CWTS BIBLIOMETRIC REPORT

Meaningful metrics

Bibliometric study of Empa (2009-2020/2021)

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Universiteit Leiden

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Report for the ETH Board

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CWTS

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General parameters of the bibliometric report

Parameters

Database	:	Web of Science (Articles, Reviews and Proceedings papers in the SCIE, SSCI, AHCI, and CPCI)
Version	:	2152 (CWTS)
Classification system	:	Publication-level classification system (about 4000 fields, referred to as research areas)
Publication window	:	2009–2020
Citation window	:	Maximum 4 years (and until 2021)
Counting Method	:	Fractional counting at the level of organisation for citation impact measurement
Self-citations	:	Excluded
Top indicators	:	Top 10%

Contents

List of indicators

Avg Reads Average number of reads per DOI. A *read* is defined by saving a publication in a Mendeley user account.

IntCov Internal coverage. Estimated Web of Science coverage of a set of publications. A description of the calculation is provided in Annex C.1.

IntDisc Measure of *interdisciplinary* research, defined by the proportion of references in a publication assigned to other fields. Fields are defined by journal categories. In addition, the cognitive distance of fields to each other is also considered (more info at Section 2.2 (p. 16) and Annex D).

MCS Mean citation score. The average number of citations received by a publication (TCS/P[full]).

MNCS The mean normalised citation score. This represents average citation score per publication, normalised by research area and publication year. Research areas are defined by a detailed publication classification system of CWTS, consisting of about 4000 areas. The average MNCS in the entire database is 1. Scores higher than 1 reflect a citation-based impact that is higher than the world average.

MNJS The mean normalised journal score. This represents the normalised average citation impact of journals. The MNJS is an average score for all publications in the same journals in which an institution published. The normalisation is based on the same principles as the MNCS. The average MNJS in the entire database is 1. Scores higher than 1 reflect a journal citation impact that is higher than the world average.

P[full] The number of publications, full counting. Each publication is counted in full (i.e. as 1).

P[fract] The number of publications, fractionally counted. The fraction is determined based on the number of co-authoring organisations.

P[OA] Number of publications, full counting, in Open Access(OA). In addition, we provide the number for the different kinds of OA: Gold, Hybrid, and Green. A publication is tagged by one type only. Gold and Hybrid overrule Green. Information is based on Unpaywall data (July 2021).

PP[OA] The proportion of publications in Gold, Hybrid or Green OA, while publications without a DOI are discarded (OA unknown).

PP[collab] Proportion of publications, full counting, involving collaboration (at least two institutions co-authoring).

PP[int collab] Proportion of publications, full counting, involving international collaboration (co-authorship of organisations from more than one country).

PP[industry] Proportion of publications, full counting, involving industry (co-authorship with companies).

PP[uncited] Proportion of publications, full counting, that are not cited.

PP[self cits] The average number of author-self citations per publication. A self-citation is defined as any of the authors of a cited publication is the same as any of the authors of the citing publication.

P[top10%] The number of publications, counted in full belonging to the top 10% of their research area. The area is determined on the basis of a detailed publication classification system of CWTS, consisting of about 4000 areas (See Annex B).

PP[top10%] The proportion of publications (P[fract]) belonging to the top 10% most cited of their area and in the same year. The areas are determined using a detailed publication-level classification system , consisting of about 4000 areas. The PP[top10%] in the entire database is 10%. A score above 10% represents impact that is higher than the world average.

PA[F inst] Share of female authors of an institution within a publication.

PA[F pubs] Share of female authors within a publication (institution plus co-authors).

A[M inst] Number of male authors of an institution.

A[FM inst] Number of authors of an institution for which we could define gender male or female.

RPA[F] Proportion of female authors compared to the total of authors for which gender (male or female) was defined (more info at Section 2.2).

TCS The total citation score. This represents the total number of citations accumulated within the citation window, excluding author self-citations.

For more details about the normalised citation indicators, please refer to Waltman et al. (2012). More information about the mentioned publication-level classification is in Annex B.

Definitions, abbreviations and acronyms

CWTS Centre for Science and Technology Studies, Leiden University

A&HCI Arts & Humanities Science Citation Index

SCIE Science Citation Index Expanded

SSCI Social Science Citation Index

CPCI Conference Proceedings Citation Index

DOI Digital Object Identifier (a permanent ID for publications)

JSC Journal Subject Category

OA Open Access

Research area A set of publications on a certain topic, identified by the Leiden Algorithm (Annex B)

Subject A set of publications in journals belonging to a (subject) category

WoS Web of Science

1 Introduction

The ETH Domain consists of two Federal Institutes of Technology, ETH Zurich and EPFL, and four research institutes PSI, WSL, Empa and Eawag. Together, they play a vital role in the Swiss science system for education, research and transfer of knowledge and technology.

The ETH Board commissions an intermediate evaluation every four years. The most recent one took place in 2019. The bibliometric study was executed in 2018. The evaluation is a moment for the Swiss Federal Council, the ETH Board, as well as staff and management of ETH Domain to find out where ETH Domain stands vis-a-vis the ambitions and measures formulated in the strategic planning document. Moreover, the intermediate evaluation should lead to recommendations relating to these ambitions and measures.

Bibliometric studies can provide evidence related to ambitions and measures as part of a self-assessment report. Although we consider that meeting the standards of objectivity for determining the impact of scientific research is important, we believe that decision-making towards the goal of evaluating the quality of institute's research ought to be multi-dimensional rather than overwhelmingly quantitative. Bibliometric measures provide objective evidence about production, collaboration and impact but only for the research that has been published in (international) journals and proceedings. Therefore, we strongly recommend that quantitative evaluations are complemented with qualitative information (for example the mission and the research goals of a department) and expert assessments.

This report includes the bibliometric analysis of the scientific output of Empa, covering the period 2009-2020, including citations up to 2021. The studies are based on a quantitative analysis of scientific publications in journals and proceedings processed for the Web of Science (WoS) versions of the Science Citation Index and associated citation indices: the Science Citation Index (SCI), the Social Science Citation Index (SSCI), the Arts & Humanities Citation Index (A&HCI) and the Conference Proceedings Citation Index (CPCI).

Although most of the methodology is similar to the study performed four years ago for Empa, the results may sometimes differ substantially, due to the fact that in the current report conference proceedings papers are included and fully integrated, but that depends on the role conferences play for an institution if this is actually the case. Moreover, new indicators were introduced: RPA[F], IntDisc, P[OA], PP[OA], and Avg Reads.

We introduce each result in brief, while more detailed information about data and method is provided in Section 2 and Annex C) of this report.

In Section 3 the results of our analysis and interpretations are reported. These results are discussed in 5 parts:

1. Section 3.1: Overall output and impact
2. Section 3.2: Research focus in context
3. Section 3.3: Collaboration and partners
4. Section 3.4: Research accessibility
5. Section 3.5: Impact and knowledge use.

In the annexes, we provide more detailed scores for some indicators, more detailed information about specific approaches, as well as information about CWTS infrastructural elements involved in the analyses.

2 Data collection and methodology

2.1 Data collection

Empa provided CWTS with a list of publications from its own repository. CWTS used these data to match the publication records with the records in its database (matched results). Simultaneously, CWTS collected Empa's publication data from its database using the author affiliations in publications. Both data sets were compared to each other.

After Empa and CWTS compared, checked and corrected these two sets, the final dataset was prepared for the bibliometric analysis.

Additionally, for the Mendeley readership analysis Empa provided CWTS with any DOI registered in its repository.

2.2 Summary of method

In this section, we discuss the methods underlying the bibliometric analysis developed. We discuss the basic principles of our indicators and the context in which they can (or should not) be used. Additional and more detailed information about methods and data can be found in the annexes.

2.2.1 Indicators

In bibliometric analyses regarding research performance, we usually discern two types of indicators: size-dependent and size-independent, taking into account the different size of institutions under investigation. Larger institutions, for instance, will be involved in more publications than smaller ones. Subsequently, this will affect the absolute number of top 10% publications, as well as all other size-dependent indicators. In Figure 1 we visualise the correlation between the two indicators for the 6 ETH institutions.

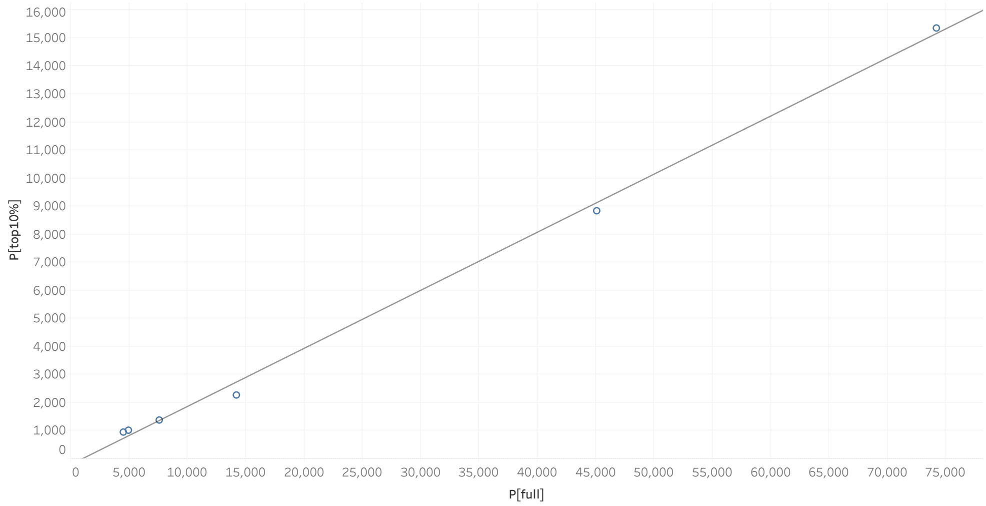

Figure 1: P[full]vs.P[top10%]for 6 ETH institutions

Proportion indicators (e.g., PP[collab], PP[int collab], PP[industry], PP[OA], PP[top10%]) and average indicators (MNCS, MNJS) are size-independent, while others used in this study (e.g., P[full], P[fract], TCS) are size-dependent. In the report we will primarily discuss the results using the size-independent indicators to account for the size differences of the organisations. Moreover, the results for size-independent indicators can, in most cases, be related to the world average.

Output indicators

Size-dependent

The total number of publications in which researchers from an institution were involved (**P[full]**) is the basic output measure. In addition, we provide the indicator **P[fract]** which assesses an institution's contribution to the output P[full]. Each individual publication is divided by the number of organisations co-authoring, regardless of the number of organisations involved. If authors have two affiliations and mention both, both affiliations are counted as fractions. P[fract] is the sum of these fractions of publications in which an institution was involved.

Size-independent

Proportion indicators characterise sets of publications regardless of the number and are therefore size-independent. They are often used to characterise output. For instance, **PP[collab]** indicates the proportion of output with at least two different organisations involved. **PP[int collab]** indicates the proportion of output involving international collaboration. In this report, a publication is tagged as an international collaboration if at least one of the co-authoring organisations is based outside of Switzerland. Furthermore, two other proportion indicators are used: **PP[industry]**, representing the proportion of P[full] co-authored with a company and **PP[OA]**, the proportion of P[full] published in Open Access (OA).

For OA publications, we discern different types: OA Gold, OA Hybrid and OA Green. The definition of the types used in this report are:

- Gold: The publisher makes all articles and related content available for free immediately on the journal's website.
- Hybrid: Publication freely available under an open license in a paid-access journal.
- Green: Published in toll-access journals, self-archived by authors (in repositories or researchers' websites), independently from publication by a publisher.

OA publications are counted only as one type at the same time. If a paper is both Green and Gold, it is counted as Gold. Bronze OA publications are free to read only on the publisher page without a license. As such, they were disregarded as OA. These were identified as *Closed Access* publications.

Impact indicators

Size-dependent

The scientific impact of an institution's output is measured by citations. We provide the total number of citations received (**TCS**) in the period of maximum 4 years after publication, up to 2021. For more recent years the citation window is shorter than 4 years. We exclude author self-citations. Another size-dependent indicator of impact is P[top10%], i.e. the absolute number of publications belonging to the top 10% most cited publications (in their area and from the same year).

