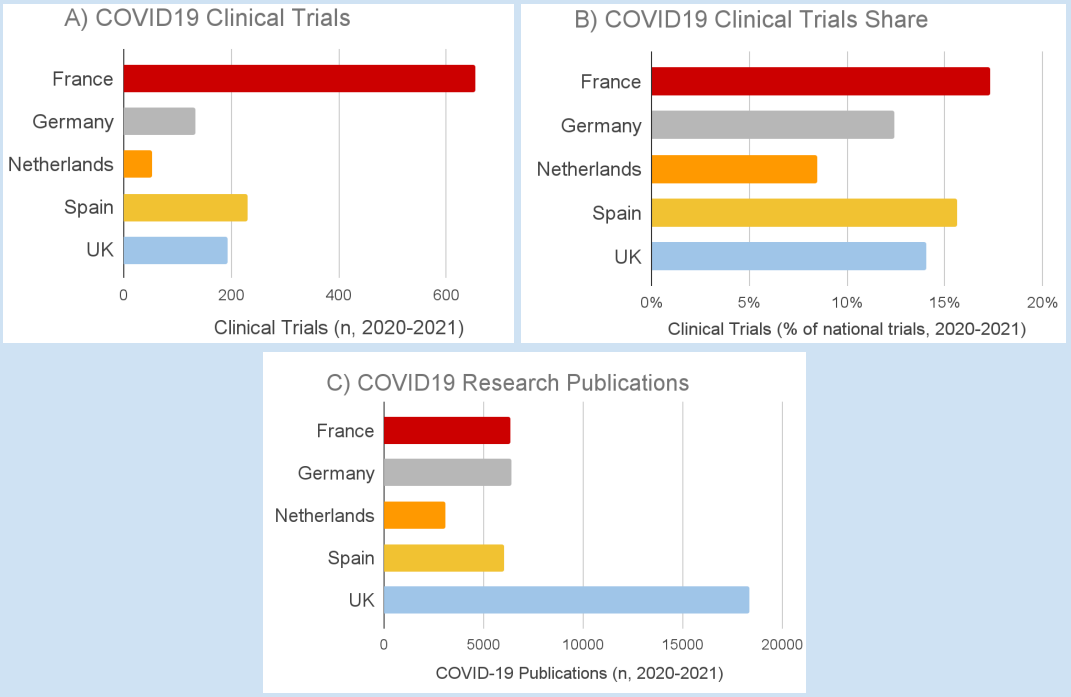
[30] A. Migus, R. Ardaillou, P. Berche, C. Boitard, B. Clément, P. Couvreur, P. Debré, P. Netter - groupe de travail bi-académique de l'Académie nationale de pharmacie et de l'Académie nationale de médecine, « Rapport 21-07. Réformer la recherche en sciences biologiques et en santé: partie II, l'organisation »

donné lieu à la multiplication d'essais souvent dupliqués et à un gaspillage inacceptable des moyens."

When comparing the total number of clinical trials initiated, France is positioned far above all benchmark countries analysed. It also shows slightly stronger dedication at national level to clinical trials in COVID-19, when compared to other countries, accounting for a national share production of clinical trials of >17%, throughout 2020-2021.

In 2020 and 2021, France was engaged in 655 non-industry sponsored COVID19 trials; as compared to 327 of Germany and the UK combined. However, and considering the perceived poor outcome of France´s pandemic response, the higher quantity of trials becomes a greater waste of resources if these are unable to reach solutions for COVID19 care in France and worldwide.

In volume of publications, France published similarly on COVID19 when compared to Germany and Spain, although far below the UK (18.4K from the UK vs 6.4K from France or Germany).



COVID-19 clinical trials (2020-2021): A) *total number of COVID-19 clinical trials;* ***B)*** *COVID-19 clinical trials % of total national clinical trials.* ***C)*** *total number of COVID-19 research publications.*
Source: SIRIS Academic, using ad-hoc vocabulary for Biomedical research and COVID19 of research[31].

Although this information is not conclusive, it does not discredit the idea that fragmentation of actors, lack of coordination and absence of a global strategy may have played a role in France's lack of success in creating COVID therapeutic 19 solutions.

[31] In order to identify the publications and the clinical trials related to COVID19, we gathered the relevant documents by querying PubMed and Clinicaltrials.gov - AACT initiative with the following MeSh terms:

- SARS-CoV-2 (B04.820.578.500.540.150.113.968)
- COVID-19 Testing (E05.200.312)
- COVID-19 (C01.748.610.763.500)
- COVID-19 Vaccines (D20.215.894.899.085)
- Severe Acute Respiratory Syndrome (C01.925.782.600.550.200.750), since the search was only conducted for 2019 and 2020, the risk of including other SARS- like MERS - was minimal.

Part 2. The main institutional players of French biomedical research

Biomedical research requires both clinical and fundamental research functioning in a continuum (not necessarily a linear continuum). This means that there is a need for coordination and exchange between all the institutions/groups that perform different "types" of biomedical research, which is naturally complex. In France, this relies on a triad of actors: Universities - CHUs - Research organisations (such as Inserm)[32].

The intuition is that France's under-performance is, at least partly, due to organisational complexity, which dilutes efforts and diminishes research efficiency. There is also the feeling that the CHU model, once quite successful, is in need of revision, to better align with the growing leadership of universities in terms of research strategy, and in order to prioritise higher quality translational research, possibly by increasing the role of scientific leadership in its governance.

> *"Replacer les CHU comme des acteurs centraux dans le dispositif de la recherche a pour prérequis une évolution de la gouvernance des CHU qui associe au plus haut niveau la dimension recherche aux décisions hospitalières. [...] Des modes de gouvernance ont été mis en place à cet effet dans des structures hospitalières particulières comme les Centres de Lutte contre le Cancer, dirigés par des médecins, ou dans beaucoup de pays européens où la gouvernance des hôpitaux universitaire est assurée par un duo composé d'un directeur administratif et d'un scientifique, comme aux Pays-Bas"*[33].

This section of the report therefore asks a simple question: if we analyse the institutions behind French biomedical research publications do we find evidence supporting these perceptions?

Specifically, the analysis focuses on the following questions:

- What is the contribution of the different French types of actors to biomedical research?
- What is the actual share of basic and translational research vs public health, epidemiology and clinical research at the different types of French institutions?
- What is the rate of Internationalisation and leadership in the different types of French institutions?

And, focusing on the university-CHU relation:

[32] This report focuses on the relation between the Universities and CHUs. Although the link to Inserm is of great importance, considering the high complexities of the French system and its affiliations, specifically those pertaining to this triad, the report does not focus on Inserm, as would require complex analysis that is out of the scope of this specific work.

[33] A. Migus, R. Ardaillou, P. Berche, C. Boitard, B. Clément, P. Couvreur, P. Debré, P. Netter - groupe de travail bi-académique de l'Académie nationale de pharmacie et de l'Académie nationale de médecine, « Rapport 21-07. Réformer la recherche en sciences biologiques et en santé: partie II, l'organisation »

- How does the research at CHUs fare in terms of performance?
- What are the topics of specialisation at CHUs and associated Universities?
- What is the contribution of CHUs and Universities to the main disease groups identified as strong in France? And what is the impact of the research in those disease areas per institution?

All these questions can not be answered if we do not first solve a specific technical difficulty: the possibility to separate the affiliations and, therefore, the different actors of biomedical research, and specifically the CHUs.

Methodological Considerations

Research attribution

Contemporary research, and specifically Biomedical research, is **increasingly conducted in a collaborative environment, which complicates the exact attribution of research credit to specific authors and/or institutions** (and therefore, categories or types of institutions).

This issue is even more complex in systems like France where (i) individual researchers affiliation typically include several institutions that contribute through salary and/or infrastructure cost; (ii) affiliations are often embedded within each others - a classical example being the CHUs, which have a strong institutional identity, but as far as research is concerned, are *de facto* fully embedded within their respective university.

Pursuing the goal of the analysis and considering the idiosyncrasies of contemporary research and the French ecosystem, the following methodological approach - in terms of published research work attribution - was defined:

1. **Only the last author of each publication is considered**: in this way what is attributed to a specific research institution are the publications "originating and/or led" from that institution (and not their collaborative work); this approach helps differentiate the research "originating" from the different *"Affiliation Groups"* (as in the table below) involved in the French biomedical research.

2. **A weighted share is not applied for multiple affiliations of the authors in publications**: i.e. a single publication is equally attributed to all of the institutions stated in the authors affiliations.

3. Similarly, when attributing published research to different *"Affiliation Groups"*: **if a publication shows more than one affiliation, this will be counted as one in each one of the affiliated groups** (e.g. if a publication's last author includes an affiliation of CHU and University and Inserm, this publication will be added to the individual counts of all: CHU, HEI and Inserm - see table below).