It should be noted that all citation-based indicators (including TCS) are calculated using a limited and fixed time-window. The total amount of citations for early publications may therefore be higher than processed for this report.

Size-independent

The **MNCS** is the indicator to measure citation impact after normalising by research area and publication year. The research area to which a publication belongs is defined by a publication-level classification (for details, see Annex B). In this classification each publication is uniquely assigned to a research area. Areas are defined by their citation environment (cited and citing publications). This classification is more fine-grained and is considered more accurate than a journal classification (Ruiz-Castillo and Waltman, 2015). In a journal classification all publications from one journal are in the same class. Similar journals are in the same class and journals may belong to more than one class. We use this journal classification to characterise an institution's output in its research profiles but not to normalise impact. The journal classification is less fine-grained and as such easier to relate to the main subjects addressed.

In addition, we provide the proportion of publications in the top 10% most cited publications (within their research area, i.e. class, and in the same year, **PP[top10%]**).

This indicator correlates strongly with the MNCS but is not sensitive to outliers. The MNCS can sometimes be biased by one paper being cited many times. The PP[top10%] is not influenced by this one paper, as it is 'just' one of the top 10% or not. An MNCS that is relatively much higher than the PP[top10%] points to a highly skewed distribution of impact across publications. In other words, a few publications receive a huge number of citations, compared to the other publications.

Finally, we also use an indicator measuring the impact of journals, the Mean Normalised Journal Score (**MNJS**). This indicator assesses the impact in term of citations of the journals (aggregated), in which the institution has published, using the same normalisation as we use for measuring the impact (MNCS). As such, the MNJS does not measure the (average) impact of an institution's publications, but rather the impact of the journals in which its researchers publish.

2.2.2 Additional indicators

In this study we introduce indicators that relate to the context of the published research. We will discuss them in brief in the next subsections.

Worldwide growth of research fields

An indicator to position an institution's research activities in the context of what happens at a larger scale is the [**Field growth**]. We use the science landscape (see Annex B) to reflect what happens worldwide, by calculating a growth indicator for each area (the [**Area Growth**]).

The [Field growth] relates the output of an institution to these area growth values ([Area Growth]) as follows. First, we calculate for each of the 4000 research areas in the science landscape, the share output of the most recent two years (2019-2020) as compared to the total in 2009-2020 (the period under study). This share of output in the most recent years is normalised by a reference value, which is the result of the number of recent years (2) and the number of years of the total period considered (12): 0.17. Areas in which the share of output in the recent years is higher than 0.17, have a [Area Growth] above 1, a positive growth.

Any value above 1 means a positive growth, while values below 1 indicate a negative growth. In Figure 2, we plotted the [Area Growth] in the landscape of all science, by color-coding. Green areas show a positive growth (>1) in the most recent two years, while red areas show a negative growth (<1). The size of a circle proportionally reflects the number of ETH Domain publications published in 2009–2020 worldwide, ranging from 1 up to 1,400.

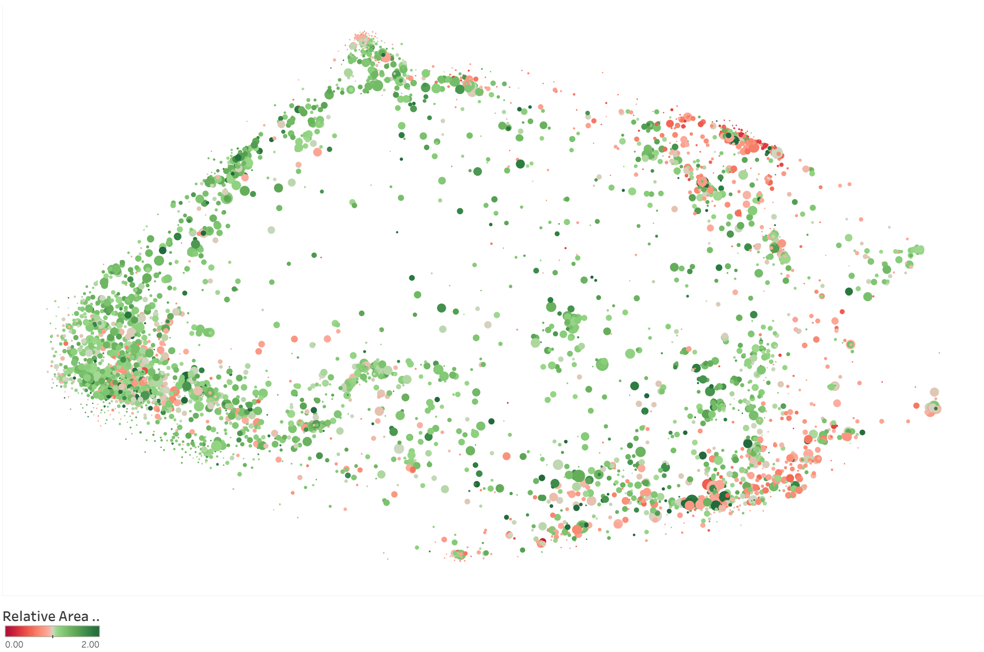

Figure 2: Landscape of all science, color-coded by [Area Growth]

[Field growth]

We use the [Area Growth] to characterise the fields in which Empa researchers are active. Thus we contribute to the answer to the question: is Empa's research positioned in fields with an increasing interest worldwide or not?

The [Field growth] is the average of [Area Growth] values of the areas in which an institution's publications can be found. Consider the output of an institution X, with 100 publications. These 100 publications may be in 20 different areas. Depending on the [Area Growth] values of these areas, these 100 publications relate to 20 different [Area Growth] scores. The average [Area Growth] values of the 100 publications, then indicates the estimated growth of fields in which X is active: the [Field growth] of institution X.

Interdisciplinary research

We introduce a measure related to the interdisciplinary character of the published research. Being more or less interdisciplinary is defined by the knowledge base (the prior art that is being cited) of the published research. The content of cited publications is defined by the journal subject categories.

If a publication cites research from one (and most likely its own) subject category only, it is defined as mono-disciplinary (measure close to 0). If a publication cites research from different subjects, we consider it as interdisciplinary. If the subjects are cognitively at a long distance from each other, the measure of interdisciplinarity is even higher, with a maximum of 1.

The cognitive distance between subject categories is determined by the density of the citation traffic between them. If a publication (A) cites output in subject X and Y, while X and Y are remote from each other (little citation traffic between them), it is considered more interdisciplinary than publication B, which cites publications from Y and Z, which are cognitively closely related (i.e., in subject categories frequently citing each other).

For each publication we calculate an interdisciplinary value and for sets of publications we then calculate their average (**IntDisc**), which is a value between 0 and 1, where 0 indicates mono-disciplinary and 1 means maximum interdisciplinarity.

In summary, interdisciplinarity is:

1. Defined by cited references in a publication;
2. On the basis of the variety of journal categories of cited publications;
3. Considering cognitive distance between these categories;
4. While this distance between categories is based on mutual citation traffic.

The above leads to the definition of interdisciplinarity we use in this report:

> The interdisciplinarity indicator (IntDisc) relates to the diversity of research supporting the current research.

In order to be able to interpret the IntDisc measure in a broader context, we calculated a reference value (**Ref Intdisc**), which is the IntDisc for the journal category at large in 2020. In this way interdisciplinarity can be assessed within each journal subject category by relating it to the world average. We integrated both scores (IntDisc and Ref Intdisc) in profiles, where interdisciplinarity is included. More info can be found in Annex D.

Share of female authors

We also introduce an indicator related to gender diversity of research staff. We calculated the probability of an author name to be male or female, by looking at the first name. If first names (or nicknames) point to a gender within a specific country, the gender is set using the following four-step procedure (also described at CWTS Leiden Ranking):

1. Author disambiguation. Using an author disambiguation algorithm developed by CWTS (Caron and van Eck, 2014), authorships are linked to authors. If there is sufficient evidence to assume that different publications have been authored by the same individual, the algorithm links the corresponding authorships to the same author.

2. Author-country linking. Each author is linked to one or more countries. If the country of the author's first publication is the same as the country occurring most often in the author's publications, the author is linked to this country. Otherwise, the author is linked to all countries occurring in his or her publications.

3. Retrieval of gender statistics. For each author, gender statistics are collected from three sources: Gender API, Genderize.io , and Gender Guesser. Gender statistics are obtained based on the first name of an author and the countries to which the author is linked.

4. Gender assignment. For each author, a gender (male or female) is assigned if Gender API is able to determine the gender with a reported accuracy of at least 90%. If Gender API does not recognize the first name of an author, Gender Guesser and Genderize.io are used. If none of these sources are able to determine the gender of an author with sufficient accuracy, the gender is considered unknown. For authors from Russia and a number of other countries, the last name is also used to determine the gender of the author. Using the above procedure, the gender can be determined for about 70% of all authorships of major universities. For the remaining authorships, the gender is unknown.

For each publication, we counted the *number* of female authors at the level of the institution (A[F **inst**]) as well as at the level of the entire publication (A[F **pubs**]). In addition we counted those for male authors. We disregarded authors for which the gender cannot be defined or is ambiguous. The total amount of authors which we defined female or male is indicated by A[FM **inst**] and A[FM **pubs**].

Hence, for each publication in which Empa authors were involved, there is a share of female Empa authors (PA[F **inst**]), and a share of female authors for the publication at large (PA[F **pubs**]). The latter is used as a benchmark for the former. RPA[F] indicates the Empa share, normalised by the share of the benchmark. A value higher than 1 for an institution X, indicates a higher proportion of female authors at X than for its community at large (X plus co-authoring partners).

2.2.3 Profiles

In the report we use two types of profiles:

1. A research profile in which we look at performance of an institution on the level of journal categories; and

2. A collaboration profile in which we look at performance of an institute of three collaboration types of publications.

In a research profile, we breakdown the Empa output into Journal Subject Categories (JSC) to add content to the general statistics. It gives a general impression of all the broad subjects in which Empa is involved. We include categories that cover at least 1% of the total output (P[full]).

For collaboration profiles, we classify all publications by their author affiliation information. The different types of collaboration are: (1) Single institution, in which only the institution under study is involved, (2) National collaboration for publications with co-authors from at least two different institutions from the same country, and (3) International collaboration for publications co-authored by institutions from at least two countries.

Output

By breaking down the output over categories, we provide a broad overview of activities and focus, by subject. In each profile we include both P[full] and P[fract], i.e. the number of publications in which an institution was involved (P[full]) and the number of publications normalised by the number of institutions involved as co-author (P[fract]). Moreover, if a publication is in a journal that belongs to two categories, it is assigned 0.5 to each category. In addition, we include an estimated growth factor for each subject [Field growth]. This growth factor is calculated on the basis of developments of research areas (see Section 2.2.2). A [Field growth] above 1 means a growth of output worldwide in the most recent two years.

By breaking down an institution's output over collaboration types, we provide insight into the publication strategy, as well as the integration of an institution into the national or international research community. Large shares of international collaboration output (P[full] and P[fract]) point to a strong international network.

Impact

In both types of profiles, the impact of individual publications is measured in the same way as for the entire institution (PP[top10%], MNCS and MNJS) and broken down over subjects and collaboration types. In the research profile, we rank subject categories on the basis of P[full] (using full counting). In this way we depict an institution's main focus by the number of publications in which its researchers are involved, while the impact is measured by the proportion to which it contributes, hence consistent with the overall impact measurement.

Research profiles in other contexts

We also used the breakdown over subject categories to provide more detailed information on the context in which research is executed and published. The main indicators we provide by subject are:

- RPA[F]: the share of Female authors relative to a benchmark
- P[OA], PP[OA]: the number and share of publications in OA
- IntDisc: the measure to which research is interdisciplinary
- PP[collab]: the proportion of output involving collaboration
- PP[int collab]: the proportion of output involving international collaboration

3 Results

3.1 Overall output and impact

Main findings

> The overall output of Empa amounts to 7,575 publications in which its researchers were involved, with the overall number of publications increasing over time. Empa exhibits an overall high citation impact, with field-normalised impact substantially above the international reference values (MNCS values always above 1.35 and PP[top10%] above 16%). Empa's publications are predominantly performed in collaboration (87%), with a predominant role of international collaboration (62%), and about 11% involving collaboration with industry. The scientific production of Empa is substantially published Open Access (49%), showing an increasing pattern over time towards more openness. Empa contributes to research areas of all the 5 main disciplines of the science landscape, although there is a stronger focus on topics related to Physical Sciences & Engineering.

3.1.1 Overall performance

In Table 1 the overall bibliometric statistics for Empa are presented. Overall Empa has produced a total of 7,575 publications, with 7,024 journal papers and 551 proceeding papers. The overall internal coverage (IntCov) is 0.81, meaning that about 81% of Empa's cited references are themselves also covered in the Web of Science database, implying that the topics researched by Empa can be considered as being well covered by the database chosen (i.e. Web of Science) for this bibliometric study.

Empa publications have received a total of 89,911 citations (excluding self-citations – which roughly represent 25% of all citations). The vast majority of citations are concentrated around journal papers, with a mean citation impact (MCS) of 12.71. The mean overall citation impact of the proceeding papers is much lower (MCS=1.10) which can be explained by the shorter nature of proceeding papers, making them less prone to receive citations, which is also supported by the rather high percentage of uncited proceeding papers (PP[uncited]=65%).

When it comes to field-normalised citation impact, the MNCS value of Empa is very high with a value of 1.44, meaning that Empa field-normalised impact is 44% higher than it would be expected by its international expected baseline. Proceeding papers have a similar high normalised impact (MNCS=1.41), indicating that although this document type is not especially prone to accrue citations, Empa is still having a high citation impact in its set of proceeding papers.

When analysing the production of highly cited outputs, Empa has produced a total of 1,382 top 10% highly cited publications (P[top10%]=1,300 of journal papers and

P[top10%]=83 of proceeding papers). In proportion Empa has produced about 17% of its contributions with high impact (PP[top10%]=17%).

About 49% of Empa publications have some form of Open Access (PP[OA]=49%). Proceeding papers are proportionally more often published in OA as compared to journal papers, with 71% of this type of publication with some form of OA version.

Empa publications are mostly performed in collaboration, with about 88% of its outputs with some degree of institutional collaboration (PP[collab]=87%), and 62% of all Empa publications involving co-authors from more than one country (PP[int collab]=62%). In the case of collaboration with industry (indicator PP[industry]), about 11% of all Empa publications are performed in co-authorship with industrial partners. In the case of proceeding papers, they tend to exhibit a slightly lower presence of institutional collaboration (PP[collab]=76% in contrast with 88% of journal papers) as well as international collaboration (PP[int collab]=44% vs. 63% of journal papers). Collaboration with industrial partners is slightly higher in proceeding papers (PP[industry]=12% vs. 10% of journal papers). This may suggest a potential role of proceeding papers at Empa as conveyors of more local and industry-related research at Empa.

Finally, Empa's publications' level of interdisciplinarity is captured by the indicator IntDisc (0.36). Compared to the overall value of the ETH Domain (IntDisc=0.35), it can be argued that Empa has a similar degree of interdisciplinarity as the domain at large. In Section 3.2 we will discuss the IntDisc values in more detail.

Most of the bibliometric results in Table 1 are provided by document type (proceedings and journals). Readership and author gender statistics are presented at the overall level only. Readership results are based on provided DOIs which were not classified by these types, while author gender could be defined in journal papers only. The results for these indicators are in their proper section (Section 3.2 and 3.5).

Overall, 21% of the Empa authors is female (3,258 vs 12,192 male, PA[F inst]: 0.21), which is just below the benchmark (all co-authors in the Empa output, PA[F pubs]: 0.22). The share of female author for the ETH Domain is 20%. The average number of reads (Avg Reads) is 3.54, while the Avg Reads for ETH Domain is 5.09.

Table 1: Overall bibliometric performance statistics Empa (1)

Indicator	Journals	Proceedings	Overall
Output			
P[full]	7,024	551	7,575
P[fract]	2,946	292	3,238
Int Cov	0.83	0.63	0.81
InterDisc	0.36	0.35	0.36
P OA [Gold, Hybrid, Green]	3,340	206	3,546
PP [OA]	48%	71%	49%
Collaboration			
PP[collab]	88%	76%	87%
PP[industry]	10%	12%	11%
PP[int collab]	63%	44%	62%
Citedness			
TCS	89,307	604	89,911
MCS	12.71	1.10	11.87
P[top10%]	1,300	83	1,382
PP[top10%]	17%	14%	17%
MNCS	1.44	1.41	1.44
MNJS	1.38	1.18	1.36
PP[self cits]	25%	20%	25%
PP[uncited]	7%	65%	12%
Author gender			
A[F inst]			3,258
A[M inst]			12,192
PA[F inst]			0.21
PA[F pubs]			0.22
RPA[F]			0.97
Readership			
N reads			12,475
N pubs read			3,525
Avg Reads			3.54

* The sum of P[top10%] by publication type may not add up to the same number overall due to rounding.

The landscape in Figure 3 is a two-dimensional representation of all science (covered by WoS) with an overlay of the output by Empa researchers in the different research areas. In Annex B we provide a more detailed description of the landscape and the way it is created. The size of a circle reflects the relative number of publications in which Empa researchers were involved. The colors in the landscape point to 5 main disciplines we use to support the interpretation of the landscape.

Figure 3 captures the topical distribution of Empa publications across all the research areas in the publication-level classification system of CWTS. As can be seen Empa has contributed to areas of all the 5 main disciplines of the classification system, although it presents a strong concentration of publications in the areas of Physical Sciences & Engineering and to a lesser extent in Life & Earth Sciences, while having also some sparse publication activity in the areas of Biomedical & Health Sciences. Via this link you can open a web-based version of the landscape in your browser. By opening the menu on the left, you can change the perspective to any of the six ETH institutions.

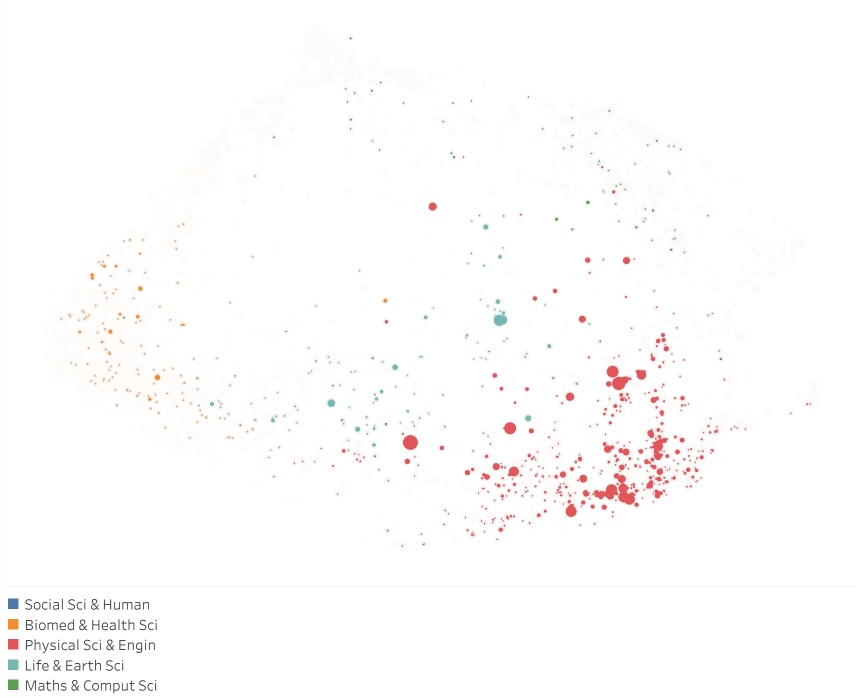

Figure 3: Distribution of Empa's output across landscape of science (interactive version via this link)

3.1.2 Trends

Table 2 below presents the trend analysis of Empa by overlapping four-year period of the indicators previously considered. Figure 4 captures the trend evolution of the Journal papers of Empa, while Figure 5 captures the trend of proceeding papers.

In general, a sustained increasing trend in the number of journal papers published by Empa is observable in Figure 4. Proceeding papers however exhibit a more fluctuating trend over time (Figure 5), with values ranging between 160 and 200 outputs per period. It is of course important to consider the relative low numbers of this type of publication in the profile of Empa, which makes it somehow more prone to temporal fluctuations.

In addition to the number of publications, Empa also exhibits patterns of increase in indicators such as IntCov, suggesting an increasing focus on research covered in Web of Science. The growth in the indicator IntDisc indicates an increase in the interdisciplinarity of the research of the institute. The proportion of OA publications (PP[OA]) has also substantially increased from 34% in the period 2009-2012 to about 63% in the most recent period 2017-2020.

The overall impact of the institute as measured by the TCS indicator shows a sustained increase from the initial period 2009-2012 up to the period 2015-2018. There is a decline in the overall TCS impact of Empa in the more recent periods (2016-2019 and 2017-2020). This decline could be partly attributed to the time lag indexing of publications and citations in Web of Science.

The share of female authors at Empa (RPA[F]) fluctuates but remains at the level of the benchmark over time. Readership is not included in the trend analyses due to missing proper publication year information in DOIs.

Table 2: Trends of Empa's bibliometric performance

Indicator	2009-2012	2010-2013	2011-2014	2012-2015	2013-2016	2014-2017	2015-2018	2016-2019	2017-2020
P[full]	2,051	2,088	2,128	2,334	2,490	2,662	2,843	2,892	3,034
P[fract]	1,007	999	974	1,034	1,060	1,092	1,141	1,132	1,171
Int Cov	0.77	0.79	0.80	0.81	0.81	0.82	0.82	0.83	0.84
InterDisc	0.34	0.35	0.36	0.36	0.36	0.36	0.37	0.37	0.38
P [OA]	642	674	730	889	1,031	1,255	1,472	1,634	1,873
PP [OA]	34%	34%	36%	40%	43%	49%	54%	59%	63%
PP[collab]	80%	82%	84%	86%	88%	89%	90%	91%	91%
PP[industry]	11%	10%	11%	11%	11%	12%	11%	11%	10%
PP[int collab]	56%	56%	58%	59%	61%	63%	64%	65%	65%
TCS	19,416	21,161	22,092	27,433	31,262	37,169	43,774	42,730	39,233
MCS	9.47	10.13	10.38	11.75	12.56	13.96	15.40	14.78	12.93
P[top10%]	373	388	405	439	433	460	505	528	577
PP[top10%]	17%	17%	18%	18%	17%	16%	17%	16%	17%
MNCS	1.49	1.54	1.55	1.53	1.45	1.38	1.38	1.35	1.38
MNJS	1.38	1.40	1.40	1.36	1.32	1.32	1.34	1.34	1.38
PP[self cits]	22%	23%	24%	24%	25%	25%	26%	26%	27%
PP[uncited]	15%	13%	12%	11%	11%	10%	9%	9%	10%
RPA[F]	0.98	0.98	1.01	1.01	1.00	1.00	0.97	0.96	0.94

In terms of field-normalised impact (i.e., PP[top10%] and MNCS; see Figures 6 and 7) there is a general stable pattern of very high citation impact of journal papers (Figure 6), with values of MNCS around or higher than 1.40, and with more than 16% of highly cited publications over the entire period. A slight decline from the period 2011-2014 onward is observable both in terms of MNCS and PP[top10%].

In the case of proceeding papers (see Figure 7), there is a general high impact of this type of publications during the entire period, with MNCS values always above the international threshold of 1, and particularly with periods (e.g. 2009-2012 till 2012-2015) when Empa achieved MNCS impact values higher than 1.50. A similar observation can be made for the indicator PP[top10%] with Empa generally producing over 12% of highly cited publications, almost reaching 16% in the most recent period (2017-2020). All in all, it is important to remind again the relatively small numbers of proceeding papers in the publication set of Empa (see Figure 5).