Considering these criteria, the affiliations found in French biomedical publications were further categorised in several affiliation groups, that included several similar types of institutions. For example, Higher Education Institutions include all affiliations of

Universities, while the Research Organisation group includes publications with signed affiliation of Inserm and CNRS (without being explicitly an UMR or UM), as well as INRA, IRD and CEA. Importantly, and specifically for the case of UMRs of CNRS or Inserm at Universities: if a publication by a last author from an UMR of Inserm at an University is signed with University, the UMR and CHU this publication will be allocated to all following affiliation groups: HEI, CHU and Inserm. If a last author does not add the UMR affiliation on a publication but does so for the University and CHU, the publication will be added to the HEI and CHU affiliation groups.

The table below represents all the "Affiliation Groups" and types of institutions considered in this study[34]:

"Affiliation Groups"	Institutions included
HEI (Higher Education Institution)	Universities
CHU	University Hospitals (CHUs)
Inserm	Inserm UMRs
CNRS	CNRS UMRs
Cancer centre	CLCCs
Hospital	Hospitals not belonging to the CHU network; private and public
IHU	IHUs
Private sector	Private research/organisations/companies
Public body, association, foundation	Includes EPICs, ETIs and INSA
Research organisation	Inserm (not UMR or UM), CNRS (not UMR or UM), INRA, IRD, CEA
Research Institute	Includes all research institutes not associated with universities and/or hospitals such as Institut Curie, etc.

Affiliations vs reality

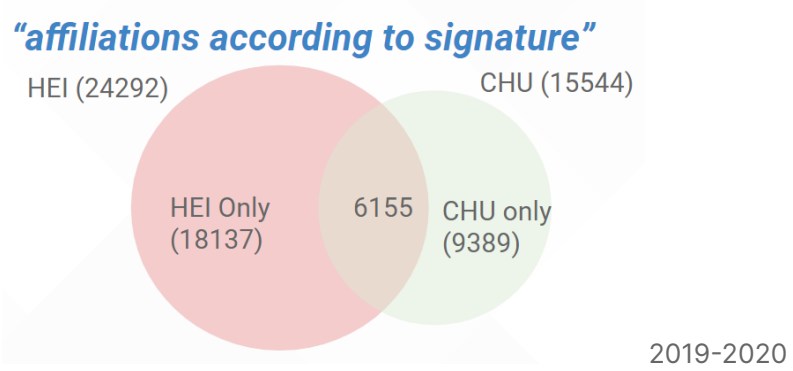
One of the main aims of the present study is to understand what is the **weight of the main types of institutional actors in the French ecosystem**, with a special focus on the Universities and CHUs.

However, when identifying the research produced by the two institutional types through the affiliations that are indicated by each last author on a publication (research group or leader of the research) **we confirmed the existence of a clear problem of feeling of belonging to the universities, which appear through the affiliation practices of CHU authors**.

Nearly all authors mentioning a CHU affiliation should also indicate a university affiliation, since most are employed by a university. However, this is far from the case, as we found that a considerable percentage of all publications of CHU´s last authors

[34] Identification and proper allocation was manually verified, based on the ScanR tool provided by the MESRI, and validated by France Universités' team. All institutions with more than 50 publications in both 2019 and 2020 were considered.

did not mention the university affiliation.



Source: SIRIS Academic, using ad-hoc vocabulary for Biomedical research

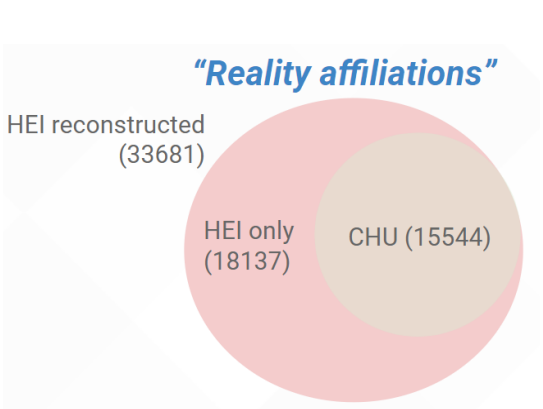
In order to portrait the French ecosystem in a more truthful manner in light of the above, the study made the following assumption:

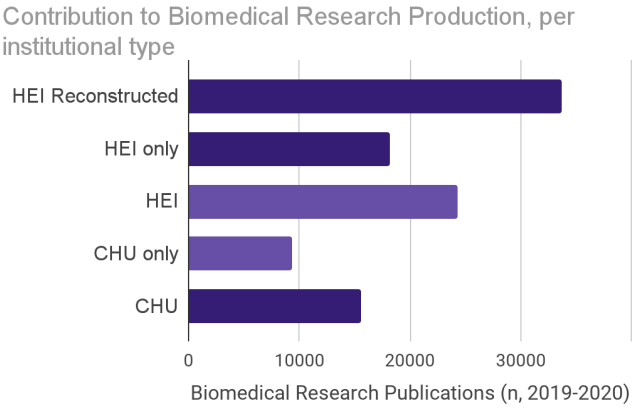
- all publications where the author has indicated only the CHU should in fact be considered as belonging both to CHU and to Universities.

Based on this assumption, the study consequently followed the premise of a "corrected" Venn diagram that is altered in the following manner (see below):

- HEI Reconstructed: unifying HEI and CHU research
- HEI only: the research conducted exclusively in the Universities, **hereinafter referred to as "Universities" or as "HEI only"**
- CHU: the research conducted in the CHUs (regardless of HEI relation being made explicit or not), **hereinafter referred to as "CHUs"**

For this study, and as an approximation of reality, these categories were mainly used.





Source: SIRIS Academic, using ad-hoc vocabulary for Biomedical research (2019-2020).

2. 1. Research volume, internationalisation and leadership

Higher education institutions (and associated CHUs) contribute to more than 60% of all biomedical research in France (33% and 29%, in Universities and CHUs respectively)(*Fig. 14*).

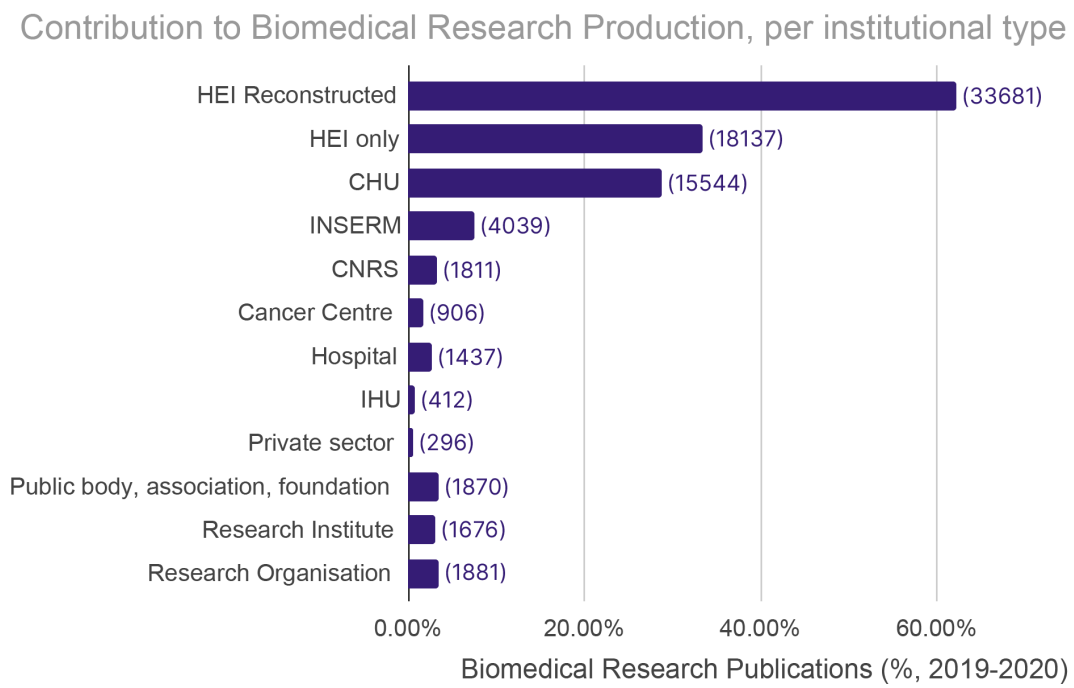


Fig. 14 French publications per institutional type group (2019-2020): *as in share of France - % of total, (numbers overlaid are the raw number of publications).*
Source: SIRIS Academic, using ad-hoc vocabulary for Biomedical research

The contribution of most institutions by research type is as expected, with the CNRS publishing substantially more in basic and translational research; CHUs and Hospitals in public health, epidemiology and clinical research and university groups (without CHU affiliation) publishing more in basic and translational research (*Fig. 15*):

- the CNRS and Research Organisations publish more on basic & translational research (70% and 80%, respectively);
- CHUs and Hospitals have a higher number of publications in public health, epidemiology and clinical research (around 75%).
- Universities publish more in basic & translational research (67%)
- Regarding specialised institutions, Cancer centres show higher scientific production in public health, epidemiology and clinical research (66%), while IHUs publish equally in both types of research.