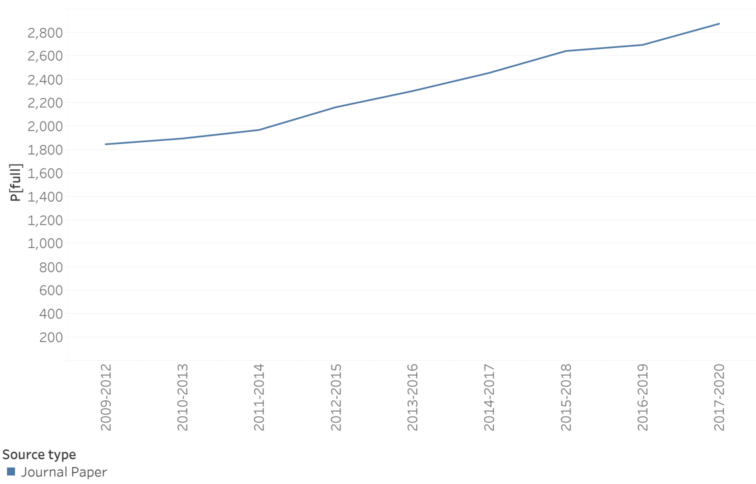

Figure 4: Empa's journal output trend (P[full]) by overlapping 4-years' period

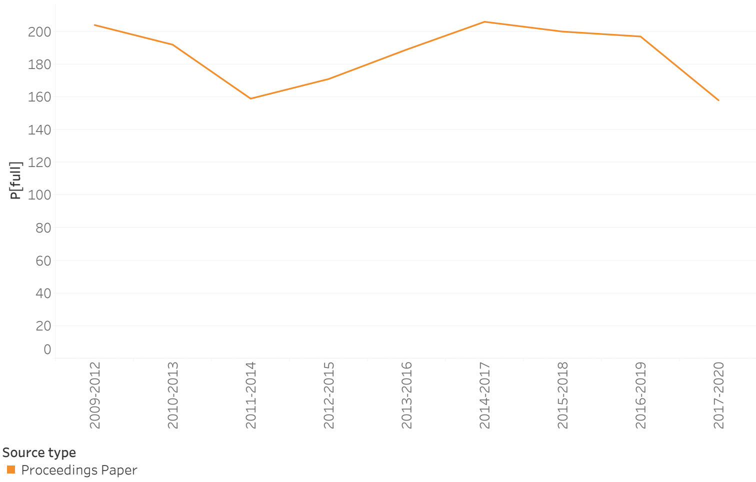

Figure 5: Empa's proceedings output trend (P[full]) by overlapping 4-years' period

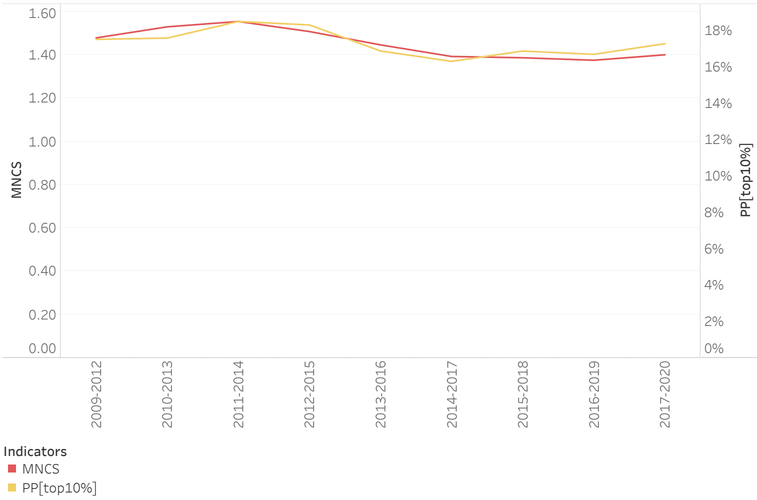

Figure 6: Empa's journal impact trend (MNCS and PP[top10%]) by overlapping 4-years' period

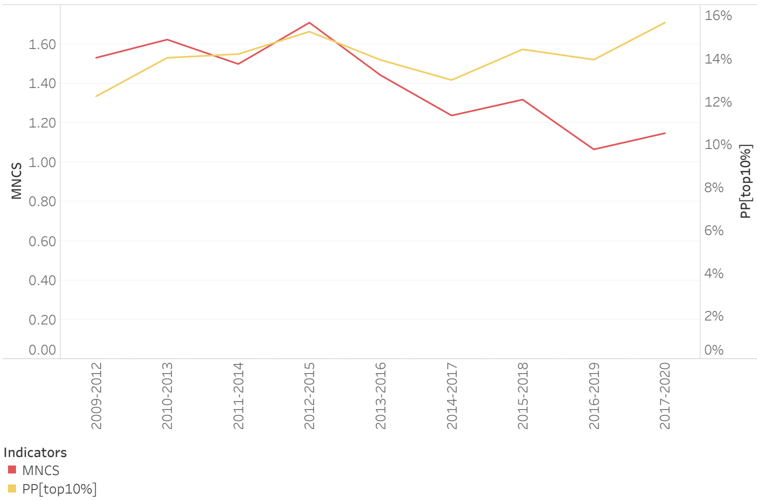

Figure 7: Empa's proceedings impact trend (MNCS and PP[top10%]) by overlapping 4-years' period

3.2 Research focus in context

Main findings

> The most important subjects for Empa in terms of output are *Materials Science, Multidisciplinary*; *Chemistry, Multidisciplinary*; *Physics, Applied*; *Chemistry, Physical* and *Environmental Sciences*. The impact of these main subject categories of activity is high. Looking at Empa's female authors, we see that in these categories the share is similar to the benchmark. Finally, Empa research in these subjects shows lower interdisciplinarity values compared to the benchmark.

3.2.1 Research profile

In this section we break down the output of Empa into Journal Subject Categories (JSC) to add context to the general statistics. We call this a research profile. It gives a general impression of broad subjects in which Empa's researchers are involved. The list of categories in the profile is limited to those that represent at least 1% of Empa's total output.

In each profile we include both P[full] and P[fract], i.e. the number of publications in which Empa was involved (P[full]) and the number of publications normalised by the number of organisations involved. Note that in such profiles, if a publication is in a journal that belongs to two subject categories, it is assigned half (0.5) to each category. The profile (Figure 8) also shows MNCS, MNJS (second column) and PP[top10%] (third column) per category, to measure impact.

It is important to keep in mind that the indicators displayed in the research profiles are distributed into journal subject categories (since these are well know and recognized discipline categories), while their normalisation has been performed based on the CWTS field categorisation (as these are more fine-tuned, see Annex B).

In addition, we include a growth indicator in Figure 8 for each category: [Field growth] (second column). This value indicates the estimated growth worldwide of a subject category. A [Field growth] above 1 means a positive growth of output worldwide in the most recent two years.

Figure 8 shows that the most important subject for Empa in terms of output is *Materials Science, Multidisciplinary*, followed by *Chemistry, Multidisciplinary*; *Physics, Applied*; *Chemistry, Physical* and *Environmental Sciences*, with at least 1% of Empa's total output. The impact of these main subjects of activity is mainly high.

Other subjects in Figure 8 with a low number of publications but high impact are *Multidisciplinary Sciences*; *Materials Science, Composites* and *Energy & Fuels*. It should be noted, however, that in the latter the number of publications is very low.

Finally, the [Field growth] indicator shows that each subject presented in Figure

8 grow worldwide during the last two years, especially *Construction & Building Technology*.

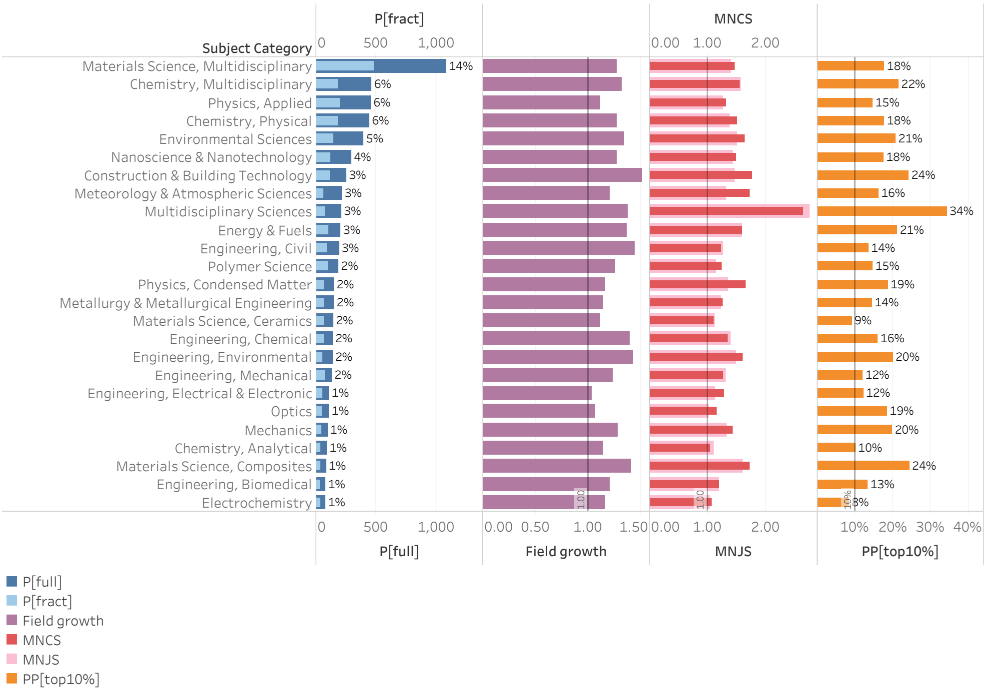

Figure 8: Empa's research profile (output, impact across subject categories)

3.2.2 Female author contribution across subjects

In Figure 9, we present the same Journal Subject Categories as in Figure 8 and added information related to author gender diversity (RPA[F], third column). Empa's authors are tagged as male or female using the first name or nickname as it appears on the publication. PA[F inst] indicates Empa's share of female authors identified for publications (second column). Subsequently, this share is compared with the share of female authors in the publication at large (including all co-authors, PA[F pubs]). The ratio of female authors within Empa and the share within the publication at large is RPA[F] and visualised in the third column with 1 as a point of reference. A value above 1 means a higher share of Empa female authors than for all institutions in the same set of publications. For instance, if a publication has 10 authors, of which 3 are female, the PA[F pubs] (reference value) is 0.33. If Empa is represented by 4 authors, 2 of which are female, the PA[F inst] is 0.5. The RPA[F] would then be 0.5/0.33: 1.52.

A more detailed description of the approach is in Section 2.2. Underlying statistics for Empa as large can be found in Annex A.

Focusing on the indicator RPA[F], Figure 9 shows that for most of the categories the share of Empa's female authors is close to the benchmark. There are a few subjects, though, mainly with a low share of the output, with quite lower than the benchmark values. These subjects are: *Energy & Fuels*; *Materials Science, Ceramics*; *Materials Science, Composites*; *Engineering, Biomedical* and *Electrochemistry*.

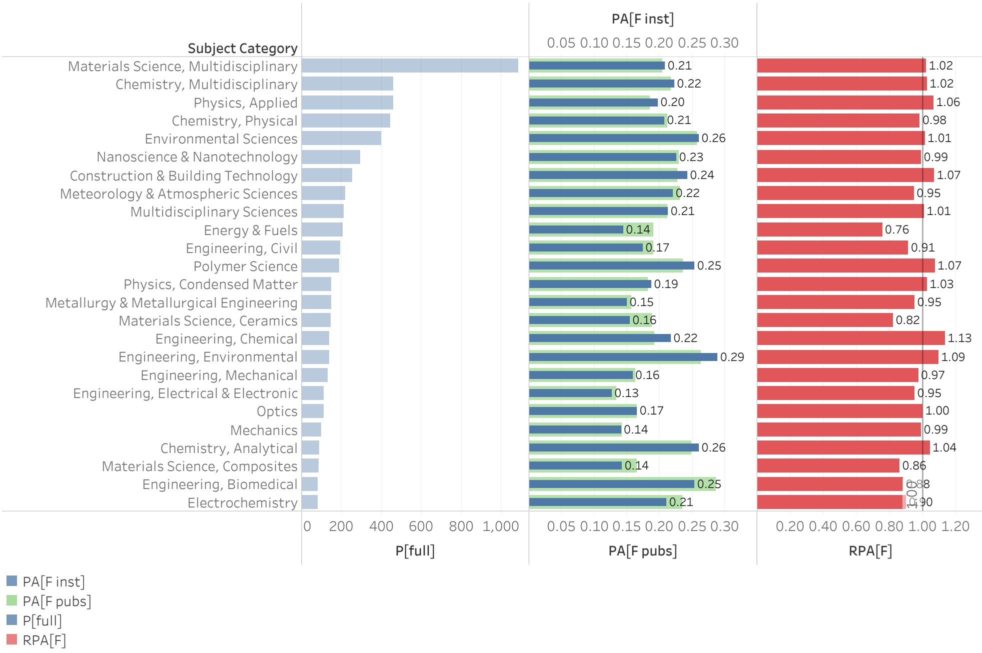

Figure 9: Empa's share of female authors across subject categories

3.2.3 Interdisciplinary research across subjects

Figure 10 represents interdisciplinarity of Empa's research output. It uses the same subject categories as in Figure 8 and relies on the publications' references (i.e. other publications cited by the publication of interest). For a more detailed explanation of our definition of interdisciplinary research, see Section 2.2 and Annex D. If a publication cites publications from different subject categories, it is more interdisciplinary than if it cites publications from the same category. In addition, we use a cognitive distance measure to value the diversity of fields being cited. If a paper cites publications from fields that are not closely related (e.g., medical sciences and mathematics) it is more interdisciplinary than if it cites publications from different medical fields. The benchmark we introduce for this indicator is the IntDisc for a subject category at large in 2020.

As Table 1 showed in Section 3.1 the overall value of IntDisc=0.36 for Empa indicates a relatively low degree of interdisciplinarity, since Empa research tends to rely on a small set of cognitively nearby disciplines. From a comparative point of view, the degree of interdisciplinarity of Empa is around the average value of ETH Domain (IntDisc=0.35), therefore not specially high or low within the context of the organization.

At the level of subject categories, Figure 10 shows broad values of interdisciplinarity. There are just a few subjects with much lower degree of interdisciplinarity compared to the overall Empa (e.g. *Physics, Condensed Matter*; *Metallurgy & Metallurgical Engineering* and *Electrochemistry*) and many subjects with much higher degree of interdisciplinarity compared to the overall Empa (e.g. *Environmental Sciences*; *Construction & Building Technology*; *Meteorology & Atmospheric Sciences* and *Engineering, Civil*).

Figure 10 also shows the overall value of IntDisc per subject categories (grey color). This value is used as the benchmark for the interdisciplinarity values for Empa (green color). *Engineering, Chemical*; *Meteorology & Atmospheric Sciences* and *Mechanics* are the ones with the highest interdisciplinarity value compared to the benchmark. On the other side, the main subjects in terms of output, *Materials Science, Multidisciplinary*; *Chemistry, Multidisciplinary*; *Physics, Applied*; *Chemistry, Physical* and *Environmental Sciences* show lower interdisciplinarity values compared to the benchmark.

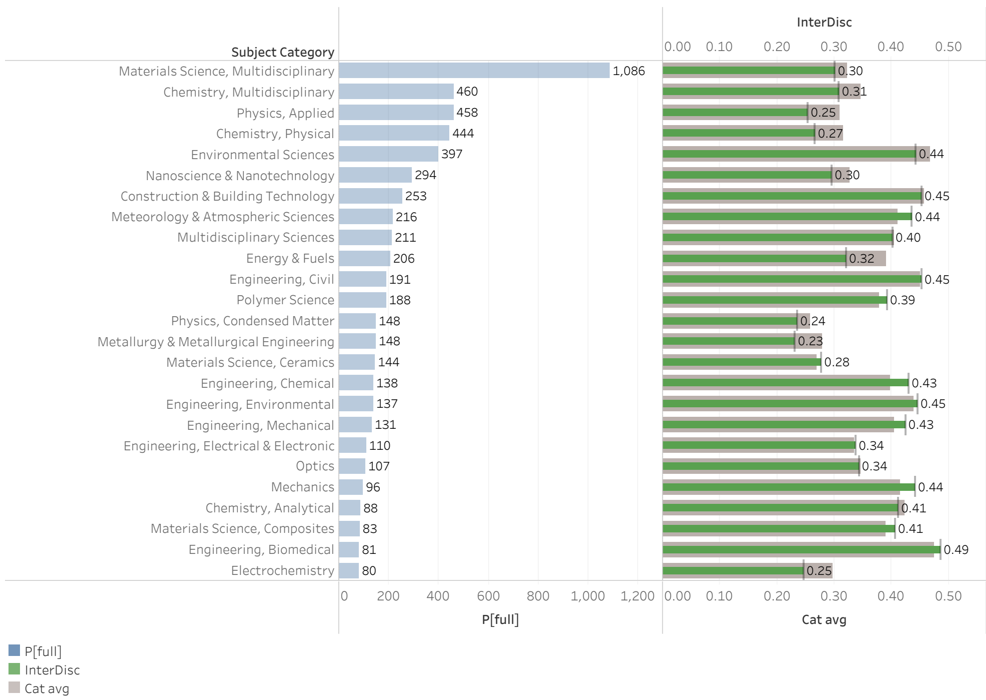

Figure 10: Empa's interdisciplinarity across subject categories

3.3 Collaboration and partners

Main findings

For Empa, proportion of publications done in collaboration and international collaboration goes up over the analyzed time period, while industry collaboration remains stable. Most Empa output is done internationally, and this category of output also has the highest impact. Of all the ETH institutions, Empa collaborates most with ETH Zurich (2,264 publications), but has the highest impact (1.64) collaborating with PSI. On a country level, it collaborates most with German institutions.

3.3.1 Collaboration profile

This section includes a trend analysis for the collaboration indicators as well as a collaboration profile.

The trend analysis in Table 3 breaks Empa's output and collaboration indicators down over time, using overlapping four-year publication windows.

In the collaboration profile in Figure 11, we break down Empa's output and impact by collaboration type, distinguishing between 'no collaboration' (single author or all authors affiliated with Empa), national collaboration (all authors having a Swiss affiliation from different institutions) and international collaboration.

Table 3: Empa's trend collaboration statistics

Indicator	2009-2012	2010-2013	2011-2014	2012-2015	2013-2016	2014-2017	2015-2018	2016-2019	2017-2020
P[full]	2,051	2,088	2,128	2,334	2,490	2,662	2,843	2,892	3,034
PP[collab]	80%	82%	84%	86%	88%	89%	90%	91%	91%
PP[int collab]	56%	56%	58%	59%	61%	63%	64%	65%	65%
PP[industry]	11%	10%	11%	11%	11%	12%	11%	11%	10%

In Table 3, we observe a trend that has been notable for other ETH Domain institutions as well, namely that both PP[collab] and PP[int collab] proportions go up over time, with PP[collab] rising from 80% to just over 90% and PP[int collab] going from 56% to 65%. Another thing that is common across ETH Domain institutions is that PP[industry] remains very stable, fluctuating a maximum of one percentage point either up or down.

Figure 11: Collaboration profile (output, impact) of Empa

Clearly notable in Figure 11 is the predominance of international collaboration when regarding publication output, particularly when using P[full]. International collaboration accounts for roughly 62% of the full-counting publication output, but this drops to 44% when using fractional counting. We can also observe that national collaboration output is larger than single institution for full-counting, but smaller for fractional counting, so that arguably the contribution of single institution publications by Empa to the respective fields might actually be bigger.

The green bars indicate the interdisciplinarity (IntDisc) measures for the different collaboration types (for more information on how this is calculated, please refer to Annex **??**). The IntDisc measure is highest for national collaboration (0,39) with the other two categories close to each other, a few decimal points behind. Such differences are very small and do not point to any pattern regarding collaboration type. See section 3.2 for more detailed analysis of the interdisciplinary aspect.

The impact indicators MNCS and MNJS are displayed in the red and light-red bars respectively. For MNCS, international collaboration stands out with 1.54, or 54% above the world average. Single institution and national are respectively 36 and 35% above world average. We see the same pattern for the MNJS, though a lower score for all three, showing that Empa's publications also outperform the journal average for the journals they are published in.

Finally, in the last (orange) column, we see another impact indicator, namely PP[top10%]. For this one, too, we find the pattern of international (18% of articles in the top 10% of their respective field) exceeding the other two categories (both 16%).

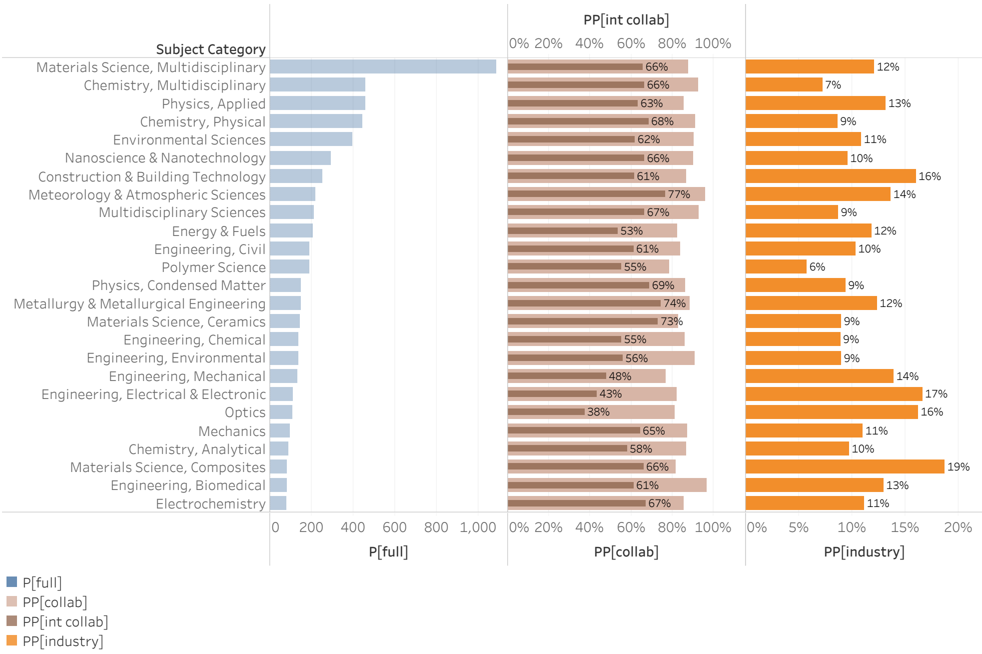

Figure 12: Empa's output and collaboration types across subject categories

In Figure 12, the collaboration indicators PP[collab], PP[int collab] and PP[industry] are calculated by Web of Science subject category for Empa publications.

In terms of output, *Materials Science, Multidisciplinary* is a clear outlier with 1,086 publications, more than double that of the next biggest subject category. As regards PP[collab], the differences run from *Engineering, Mechanical* with 77% to *Engineering, Biomedical* with 97%. For PP[int collab], the differences can be more pronounced, from *Optics* with 38% to *Meteorology & Atmospheric Sciences* with 77%. Industry collaboration, finally, is particularly low for *Polymer Science* (6%) and *Chemistry, Multidisciplinary* (7%), with the standout among the higher-output categories being *Construction & Building Technology* (16%).

3.3.2 Collaboration within the ETH Domain

Table 4: Co-authorship and impact within the ETH Domain

Indicator	ETH Zurich	EPFL	PSI	WSL	Empa	Eawag
P[full]	2,264	591	512	20	7,575	121
MNCS	1.57	1.42	1.64	1.06	1.44	1.54

Table 4 shows Empa's output and impact (highlighted column), as well as the number of co-publications and impact of Empa with other ETH institutions.

It is immediately clear that ETH Zurich stands out as a collaborative partner for Empa, and that collaboration with WSL is well-nigh non-existent (and has relatively low impact, too, though care needs to be taken on this with fewer publications). Impact (as measured by MNCS) is also high with ETH Zurich, but even higher when Empa collaborates with PSI.