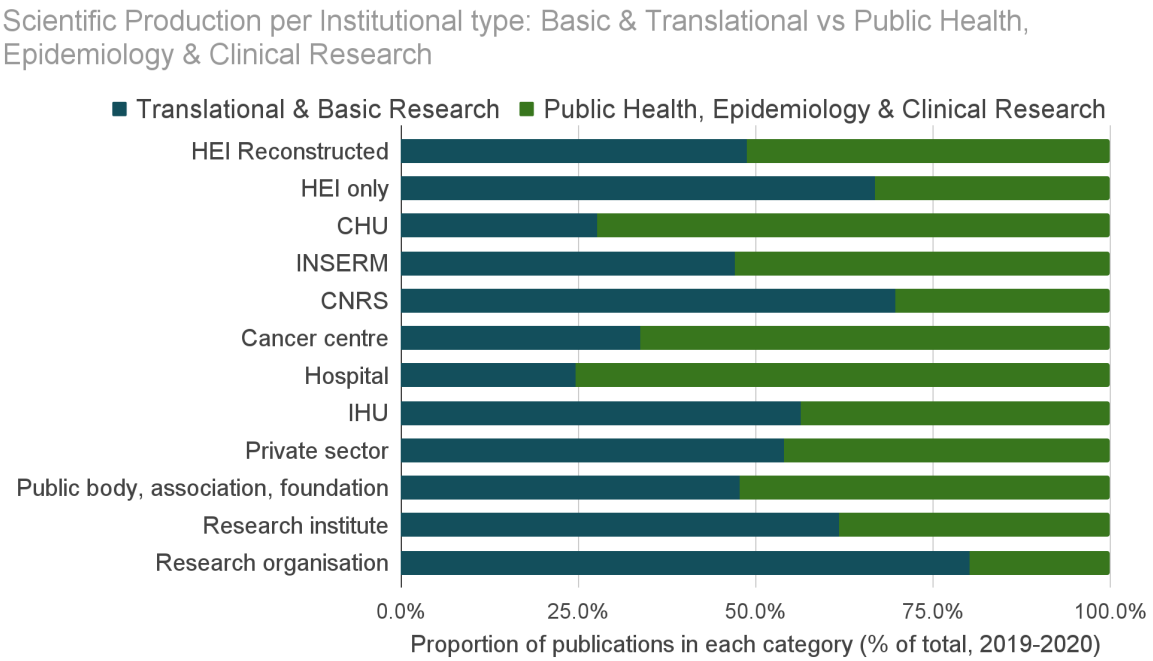


Fig. 15 Share of biomedical research publications by research type and per institutional type (2019-2020).

Source: SIRIS Academic, using ad-hoc vocabulary for Biomedical research and Research Type (see Methodology section for more details)

In terms of internationalisation[35] and leadership[36], we find that **CHUs and Hospitals have the lowest share of publications with international partners** (around 45%, while all other actors have >50% share) and, simultaneously, the **highest share of publications led as first or last author** (66% and 70%) (*Fig. 16A*).

An increased capacity to lead, although in itself good, is also often a trade-off that indicates reduced collaborative work, which may decrease international visibility, peer recognition and research excellence. It should be noted, however, that both CHUs and HEI are much larger contributors of research and therefore there may be very different practices taking place within each University or CHU.

Inserm, CNRS and IHUs show a fairly balanced distribution of leadership and internationalisation, showcasing the capacity to collaborate internationally, without losing the capacity to lead. While research institutes and cancer centres have a higher international collaborative profile, and consequently a lower share of leadership positions (although still significant, around 45%) (*Fig. 16A*).

The pattern of internationalisation and leadership does not change substantially for each institution when just basic & translational or public health, epidemiology and clinical research are considered (*Fig. 16B-C*). However, there is overall slightly lower internationalisation for research within the more clinical fields for most institutional types (mostly below 60% except for public bodies and the specific case of the private

[35] Using as proxy the share of publications that include at least one international institution in co-authorship.
[36] Using as proxy the share of publications in which the institution of relevance is part of the first or/and last author affiliations.

sector), as well as a similarly lower level of leadership (*Fig. 16B-C*).

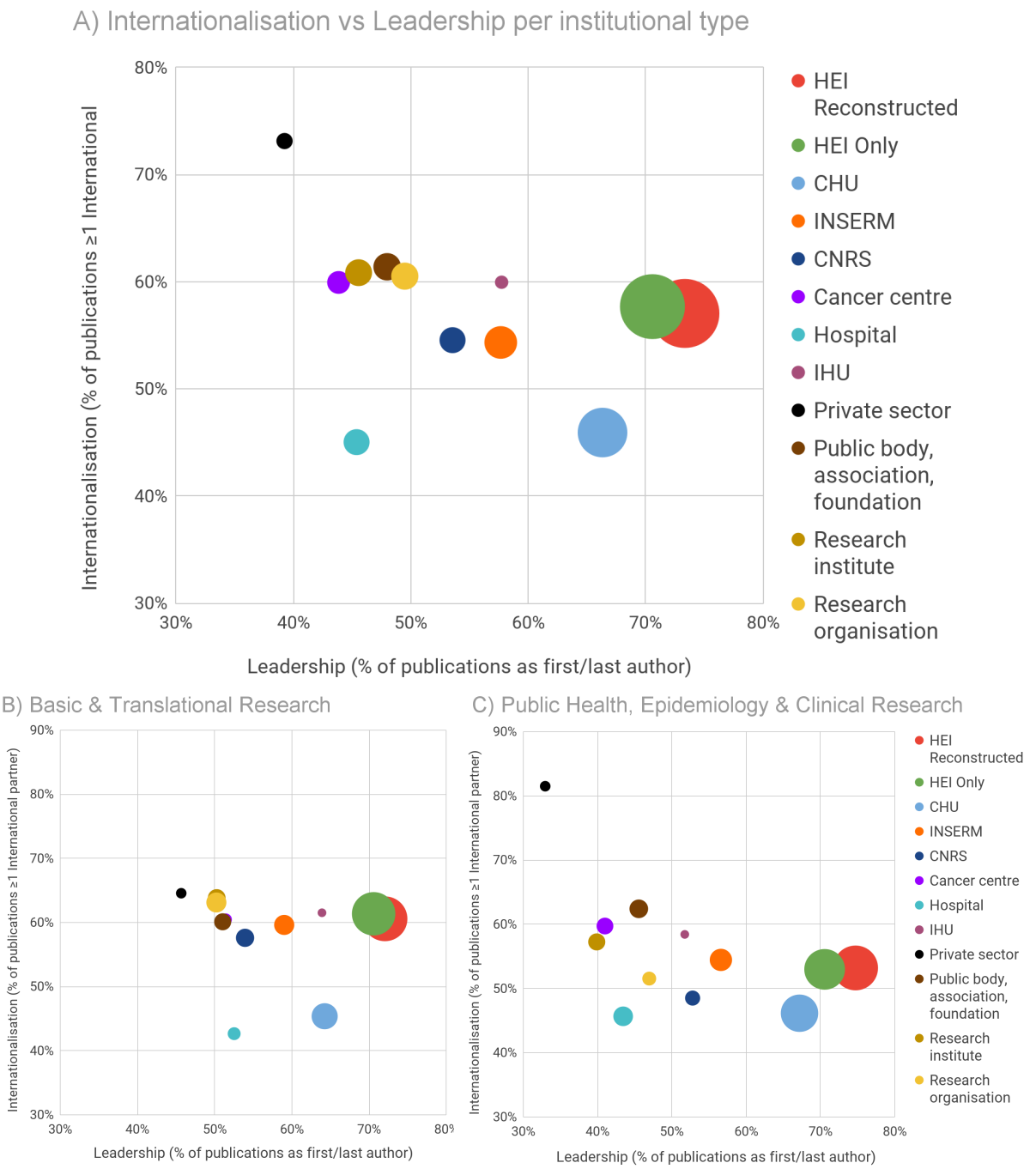


Fig. 16 Internationalisation vs leadership per Institutional type and research type (2019-2020): *percentage of publications with more than one international partner versus percentage of publications led by a French researcher (dot size is relative to the total number of documents in biomedical research per institutional type), in **A)** all publications or **B)** and **C)** those categorised by research type.*
Source: SIRIS Academic, using ad-hoc vocabulary for Biomedical research and Research Type (see Methodology section for more details)

As expected, more than **60% of biomedical research in France originates from the combined Universities and CHUs**; with Universities dedicating more to basic and translational research and CHUs dedicating approximately 75% of research activities to clinical research, as predicted.

CHUs and Hospitals display a lower international profile in research with simultaneous higher leadership; while other institutional types show a fairly balanced distribution of leadership and internationalisation, showcasing the capacity to collaborate internationally, without losing the capacity to lead.

2.2. Scientific Impact and visibility

The definition of research impact is complex and not consensual. The present study focuses on the following measures of scientific impact: citations per document/publication and the capacity to publish in top tier journals of the Scimago ranking (understanding that there is also a *perceived* quality of these journals); it does not claim to measure or assess anything else.

Citation behaviours are distinct for basic & translational research vs the clinical research domain. The latter generally has a dichotomy of highly cited studies (e.g. big clinical collaborative studies on major diseases) and very low cited research (e.g case studies or regional public health studies); while research categorised as basic research tends to have a more uniform type of studies. This pattern is reflected in the citation metrics we see for Fundamental and Clinical research in Universities and CHUs.

A first measure of impact is one that deals with the ability to publish in specific journals. Although using scientific impact measures such as the share of publications in top journals according to the Scimago ranking has limitations[37] - especially when comparing different types of institutions -, it is helpful to have a breakdown of the scientific impact by type of institution in comparison to what has been observed for France's overall scientific impact.

It is of note that, of the biggest contributors in biomedical research (the Universities+CHU group) the CHUs themselves are those with the lowest percentage of publications in Top 10% of Scimago journals, possibly due to the type of research that is performed at these institutions (e.g clinical case studies) (*Fig. 17*).

Because i) Universities and CHUs are the biggest contributors of biomedical research in France, ii) comparisons of performance with very different institutional types (with different sizes, missions, and/or resources) such as IHUs or cancer centres would not

[37] The SCImago Journal Rank (SJR) measures the scientific influence of scholarly journals and accounts for both the number of citations received by a journal and the importance or prestige of the journals where the citations come from. Its caveats are mainly linked to the fact that:

- it relates to *journals* (and not individual publications), so is not directly measuring the scientific impact of a concrete group of publications, but is rather an indirect measure - through the journals the work is published in (which is famously more linked to author's and institutional visibility, prestige and credibility; and even trending versus outdated topics - than actual research quality);

be reliable or fair, Universities and CHUs (and Inserm, to which these are associated), are the focus for the remainder of this section.

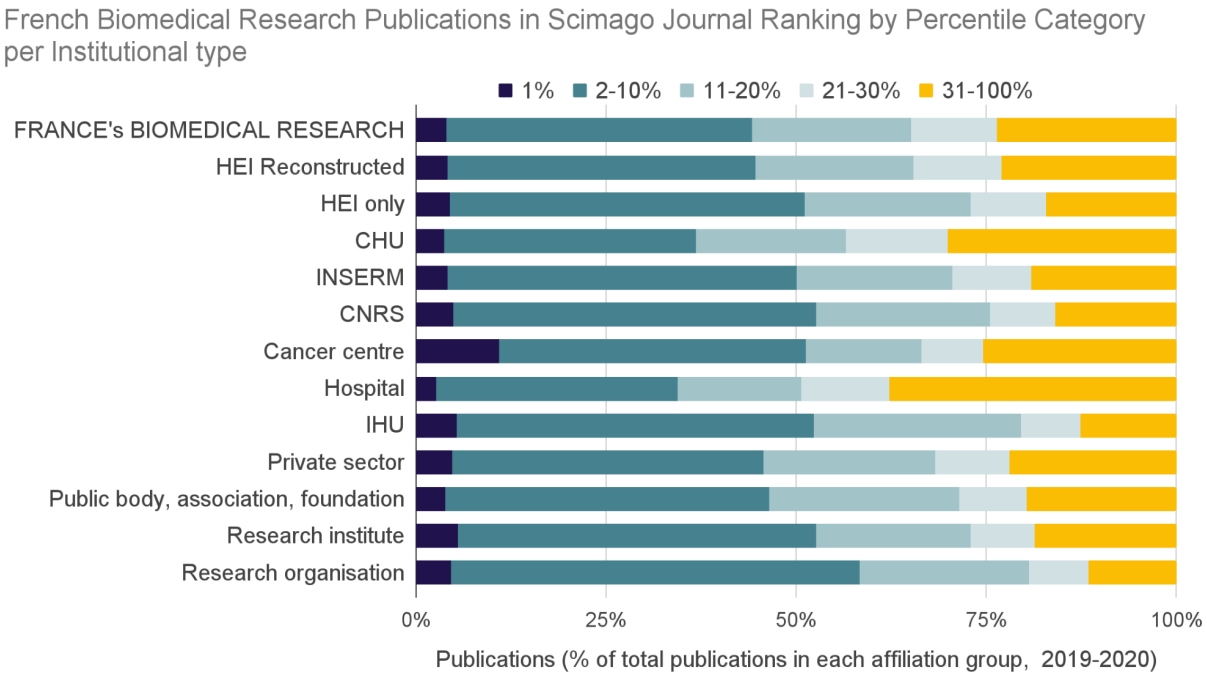


Fig. 17 French Biomedical research capacity to publish in top journals, per institutional type (2019-2020): *share of publications per citation percentile of their publishing journals ,according to Scimago ranking, per institutional type.*
Source: SIRIS Academic, using ad-hoc vocabulary for Biomedical research and Scimago SJR.

In order to have a better (and more direct) understanding of the scientific impact of these groups, the study also analyses the degree to which the publications produced by each are being cited.

In agreement to what was seen for the metric based on Scimago Journal Ranking, research from **CHUs receives the lowest rate of citations**, with a lower number of citations per publication on average (*Fig. 18A*), and with two thirds of the publications gathering less than 5 citations **in both research types** (*Fig. 18B*).

This indicates a lower impact in and/or lower interest from their communities; and, as before, could be due to the type of studies performed at CHUs, since clinical research performed by Inserm/university groups can represent different types of studies that have different citation behaviours.

Basic and translational research at Universities and Inserm gather slightly better citation metrics (8.5-10.8% of publications have >20 citations) than seen for public health, epidemiology and clinical research (7.4-7.7% with >20 citations) (*Fig. 18B*).

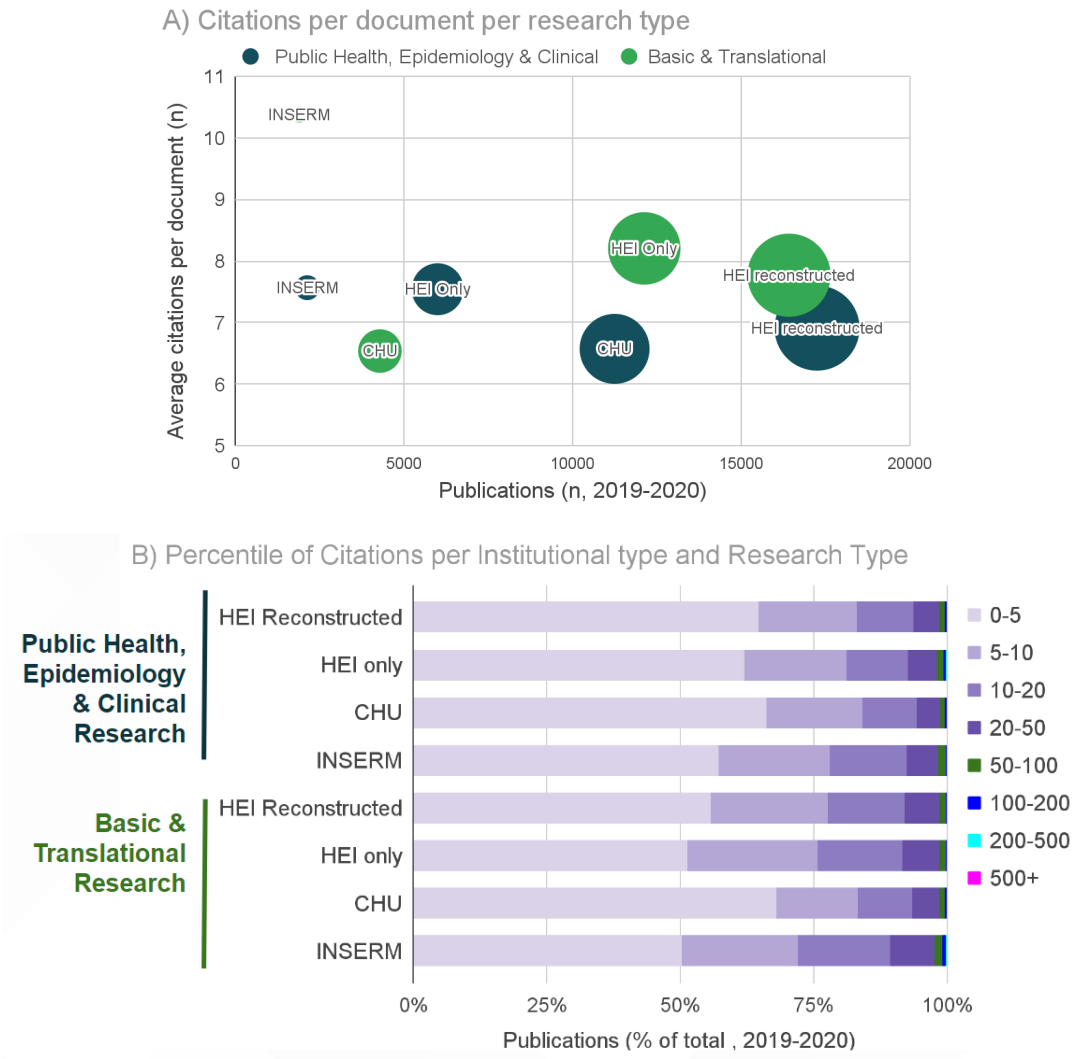


Fig. 18 Citation Metrics for France affiliations per research type *(2019-2020):* ***A)*** *Mean citations per publication (size of dot related to number of publications)* ***B)*** *share of publications by citation range/percentile per, both per institutional type and research types (citation range from 0 to 500+).*
Source: SIRIS Academic, using ad-hoc vocabulary for Biomedical research and Research Type (see Methodology section for more details).