3.3.3 Collaboration outside the ETH Domain

This section seeks to delve deeper into Empa's collaboration partners outside of the ETH Domain, categorising them first by country and then by institution. Tables 5 and 6 highlight the top collaborators in terms of output. For the results at country level, we used full counting. The output numbers reflect the number and share of output in which countries were involved. For the analysis of co-authoring institutions (Table 6), we used fractional counting. The output numbers indicate the contribution of partnership compared to the total.

The map in Figure 13 highlights countries with more intensive collaboration, with the darkness or intensity of the red indicating the relative level of co-authorship.

In this section we exclude collaborations within the ETH Domain. However, if a publication involves a ETH Domain member and also an external member, it is included.

Country-level

Table 5: Top 12 countries co-authoring with Empa researchers, excluding ETH Domain internal co-authorship. P[full] and % to Empa's total

Country	Co-pubs	% to total
Germany	1,198	16%
Switzerland	1,111	15%
United States	803	11%
United Kingdom	610	8%
France	493	7%
Italy	391	5%
China	365	5%
Spain	331	4%
Netherlands	282	4%
Belgium	261	3%
Austria	236	3%
Poland	233	3%

In Table 5 we find Germany on top, actually surpassing in output the non-ETH collaboration done by Empa in Switzerland. United States follows after these two, which accounts for a common top three among the ETH Domain institutions.

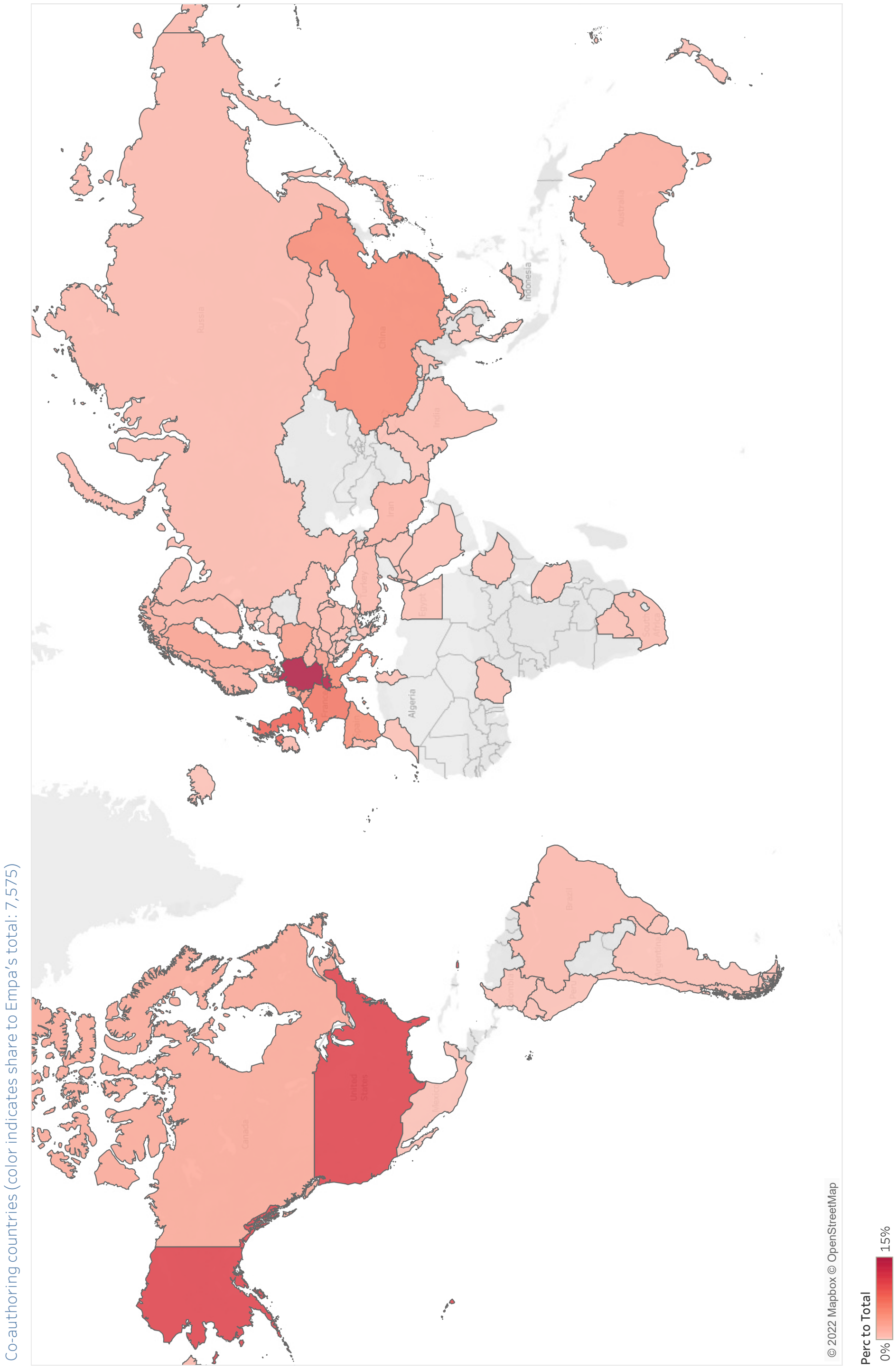

Figure 13: Map of countries co-authoring with Empa

Institutions

Table 6: Top 20 collaborating institutions of Empa, excluding ETH Domain internal co-authorship (fractional output and impact)

Inst	Country	Co-pubs	MNCS
University of Zurich	CH	101	1.42
University of Bern	CH	57	2.07
Max Planck Society for the Advancement of Science	DE	56	2.48
University of Basel	CH	53	1.42
Katholieke Universiteit Leuven	BE	37	1.56
AGH University of Science and Technology	PL	32	1.00
University of Fribourg	CH	30	1.09
Centre National de la Recherche Scientifique	FR	28	1.80
Spanish National Research Council (CSIC)	ES	23	1.64
University of Freiburg	DE	20	1.21
University of Groningen	NL	20	1.66
Delft University of Technology	NL	18	1.83
Karlsruhe Institute of Technology	DE	18	1.65
Consiglio Nazionale delle Ricerche	IT	17	1.03
Montanuniversität Leoben	AT	17	1.03
Zurich University of Applied Sciences	CH	17	1.21
Technical University of Denmark	DK	17	1.46
Technische Universität Bergakademie Freiberg	DE	16	1.06
University of Geneva	CH	16	1.57
KTH Royal Institute of Technology	SE	16	1.99

In Table 6, we find three Swiss universities among the top five collaborating institutions. Particularly the University of Zurich stands out with regard to output. Looking at impact, the MNCS of the Max Planck Society for the Advancement of Science is notable (2.48), while the University of Bern is the only other top 20 collaborating institution with an MNCS of over 2 (2.07).

3.4 Research accessibility

Main findings

> Empa's research is published increasingly in Open Access. The number (and share) of all three types of OA publications grows steadily during the period 2009 up to 2020, while the share of Closed Access publications decreases. Furthermore, the impact of OA publications increases, while the impact of Closed Access publications decreases over time.

3.4.1 OA publishing and impact

In this section we discuss the accessibility of Empa's research output. For publications with a DOI we could define whether it was published Open Access (OA) or not based on Unpaywall data (version July 2021). Therefore, the below statistics only include publications for which we could define OA or not. In addition, we could also determine the type of OA (Gold, Hybrid or Green). The trend analyses allow us to monitor the evolution of Empa regarding OA publishing.

Using OA information we assess the overall accessibility of Empa's OA output as well as its citation-based impact, by benchmarking it to non-OA output.

Table 7: Empa's Open Access (OA) performance statistics by type, excluding publications for which no OA info available

Indicator	OA Gold	OA Hybrid	OA Green	Closed Access	Total
P[full]	992	625	1,929	3,706	7,252
P[top10%]	184	153	373	643	1,353
PP[top10%]	17%	22%	17%	17%	17%
PP[int collab]	65%	69%	65%	59%	62%

In Table 7, we provide an overview of main performance statistics for three types of OA (Gold, Hybrid and Green) together with their overall performance. P[full] reflects the total number of publications, P[top10%] the number belonging to the top 10% most cited (within its year and field). PP[top10%] assesses the impact of each type, while PP[int collab] reflects the share of output involving international collaboration.

Looking at the entire period (2009-2020), we see a preference for Green OA publications (P[full]). The impact is particularly high for Hybrid OA publications (PP[top10%]: 22%). The share of output involving international collaboration is also highest for this type (PP[int collab]: 69%).

Table 8: Empa's performance statistics trend, Closed vs. Open Access publications

	Indicator	2009–2012	2010–2013	2011–2014	2012–2015	2013–2016	2014–2017	2015–2018	2016–2019	2017–2020
Closed	P[full]	1,268	1,286	1,295	1,342	1,344	1,291	1,263	1,158	1,094
	P[top10%]	241	244	249	251	226	208	203	170	176
	PP[top10%]	19%	18%	19%	19%	16%	15%	15%	14%	16%
	PP[int collab]	56%	56%	57%	57%	58%	59%	59%	62%	64%
Open	P[full]	642	674	730	889	1,031	1,255	1,472	1,634	1,873
	P[top10%]	119	132	149	181	198	243	294	348	393
	PP[top10%]	16%	17%	18%	19%	18%	18%	19%	19%	18%
	PP[int collab]	61%	61%	63%	64%	67%	67%	68%	68%	67%

In Table 8, we provide trend results for the same indicators as in Table 7, comparing OA publications with non-OA (Closed Access) publications. These results only include publications for which OA information was available (included in Unpaywall, have a DOI). In Figures 14 and 15, P[full] and P[top10%] are depicted by OA type.

The results in Table 8, show the steady increase of OA publications (642 up to 1873), together with the top 10% output (119 up to 393). Normalised by the total number of output per year, we discern an increasing impact (PP[top10%]) from 16% up to 18%. The impact of Closed Access publications moves in the opposite direction (PP[top10%]: from 19% down to 16%). From the collaboration perspective, we see that both Closed and Open Access publications is increasingly done with foreign partners (PP[int collab]).

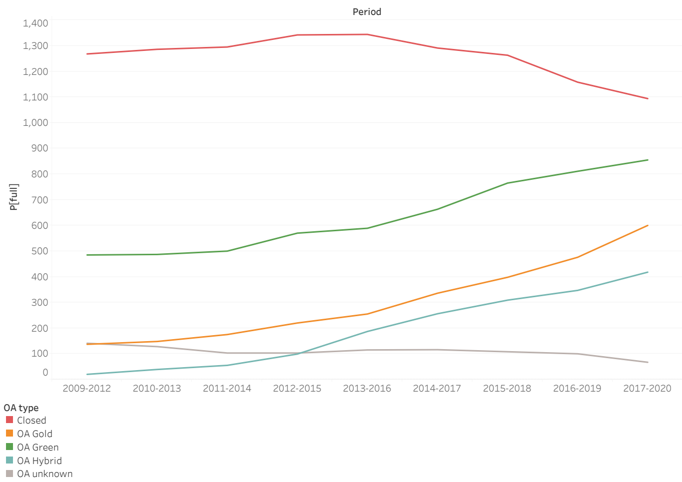

Figure 14: Empa's output trend by Open Access (OA) type

In Table 2, we already showed the increase of the number and proportion of Empa's OA publications. In Figure 14, this is visualised in more detail for the different types of OA. All three types (Gold, Hybrid, Green) increased gradually over the years. Meanwhile the volume of Closed Access publications decreased since 2016 (from around 1,300 down to 1,100).