CHUs do not fare well in the scientific impact of their publications, and especially so in basic and translational research, **having citation metrics below Universities and Inserm in both research types.** The low citation metrics in basic and translational research suggests that there is not a focus on excellent translational research in the CHUs, even if the dedication to this research type is expected to be low.

2. 3. Topics of Specialisation of Universities and CHUs

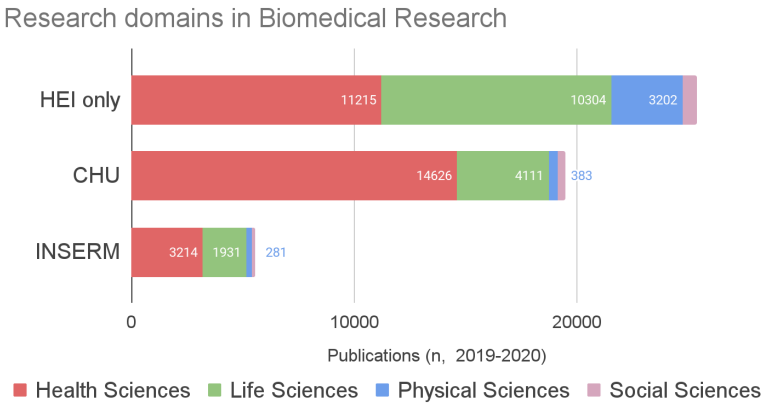
This study aims to assess the contribution and performance of the CHUs in relation to the Universities to which they are associated. One of the key discussions occurring in France and highlighted in recent reports is whether the current CHU model is impacting not only the execution of translational research but also the type of research taking place in the Universities-CHUs-Inserm research ecosystem.

> *"La difficulté de mise en œuvre des recherches translationnelles en biologie-santé dans toute leur continuité, comme, celle plus générale, de mener des recherches pluridisciplinaires, n'est pas spécifique à la France. Favoriser de telles approches nécessite un travail continu, dépendant aussi bien de la volonté des personnels de la recherche de sortir du confort de leur sillon disciplinaire, que de leur formation et surtout de la structuration de la recherche et des processus d'attribution des moyens et d'évaluation"*[38].
>
> *"À l'interface, la recherche translationnelle, qui doit mobiliser à la fois les connaissances fondamentales et les études cliniques et thérapeutiques relève de l'ensemble des acteurs"*[39].

This section provides elements to address three questions:

- Where is multidisciplinary or interdisciplinary research being produced?;
- What are the topics being researched?, and
- Is there any alignment between the research being done in Universities and CHUs?

Universities (HEI only) **and CHUs show distinct biomedical research dedication patterns**: CHUs are significantly less dedicated to Life Sciences (only ¼ of their research), and even less so to Physical Sciences (only 2%); specially when compared to the Universities which harbour a more varied and multidisciplinary and interdisciplinary research (including 18% with contribution of the Physical Sciences) (*Fig. 19*).



[38] A. Migus, R. Ardaillou, P. Berche, C. Boitard, B. Clément, P. Couvreur, P. Debré, P. Netter, au nom d'un groupe de travail bi-académique de l'Académie nationale de pharmacie et de l'Académie nationale de médecine, *Rapport 21-07. Réformer la recherche en sciences biologiques et en santé: partie II, l'organisation*.

[39] Le rôle des CHU dans l'enseignement supérieur et la recherche médicale - Dec 2017, Cour des comptes

	Share of biomedical research publications (% of each institutional type)[40]		
	HEI only	CHU	Inserm
Health Sciences	62%	94%	80%
Life Sciences	57%	26%	48%
Physical Sciences	18%	2%	7%
Social Sciences	4%	2%	4%

Fig. 19 Overall biomedical research dedication per main institutional types (2019-2020): *absolute values and share of each institutional type biomedical research per Scopus cluster (% of total).*
Source: SIRIS Academic, using ad-hoc vocabulary for Biomedical research, as well as their classification in the 5 main domains existent in Scopus' categorization system (Cluster - 1st level of Scopus classification).

Furthermore, when compared to the national baseline, **Universities are more specialised**[41] **in Life sciences fields** *(Fig. 20)* **and more prone to interdisciplinary research** (fields in the Physical Sciences - *Fig. 21*); **while CHUs are almost exclusively specialised in the Health Sciences fields** *(Fig. 20)* **and not particularly interdisciplinary** - although having a higher volume of research in the social sciences than Universities *(Fig. 21,* where bigger size of dots represent bigger research volume*)*.

There is, however, one interesting exception to this pattern: Public health is in fact a specialisation of the Universities, despite it being classified in Health Sciences. In this context, there is clearly a problematic gap in terms of health-related research flow between Public Health Schools and Medical Schools, which is also reported in other countries[42].

Specifically, and compared to French Biomedical research, research from Universities is more likely to include many aspects of the Physical Sciences (mainly chemistry, computer sciences, but also bio-engineering, material sciences and environmental sciences), as well as cognitive sciences, while the biomedical research performed at the CHUs is not specialised in any topic of Physical or Social Sciences (*Fig. 21*).

Overall, this almost exclusive dedication to Health Sciences topics and lack of interdisciplinarity of research originating from the CHUs may be indicative of its lower capacity at performing translational research.

[40] The sum for each institutional type is above 100% due to the fact that each journal, and therefore publications, in Scopus database can belong to more than one domain.
[41] Here only predominant Scopus fields (with approximately >500 publications in Health Sciences and in Life Sciences; and >100 on Physical Sciences) were analysed to compose the pattern of specialisation per fields for the "HEI only" and "CHU", since the goal was to have a birds-eye view of how both institutional types compare.
[42] Ruis, A R. MA; Golden, Robert N. MD. The Schism Between Medical and Public Health Education: A Historical Perspective. Academic Medicine 83(12):p 1153-1157, December 2008. | DOI: 10.1097/ACM.0b013e31818c6583

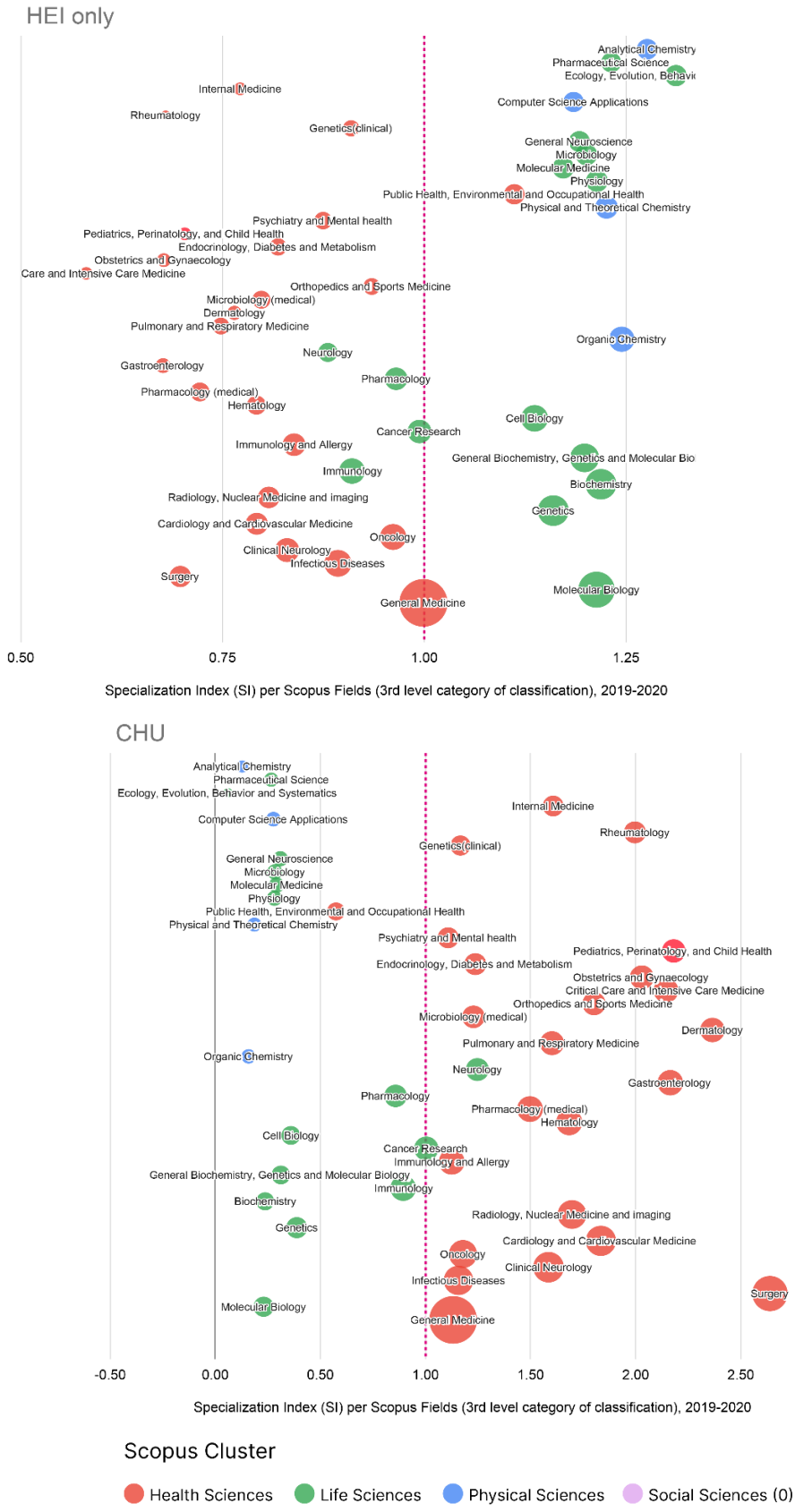


Fig. 20 Specialization Index of biomedical research in the major Scopus Fields *(>530 publications)* ***for HEI Only and CHUs, all Scientific domains****: baseline* ***France****, size of dots relative to the number of publications in 2019-2020.*

Source: SIRIS Academic, using ad-hoc vocabulary for Biomedical research and Scopus categorization system (Clusters - 1st level of Scopus classification, and Fields - 3rd level of Scopus classification.

***Fig. 21 Specialization Index of biomedical research in the major Scopus Fields** (>100 publications) **for HEI Only and CHUs, only in Physical and Social Sciences**: baseline **France**, size of dots relative to the number of publications in 2019-2020.*

Source: SIRIS Academic, using ad-hoc vocabulary for Biomedical research and Scopus categorization

system (Clusters - 1st level of Scopus classification; Fields - 3rd level of Scopus classification). A SI=1 means that the institutional type is specialised on, on average, the same as the whole of France; A SI around 2 would mean that they are twice more specialised than France as a whole.

Both Universities and CHUs show a fairly similar pattern of research production in the disease groups previously identified as strong in France (*Fig. 22*). It is interesting, nevertheless, that there is a reasonable percentage of research in diseases in universities (HEI only).

Of these areas, there is a slightly higher contribution of CHUs to cardiovascular and hemic & lymphatic diseases, a pattern which is probably linked to its clinical setting (*Fig. 22*).

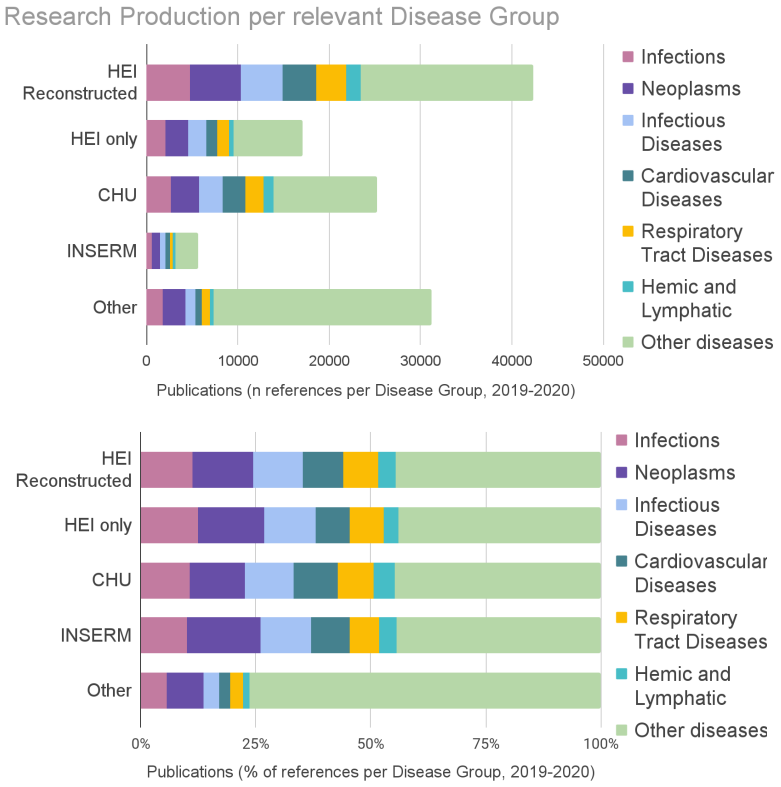


Fig. 22 Biomedical research production per disease area per institutional type (2019-2020): A) *total number of references to disease groups in publications per institutional type;* ***B)*** *percentage of references to disease groups in publications per institutional type.*

Source: SIRIS Academic, using ad-hoc vocabulary for Biomedical research and NIH-NLM MeSh Taxonomy - specifically the MeSH terms that can be found in the C-Diseases and F03-Mental Disorders branch of the MeSH NIH-NLM taxonomy). Documents can be classified in several disease groups (e.g. research in Asthma will classify as an immune and respiratory disease).

When analysing the scientific impact of the research on Disease Groups by the different institutional types (*Table 2*), the following insights emerge (here focusing on major contributors such as CHU and Inserm):

- Despite overall lower scientific impact metrics, CHUs actually have a higher share of their publications on these major diseases in the Top 1-10% , when compared to HEI. This seems specific, and probably due to the quality and/or high impact clinical research being conducted in CHUs in these major conditions.
- CHUs and Inserm display the highest proportion of publications in Top 2-10%

Scimago in Cardiovascular Diseases and Infections; while Inserm´s publications have the highest scientific impact in the fields of Neoplasms and Nervous System Diseases.

- All groups have a reasonable contribution in publications in Top 1-10% in Infectious diseases and Cancer (Neoplasms).
- In disease areas in which CHUs produce more and there is a significant share in top tier journals (Top 1-10%), such as in research in Cardiovascular and Hemic & Lymphatic diseases, there is also a significant share of research in the lowest tier journals (Top 31-100%). This suggests significant variability in terms of the recognition of the research from CHUs and that is not seen, for the same areas, on research originating from Inserm, for example (in which research is published more in top tier journals).

		Publications in Scimago Journal Rankings Percentiles (% off institutional type total)				
Disease Group	**Institutional type**	**1%**	**2-10%**	**11-20%**	**21-30%**	**31-100**
Cardiovascular Diseases	HEI Reconstructed	0.5%	4.1%	1.9%	1.6%	2.9%
	HEI Only	0.4%	2.9%	1.3%	0.9%	1.4%
	CHU	0.7%	5.4%	2.6%	2.4%	4.7%
	Inserm	0.8%	4.9%	2.1%	1.9%	1.2%
	Other	0.2%	2.0%	0.8%	0.6%	1.6%
Hemic and Lymphatic Diseases	HEI Reconstructed	0.2%	1.7%	1.0%	0.6%	1.4%
	HEI Only	0.2%	1.1%	0.6%	0.3%	0.7%
	CHU	0.3%	2.3%	1.4%	1.0%	1.6%
	Inserm	0.4%	2.3%	1.0%	0.5%	0.6%
	Other	0.2%	1.1%	0.6%	0.3%	0.8%
Infections	HEI Reconstructed	0.5%	5.7%	3.1%	1.5%	3.0%
	HEI Only	0.4%	5.2%	2.7%	1.0%	2.1%
	CHU	0.6%	6.3%	3.5%	2.0%	3.1%
	Inserm	0.5%	6.4%	3.2%	1.4%	1.3%
	Other	0.4%	4.1%	2.9%	0.7%	2.0%
Neoplasms	HEI Reconstructed	1.0%	5.8%	3.1%	1.9%	4.5%
	HEI Only	0.9%	5.9%	2.5%	1.4%	2.9%
	CHU	1.1%	5.7%	3.8%	2.5%	4.8%
	Inserm	1.2%	9.7%	4.5%	2.3%	3.3%
	Other	1.6%	6.9%	3.2%	1.8%	4.8%
Nervous System Diseases	HEI Reconstructed	0.5%	4.8%	2.7%	1.8%	3.6%
	HEI Only	0.4%	4.4%	2.2%	1.2%	2.2%
	CHU	0.5%	5.2%	3.2%	2.6%	3.7%
	Inserm	0.5%	7.4%	2.8%	1.6%	1.8%
	Other	0.3%	2.2%	1.1%	0.8%	1.7%
Respiratory Tract Diseases	HEI Reconstructed	0.4%	3.6%	1.9%	1.0%	2.5%
	HEI Only	0.4%	2.8%	1.4%	0.7%	1.7%
	CHU	0.5%	4.6%	2.5%	1.5%	2.8%
	Inserm	0.4%	3.7%	2.0%	0.9%	1.2%
	Other	0.4%	2.2%	1.1%	0.4%	1.3%
Other Diseases	HEI Reconstructed	4.0%	39.8%	20.5%	11.4%	22.4%
	HEI Only	4.4%	45.9%	21.6%	9.9%	16.6%
	CHU	3.5%	32.6%	19.3%	13.3%	29.2%
	Inserm	4.1%	45.2%	20.1%	10.3%	18.6%
	Other	4.8%	44.1%	20.9%	7.3%	19.6%