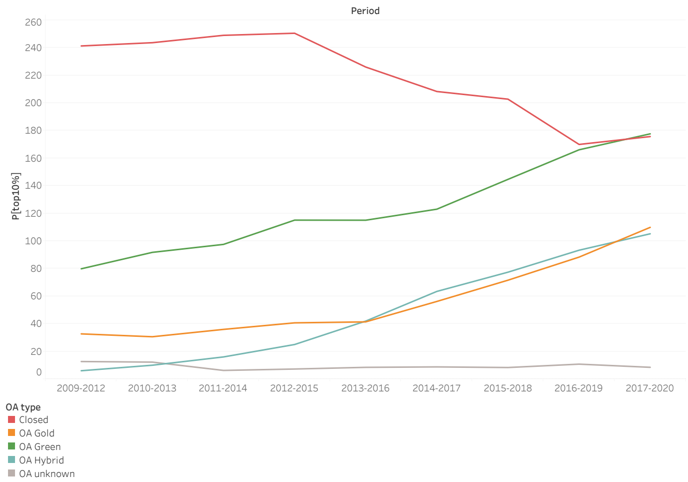

Figure 15: Empa's trend of top 10% publications by Open Access (OA) type

Figure 15 shows a steep increase of the number of top 10% publications for all three OA types, particularly from 2015 on-wards. Moreover, the number of Closed Access top 10% publications drops dramatically since 2015 (from almost 240 down to less 180). The number of Green OA Top 10% publications equals the number of Closed Access top 10% publications in the most recent years.

3.4.2 OA publishing and impact by subject

In this section we present Empa's performance statistics by journal subject category. In Figure 16, we visualise the share of OA publications, related to the overall output (for which access information was available). The bars in the second column of the diagram represent the ratio of the sum of OA publications to the sum of all publications. The light blue bar in the profile in the first column represents the total number of publications. The list of subject categories is limited to those that cover at least 1% of the total output of Empa.

In Figure 17, the second column visualises the impact of both Closed and Open access publications by PP[top10%] by subject.

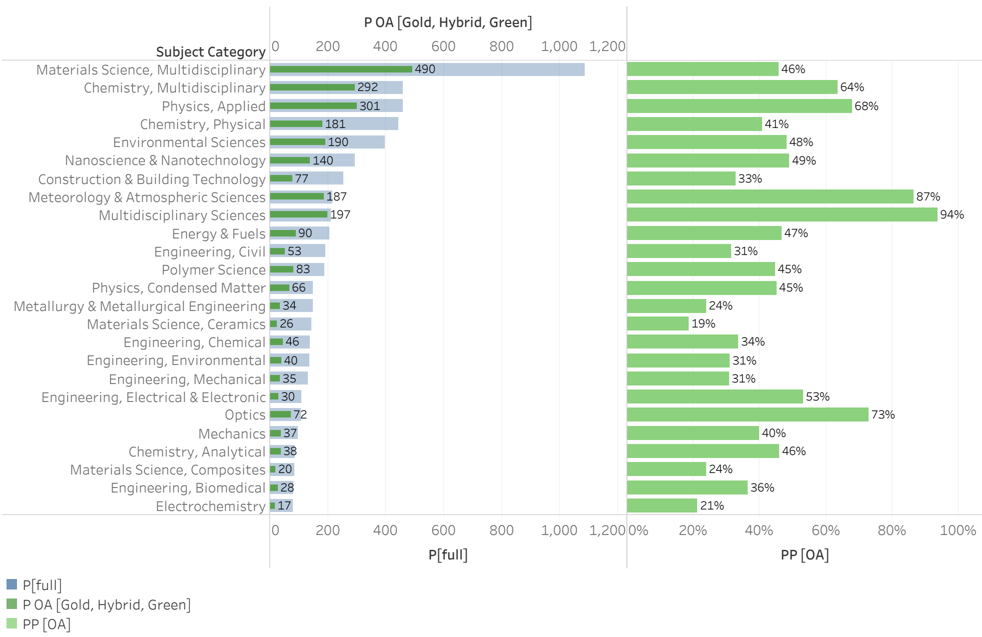

Figure 16: Empa's output and share of OA publications across subject categories

In the above profile, the share of OA publications (PP[OA]) in *Multidisciplinary Sciences* journals, and *Meteorology & Atmospheric Sciences* stand out with more than 85% published OA. Another category to mention here is *Optics* with more than 70% published OA. The only category with less than 20% published OA is *Materials Science, Ceramics*.

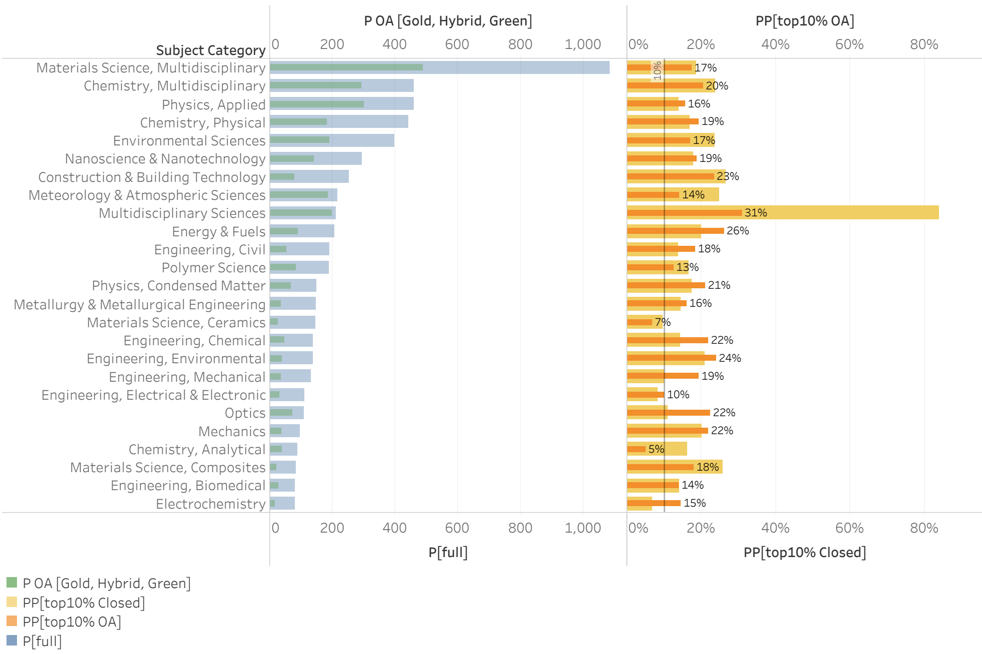

Figure 17: Empa's impact distribution (PP[top10%]) of Open and Closed output across subject categories

In Figure 17, the impact of Closed Access *Multidisciplinary Sciences* publications stands out. Obviously, publications in journals like *Nature* and *Science* still have a high impact (PP[top10%]: 84%), while the share of publications in these journals is low (see Figure 16). Also the OA publications in this category have a high impact (PP[top10%]: 31%). In most other categories the impact of OA publications is higher than the impact of the Closed Access ones, while in almost all categories both Open and Closed Access publications are above world average. OA publications in *Construction & Building Technology*; *Energy & Fuels*; *Physics, Condensed Matter*; *Engineering, Chemical*; *Engineering, Environmental*; *Optics* and *Mechanics* have a PP[top10%] higher than two times the world average (i.e., higher than 20%).

3.5 Impact and knowledge use

Main findings

> Empa's research is read and cited from all over the world. The citation-based impact is primarily determined by institutions located in Asia and Europe. Readership analysis also shows significant impact of Empa's research in countries that are not well represented in WoS (e.g., Brazil, Japan).

In this section, we discuss the actors (countries, institutions) that define the impact and use of Empa's research. We estimate the impact and use by analysing (1) the publications citing Empa's publications and (2) the country of people reading its publications.

The analysis of publications citing Empa's output shows the most prominent countries and institutions. Thus we provide an overview of the geographical distribution of Empa's impact and more specifically the institutions that use Empa's research.

The readers are analysed using Mendeley data, in which a 'read' is defined by a person (i.e., Mendeley user) saving a publication. The results should be interpreted with that disclaimer in mind. The user information includes the country of origin (if available). In this report, we will present the countries and compare these to the ones citing Empa's output. Including readership in this study does not show a broader (e.g., societal) impact of Empa research but merely catches the (potential) scientific impact beyond the WoS data.

3.5.1 Impact and knowledge use at country level

The citation-based impact is defined by publications citing Empa's output. In these citing publications, we use the affiliations of authors to measure their contribution to the impact of Empa's research. Table 9 shows the 20 most prominent countries citing Empa's research output. In the table we include the number of Empa publications being cited, the number of citations they receive and the average number of citations per publication. The top 20 is defined by the number of citations received (N cits). This list is obviously dominated by countries with many publications in WoS, and we cannot deny their significant role in determining the citation-based impact. By considering the top countries and subsequently looking at the average number of citations given, we normalise to some extent the results.

Table 9: Empa given citations by country (top 20 most given citations)

Country	N pubs	N cits	Avg cits
China	4,602	22,910	4.98
United States	4,046	14,270	3.53
Germany	3,136	6,989	2.23
United Kingdom	2,602	4,916	1.89
France	2,317	4,033	1.74
Italy	2,018	3,421	1.70
South Korea	1,686	3,369	2.00
Japan	1,808	3,301	1.83
Spain	1,843	3,160	1.71
Switzerland	2,019	3,043	1.51
India	1,542	2,804	1.82
Australia	1,654	2,641	1.60
Canada	1,622	2,544	1.57
Netherlands	1,344	1,908	1.42
Sweden	1,180	1,672	1.42
Belgium	1,104	1,354	1.23
Poland	1,068	1,326	1.24
Singapore	800	1,254	1.57
Brazil	876	1,192	1.36
Russia	871	1,191	1.37

In Table 9, we clearly see the dominance of China and the United States defining Empa's impact. Not only by absolute numbers of citations but also by the averages, these two countries attribute great value to Empa's research. Chinese researchers cite on average a Empa publication almost 5 times and US researchers almost more than 3.5 times. Next in line are primarily researchers from European countries, but also South Korea, Japan, India, Australia, Canada, Singapore, Brazil, Russia with between 1 and 2 citations per publication on average.

In Table 10, we introduce a different perspective on the impact Empa's research has. By looking at the number of reads by Mendeley users from different countries, we get a better view on the geographical distribution beyond the perimeter of the academic debate (as defined by citations). We realise that this distribution is defined primarily by the authors citing Empa's output but we hope to broaden the view on the impact somewhat. The List in Table 10 shows the top 20 most prominent countries 'reading' Empa's publications. The list order is defined by the number of reads (second column: N reads). In the table the first column shows the number of publications being read (N pubs). The third column shows the average number per read publication (Avg Reads). We consider the countries that end up in the readership list (Table 10) but not in the citing countries list (Table 9) as the ones showing the impact beyond the WoS.

Table 10: Empa readership by country (top 20, by most reads)

Country	N pubs	N reads	Avg Reads
United States	1,081	1,917	1.77
United Kingdom	790	1,081	1.37
Germany	756	1,046	1.38
Switzerland	778	916	1.18
Japan	417	545	1.31
France	440	533	1.21
India	402	498	1.24
Netherlands	384	453	1.18
Spain	372	446	1.20
Brazil	350	423	1.21
Belgium	297	372	1.25
Canada	290	355	1.22
Italy	296	336	1.14
Denmark	254	293	1.15
Sweden	187	214	1.14
China	179	196	1.09
Portugal	158	186	1.18
Malaysia	169	185	1.09
Colombia	141	157	1.11
Austria	136	151	1.11

From the reader perspective we see some interesting differences in results, comparing them to Table 9. First of all, the much lower of China which is an artefact of the data being used. Chinese researchers and academics do not use Mendeley to manage their literature (Fairclough and Thelwall, 2015; Zahedi and Costas, 2020). This lower uptake of Mendeley in Asia may also explain the absence of South Korea in this list. In addition, we see a much more prominent position of, for instance, Brazil in this list. Other remarkable countries included in Table 10 but not in Table 9 are: Malaysia and Colombia, indicating the value of Empa's research that is not visible from the citation perspective.

3.5.2 Impact by citing institution

In Table 11, we list the top 20 most prominent citing institutions of Empa's publications. This list provides more insight in the actual research actors being impacted by Empa. As the list is based on the number of citations given (N citing pubs, second column), it will be biased towards large institutions (with many publications). We normalise these large numbers by including the number of publications being cited (N cited pubs, first column), which leads to the average in the third column (Avg cits).