Table 2. Percentage of disease group publications in its journal percentile category, according to the Scimago Journal ranking, over the total biomedical research publications of each institutional type (2019-2020).

Source: SIRIS Academic, using ad-hoc vocabulary for Biomedical research and NIH-NLM MeSh Taxonomy - specifically the MeSH terms that can be found in the C-Diseases and F03-Mental Disorders branch of the MeSH NIH-NLM taxonomy). Documents can be classified in several disease groups (e.g. research in Asthma will classify as an immune and respiratory disease).

Universities and CHUs show different specialisation patterns: **Universities are more dedicated to and specialised in Life sciences, as well as more prone to interdisciplinary research** (mainly in fields of the Physical Sciences)**, compared to CHUs, which are mainly dedicated and specialised in Health Sciences fields.**

CHUs have a proportionally higher volume of research per disease group than other organisations. It is interesting to note that although producing more in basic and translational research, university groups have a reasonable percentage of research in diseases; likely in fields such as molecular basis of disease or disease models.

Despite an overall lower scientific impact in both fundamental and clinical research, **in research on these major disease groups, CHUs actually have a higher share of their publications in the Top 1-10%, when compared to Universities**.

There are only slight difference in terms of specialisation per disease groups between the major institutional types: CHUs and Inserm display the highest proportion of publications in Top 2-10% Scimago in Cardiovascular Diseases and Infections; while Inserm publications have the highest scientific impact in the fields of Neoplasms and Nervous System Diseases; While the **national specialisation in infectious diseases and cancer is distributed through all institution types** (CHUs, Universities, Inserm and others), with all having a reasonable contribution in publications in Top 1-10%.

Methodology of the Bibliometric Analysis

The present report relies exclusively on bibliometric data or information, extracted from Pubmed and Scopus databases over the period 2010-2020. Specific ranges within this time window (2015-2020 and 2019-2020) were chosen according to the questions being addressed and the limitations of the analysis carried out (in terms of volume of information).

How to Identify the Biomedical domain

Analysing Biomedical Research with current categorisations often limits the scope of the biomedical field. For example, using Scopus' "Health Sciences" cluster will exclude relevant areas assigned to "Life Sciences", such as Immunology and Molecular Biology. Likewise, Pubmed's database includes other life sciences areas, closely related but not strictly biomedical.

To go beyond these limitations, this study relies on *ad-hoc* semantic techniques. They are more time-consuming and require expert validation, but hopefully provide a more precise grasp of the domain.

In this context, and whenever possible, two controlled vocabularies (VOC)[43] have been used to identify *Biomedical Research*, and then separate *Basic & Translational* from more *Applied Research*.

The Biomedical Research Controlled Vocabulary

In this study we have used a controlled vocabulary developed by SIRIS, which encompasses the whole spectrum of the biomedical field, from fundamental research, on the cellular basis of health and disease, to classical clinical research and epidemiology, while excluding some aspects of life sciences such as ecology and evolution studies (see visualisation below).

What is a Controlled Vocabulary (VOC)?

Specific VOCs in Biomedical Sciences have been created by SIRIS Academic with field experts. Their construction starts with the definition of a conceptual map that depicts the perimeter to be included in a given vocabulary. Typically, controlled vocabularies are composed of a list of unequivocal terms that fully represent a domain; and in Biomedical research domains they are based on specifically selected keywords from an existing thesaurus: MeSH Taxonomy. The title, abstract and/or author keywords of publications are then scanned with the vocabulary to see whether or not they pertain to the domain under study. In order to minimise error, the

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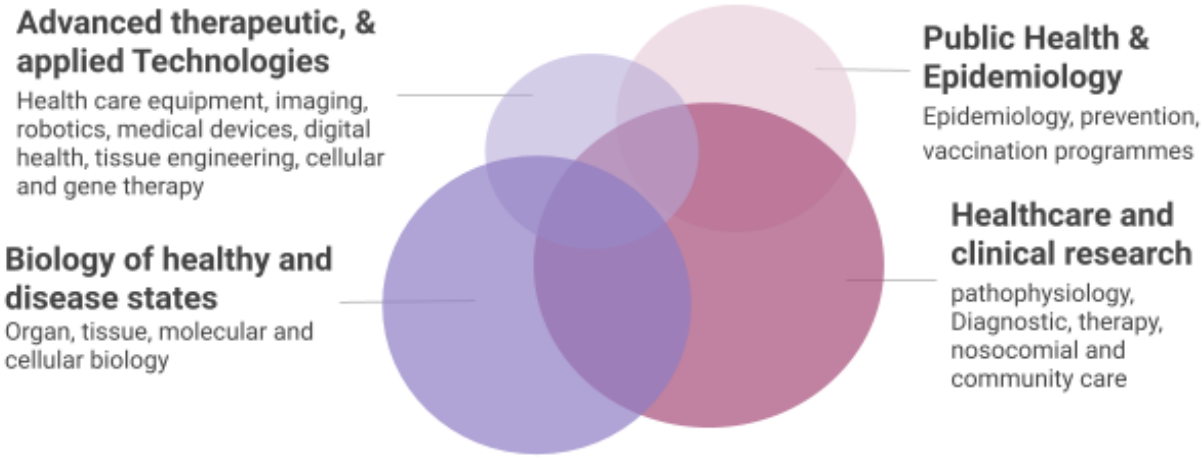
vocabularies are submitted to several rounds of testing linked to iterations (normally between five and ten), to achieve quality performance: <5% False positives, <1% False negatives.

The Biomedical Research Vocabulary used in this study is composed of (>36 000 terms).



Biomedical Research Controlled Vocabullary_Conceptual Map

This perimeter is also the closest related to the field of "Biologie-Santé" or "biomédicale" (vs "médicale") in France. This controlled vocabulary was used to filter Pubmed and create an accurate corpus of publications on biomedical research for France and benchmarks, that was subsequently used in the analyses.
However, in some analysis where it was not possible to use our Biomedical Research VOC, we have delimited the perimeter by using a specific selection of Scopus Health and Life Sciences Areas[44], to approximate our perimeter as much as possible. We have used:

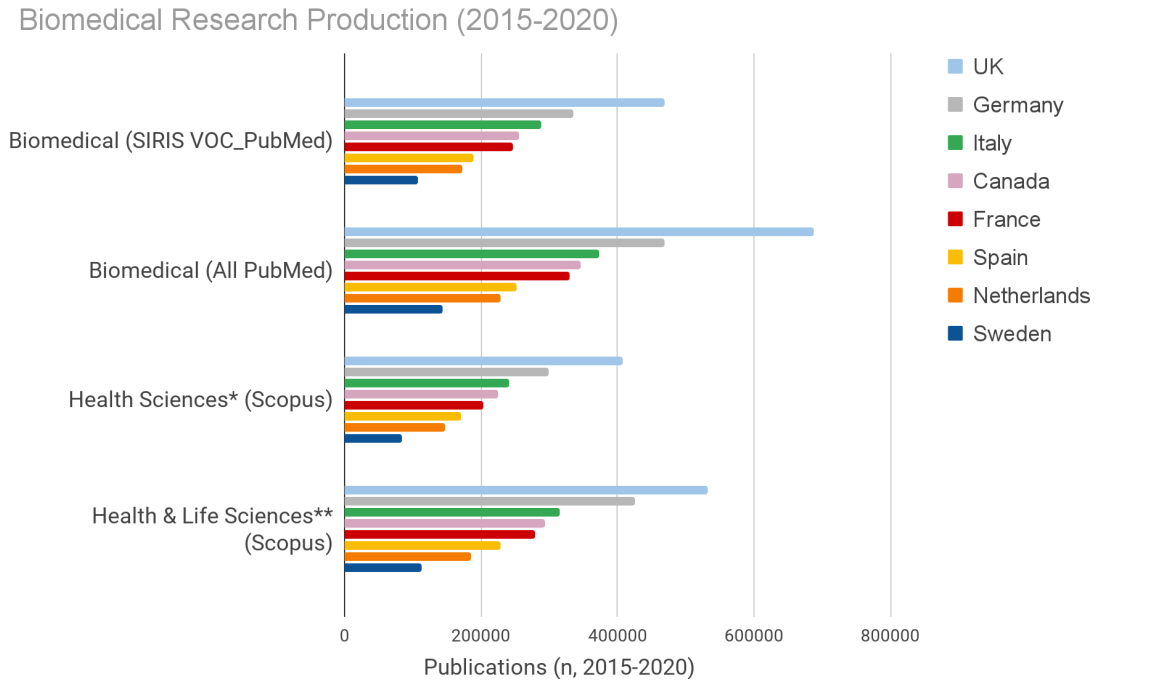
- From Health Sciences, the areas of: Medicine, Nursery, Dentistry, Health professions (excluding Veterinary)
- From Life Sciences, the areas of: Biochemistry, Genetics and Molecular Biology, Immunology and Microbiology, Neurosciences and Pharmacology, Toxicology and Pharmaceutics (excluding Agricultural and Biological sciences)

The following plot shows a comparison between the different data sources and approaches to delimiting Biomedical Research, showing that they are comparable in

[44] What are Scopus subject area categories and ASJC codes? (elsevier.com)

tendencies and magnitude, even if not completely equivalent.

For this study, as Biomedical Research Publications we used mainly those categorised by SIRIS (applying our Biomedical Research VOC) in PubMed Database and, when not possible for technical reasons, Scopus Health & Life Sciences Selected Areas.



Comparison between the number of publications identified through different approaches and databases, for different countries (2015-2020).

** Selected Health Sciences Areas: Medicine, Nursery, Dentistry, Health professions*

*** Selected Health & Life Sciences Areas: Medicine, Nursery, Dentistry, Health professions, Biochemistry, Genetics and Molecular Biology , Immunology and Microbiology, Neurosciences and Pharmacology, Toxicology and Pharmaceutics*

The Basic & Translational vs Applied research Controlled Vocabulary

In this study, a second Controlled Vocabulary developed by SIRIS was applied in order to distinguish between basic and translational research on the one hand, and public health, epidemiology and clinical research on the other. This was relevant for two reasons:

i. these two types of research have different publishing behaviours and citation metrics, the distinction and separation of publications in these two broad categories thus allows us to make fairer and more accurate comparisons across the same type of research;

ii. one of the concerns that has been raised is that France is specifically lagging in the ability to do translational research; with this tool we can thus try to address that perception within the analysis presented in this study.

This vocabulary identifies within a set of publications those that are related to *Public health, Epidemiology and Clinical Research*, and, by exclusion, the remaining is

considered *Translational and Basic Research*. The distinction is based on criteria and topics shown below.

For this study, we applied this vocabulary on the biomedical research set of publications, for France and benchmarks, as well as those identified for each institutional type, as required for each question to be addressed.

Public Health, Epidemiology and Clinical Research	Translational and Basic Research
✓ Clinical trials ✓ Research regarding patients treatment protocol ✓ Research implicating patients directly ✓ Research with patient samples as central feature (genetics of disease, biomarkers, prognostic markers, diagnostic from the application point-of-view) ✓ Epidemiology, Global Health & Public Health ✓ Medical guidelines ✓ Mental Disorders ✓ Cultural/socioeconomic impact on Health ✓ Health Literacy, Health promotion & QOL ✓ Health Education ✓ Health Policy	✓ Study of processes or diseases with the *intent to treat* ✓ Drug and vehicle development (since they have a therapeutic target) ✓ Preclinical models (including advanced ones like sheep and pig) ✓ With patients samples only as proof of concept, as in tumor samples/biobank usage which is not central to the paper; or to establish research pre-clinical models (*e.g* cell lines, organoids) ✓ Tissue, Cellular & Molecular basis of disease ✓ Tissue, Cellular & Molecular understanding of biological mechanisms ✓ Development of applied techniques - at protein, chemistry, molecular, or cellular level

Analysing biomedical topics

Based on Scopus' Science Journal Classification Codes (ASJC)

Scopus uses a classification system (ASJC) that organises research into large domains and sub-topics, in a hierarchical fashion. It is based on the journals' self-description, and each journal can belong to more than one category.

Scopus subject categories organise published documents into larger clusters (1st level), areas (2nd level) and fields (3rd level).

The publications analysed in this study: i) either all research of a certain country or group, ii) all the biomedical research identified through SIRIS' controlled vocabulary, or ii) any specific sub-group of publications, will have been classified by Scopus into ASJC, so we can exploit that information to analyse research dedication and specialisation of any given group.

Cluster	Areas	Fields (e.g. Immunology & Microbiology)
Health Sciences	Dentistry	
	Health Professions	
	Medicine	
	Nursing	

	Veterinary	
Life Sciences	Agricultural and Biological Sciences	*General Immunology and Microbiology* *Immunology and Microbiology (miscellaneous)* *Applied Microbiology and Biotechnology* *Immunology* *Microbiology* *Parasitology* *Virology*
	Biochemistry, Genetics and Molecular Biology	
	Immunology and Microbiology	
	Neuroscience	
	Pharmacology, Toxicology and Pharmaceutics	
Physical Sciences	Chemical Engineering	
	Chemistry	
	Computer Science	
	Earth and Planetary Sciences	
	Energy	
	Engineering	
	Environmental Science	
	Materials Science	
	Mathematics	
	Physics and Astronomy	
Social Sciences	Arts and Humanities	
	Business, Management and Accounting	
	Decision Sciences	
	Economics, Econometrics and Finance	
	Psychology	
	Social Sciences	
Multi- disciplinar	Multidisciplinary	

Based on the MeSH Taxonomy

The Medical Subject Headings (MeSH) thesaurus is a tree-like hierarchically-organised taxonomy curated by the NIH's National Library of Medicine. It is used for indexing, cataloguing, and searching of biomedical and health-related information.

MeSH subject headings are used in MEDLINE/PubMed, the NLM Catalog, and other NLM databases (like Clinicaltrials.gov). Each document entry is assigned a set of MeSH terms that describe the content of the document (similar to author keywords).

It is possible to utilise the MeSH taxonomy to classify publications into Disease Groups according to presence of MeSH terms within the C:1-26 Diseases and F01: Mental Disorders headings. Since each publication may have several MeSH terms associated, one single publication may be assigned to more than one disease group (for example a publication in Lung Cancer belongs both to C01:Neoplasm and C08: Respiratory tract diseases).

Main Bibliometric indicators used in this study

The following is a list of the main indicators used throughout the study, as well as their relevance for the study:

- Share of publications per percentile of its publishing journal according to the Scimago Journal Ranking (SJR): the percentage of publications from an institution that pertains to specific percentiles (Top 1%, Top 10%, etc) of the Scimago Journal Ranking. The SCImago Journal Rank (SJR) measures the scientific influence of scholarly journals and accounts for both the number of citations received by a journal and the importance or prestige of the journals where the citations come from. It is a numeric value representing the average number of weighted citations received during a selected year per document published in that journal during the previous three years, as indexed by Scopus. For more information: https://www.scimagojr.com/files/SJR2.pdf

- Citations per paper: the number of cites per document. The citations per paper is another metric of Scientific Impact and a proxy of the impact and quality of the scientific work done and its interest on the community.

- Share of publications in the Nature Index: the percentage of publications from an institution that were published in the journals considered for this index. The Nature Index defines itself as an indicator of research performance (albeit biassed towards large institutions). The metrics of Count and Share used to order Nature Index listings are based on an institution's or country's publication output in 82 natural-science journals, selected on reputation by an independent panel of leading scientists in their fields. Natureindex.com. Because the journals represented by the NI are of mainly of fundamental research nature, this metric was only used to evaluate Basic & Translational Research.

- Specialization Index: Because it is an Index, SI is calculated for a specific baseline (in this study, for Part1 the SI of France was established versus EU27+UK, and a set of defined countries; for Part2 The SI of Institution types was established versus the whole France). A SI=1 means that France or group is specialised on, on average, the same as the baseline (i.e, the research shows a level of specialisation higher than the baseline to which is being compared to); A SI around 2 would mean that they are twice more specialised than the baseline. (example: specialisation of France in Health Sciences versus EU27: SI France = (#PubsHealth_France / Total Pubs France) * (Pubs Total EU27 / #PubsHealth_EU27).