Table 11: Empa's top 20 most citing institutions (by number of given citations)

Institution	Country	N cited pubs	N citing pubs	Avg cits
CHINESE ACAD SCI	CN	1,567	3,536	2.26
CNRS	FR	1,621	2,535	1.56
UNIV CHINESE ACAD SCI	CN	704	1,164	1.65
ETH ZURICH	CH	855	994	1.16
TSING HUA UNIV	CN	647	886	1.37
EMPA	CH	814	852	1.05
MAX PLANCK SOCIETY	DE	598	763	1.28
ZHEJIANG UNIV	CN	482	666	1.38
PEKING UNIV	CN	476	640	1.34
ECOLE POLYTECN FEDERALE LAUSANNE	CH	515	640	1.24
NANYANG TECHNOL UNIV	SG	419	637	1.52
UNIV SCI & TECHNOL CHINA	CN	421	621	1.48
CSIC SPAIN	ES	522	621	1.19
RUSSIAN ACAD SCI	RU	484	614	1.27
HARBIN INST TECHNOL	CN	460	598	1.30
CNR ITALY	IT	469	563	1.20
UNIV CALIF BERKELEY	US	447	561	1.26
KARLSRUHE INST TECHNOL (KIT)	DE	516	559	1.08
SHANGHAI JIAO TONG UNIV	CN	437	538	1.23
HUAZHONG UNIV SCI & TECHNOL	CN	383	536	1.40

This table too is dominated by the largest research institutions in the world with many WoS publications and located in the countries in Table 9, the Chinese Academy of Science and CNRS being mega-institutions with huge numbers of publications in WoS. ETH Zurich, Empa and EPFL are just below the top 3, contributing to Empa's impact. Worth mentioning is the presence of the Singaporean Nanyang Technology University in this list.

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Annexes

A Empa's author gender statistics

Table 12: Empa: Underlying gender diversity statistics

Indicator	Value
A[F inst]	3,258
PA[F inst]	0.21
A[FM inst]	15,450
A[F pubs]	7,388
PA[F pubs]	0.22
A[FM pubs]	34,113
RPA[F]	0.97

The indicators presented in this table are described in Section 2.2, p. 17.

B Publication level classification

The CWTS citation database is a bibliometric version of Web of Science (WoS). One of the special features of this database is the publication-based classification. This classification is an alternative to the WoS journal classification, the WoS subject categories. The reason to have this publication-based classification is the problems we encounter using the journal classification for particular purposes. We discern the following as the most prominent ones.

B.1 Journal scope (including multi-disciplinary journals)

A journal classification introduces sets of journals to represents a class, in this case a subject category. This implies that journals have a similar scope. They do not need to be comparable with regard to volume (number of articles per year) but they should represent a similar specialisation. This is not the case, of course. Journals represent a very broad spectrum. There are very specialist journals (e.g., Scientometrics) and very general ones (e.g., Nature or Science but also British Medical Journal). The classification scheme can therefore not be very specialised. In WoS, a subject category Multi-disciplinary hosts the very general ones so that a bibliometric analysis of, for instance, the Social Sciences or Nanotechnology, using this classification, will not take papers in Nature into consideration.

B.2 Granularity of the WoS subject categories

The WoS journal classification scheme contains 255 elements. As such it is a stable system. In many cases however, it appears that these 255 subject categories are insufficient to be used for proper field analyses. The problem is that the granularity of the system looks somewhat arbitrary. 'Biochemistry & Molecular Biology' on the one hand and 'Ornithology' on the other, for instance, represent rather different aggregates of research. This is illustrated by the number of journals in each of them. Where the 'Biochemistry & Molecular Biology' category contains almost 500 journals, 'Ornithology' has only 27. We acknowledge that there is no perfect granularity, but we argue that in the WoS subject categories the differences are really too big. A classification based on more objective grounds does not solve this problem but is at least transparent.

B.3 Multiple assignment of journals to categories

In journal classifications from multi-disciplinary databases, journals are assigned to more than one category. Journals often have broader scopes than the categories allow. Also here there are large differences between categories. In the example we used before, 'Biochemistry & Molecular Biology,' journals are on average assigned to almost 2 categories. This means that (on average) each journal in this category is also assigned to one other category. For the more specialist category of 'Ornithology', the average is 1. This means that in this category all journals are assigned to this category only. If publications in journals with a multiple assignment would always cover the categories at stake, this should not necessarily be a problem. However, it mostly means that such journals structurally contain publications from the different categories. Therefore, publications may be assigned to two categories although they belong to just one of them.

B.4 The CWTS publication-based classification scheme

CWTS has developed an advanced alternative for the Web of Science journal classification. It counters three major issues:

1. Journal scope (including multi-disciplinary journals)
2. Granularity of the WoS subject categories
3. Multiple assignment of journals to categories

The CWTS publication-based classification is developed as described in Waltman and van Eck (2012). Since the first version there have been yearly updates of the system. The main characteristics of the classification are as follows.

Publication to publication citation clustering

Clusters of publications are created on the basis of citations from one publication to another. Tens of millions of publications have been processed. The clusters contain publications from multiple years (2000–2020). Each publication is assigned to one cluster only at each level. A cluster is considered, and in many cases validated as, representative for disciplines, research areas, fields or sub-fields. For each cluster, we can calculate growth indices pointing at changing research focus over time.

Multi-level clustering

The classification scheme has at present three different levels. The clusters are hierarchically organised. Currently we discern the following levels.

1. A top level of 25 clusters (fields)
2. A second level of around 800 clusters (sub-fields)
3. A third level of more than 4,000 clusters (research areas or micro-fields)

A common way of visualising the landscape of science by the publication clusters is a 2-dimensional map. In such a landscape (see Figure 18), we position publication clusters in relation to each other on the basis of citation traffic. The denser the traffic between two clusters, the closer they are. The two dimensions do not represent anything. The only thing that matters is the distance. Furthermore, the size of a cluster represents the relative volume (number of publications included), while the color coding adds a main clustering labeled by main disciplines.

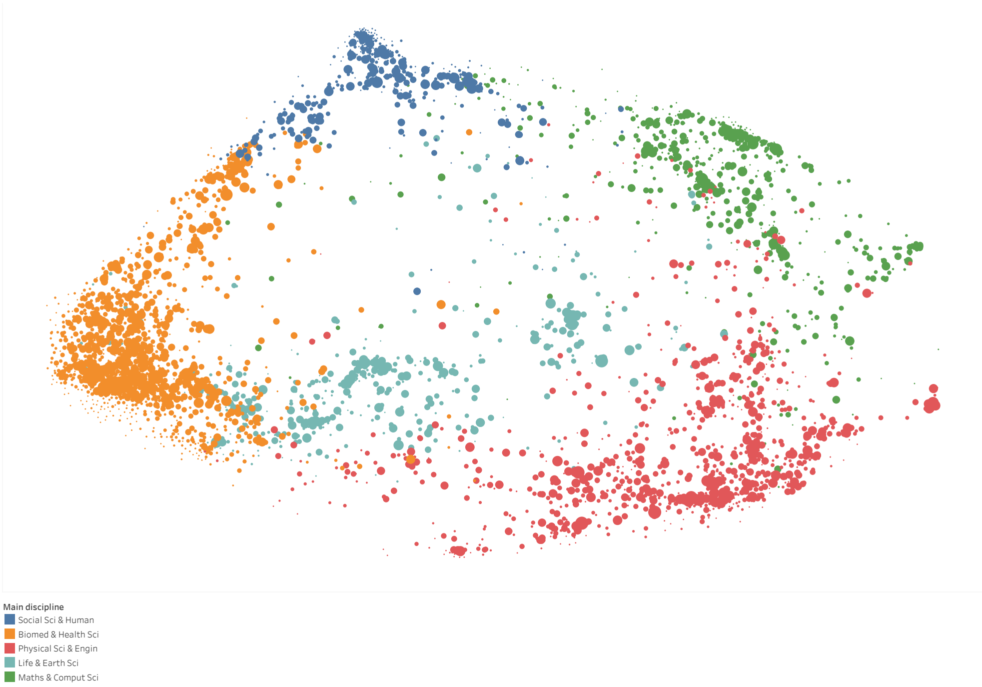

Figure 18: Landscape of all science (around 30 million WoS publications). Circles represent (over 4,000) publication clusters. Position is defined by citation traffic between clusters. Size indicates relative volume. Color reflects 5 main disciplines

C Citation data and analysis

In this annex we provide more detail about the methodology developed at CWTS and applied in this study.

C.1 Database coverage

In a bibliometric study, we base the analyses on publication data. To relate counting and measuring to standards, we depend on international bibliographic databases, such as Web of Science, Scopus, Dimensions. We realise that by using such databases, we may be missing relevant scientific outputs and achievements. In order to assess how much the database *does* cover we calculate the Internal Coverage (**IntCov**) indicator. This indicator is the ratio of cited references covered by the database, to the total number of cited references. If a publications contains 10 references, five of which are also in the database, the IntCov of this publication is 0.5. For a set of publications the IntCov is defined by the average IntCov per publication. If the IntCov of an institution's output in WoS is 0.8, we estimate the coverage of WoS for this institution at 0.8 (80%).

C.2 Database Structure

At CWTS, we calculate bibliometric indicators based on an in-house version of the Web of Science (WoS) online database, which will be referred to as the CI-system. The WoS is a bibliographic database that covers publications of about 12,000 journals and each of these journals is assigned to one or more Journal Subject Categories (JSC). Each publication in the CI-system has a document type. The most frequently occurring document types are 'articles', 'reviews', 'proceeding papers', 'corrections', 'editorial material', 'letters', 'meeting abstracts' and 'news items'. In this report, we only consider document types 'articles', 'reviews' and 'proceedings papers'. In limiting the analysis to these three types of publications, we consider that these documents reflect most of the original scientific output in a field.

The CI-system is an improved and enhanced version of the WoS database versions of the Science Citation Index (SCI), Social Science Citation Index (SSCI), and Arts & Humanities Citation Index (A&HCI). The CI-system implements a publication-based field classification which clusters publications into research areas based solely on citation relations (Waltman and van Eck, 2012) (more detail in Annex B). One important advantage of this publication-level classification system is that it allows for a taxonomy of science that is more detailed and better matches the current structure of scientific research. This not only reduces classification bias but is also essential for calculating field-normalised indicators (Ruiz-Castillo and Waltman, 2015).

Moreover, in this study we include citation data up to 2021. Please note that publications require at least one full year to receive citations in order to make robust calculations of citation impact indicators. For this reason, we will work with publications up to and including 2020, counting citations up to and including 2021. For each publication (and its benchmark publications), we consider 4 years of citations since the year of publication. For a publication from 2010, we count citations in the years 2010-2014.

C.3 Citation Window, Counting Method and Field Normalisation

Citation window

Several indicators are available for measuring the average scientific impact of the publications of a research unit, e,g. and institution. These indicators are all based on the idea of counting the number of times the publications of a unit have been cited. Citations can be counted using either a fixed-length citation window or a variable-length citation window. In the case of a fixed-length citation window, only citations received within a fixed time period (e.g. four years fixed window) are counted. The main advantage of a fixed-length citation window is that it is possible to meaningfully analyse the trend patterns of the non-normalised impact indicators, setting the same criteria for all publications included. A variable-length window, on the other hand, uses all the citations that are available in the database until a fixed point in time, which not only yields higher citation counts (depending on the window length), but also more robust impact measurements. When using a variable-length citation window, impact indicators such as the average impact (MCS) and the total impact score (TCS) may systematically present a decreasing pattern.

In this study, we use a fixed-length window of 4 year (if available) for the overall period of the analysis (2009-2020). The most recent year for receiving citations is 2021.

Self-citations

In the calculation of advanced citation impact indicators, we disregard self-citations. A citation is considered a self-citation if the cited publication and the citing publication have at least one author (i.e. last name and initials) in common. The main reason for excluding self-citations is that they often have a different purpose from ordinary citations. Specifically, self-citations may indicate how different publications of a researcher build on one another, or they may serve as a mechanism for self-promotion rather than for indicating relevant related work. Self-promotion can in turn be used to manipulate the impact of a publication in terms of the number of citations received. Excluding self-citations from the analysis effectively reduces the sensitivity of impact indicators to potential manipulation. In doing so, impact indicators can be interpreted as the impact of researchers' work on other members of the scientific community rather than on his or her own work.

Field Normalisation

There can be quite large differences in citation practices in different scientific fields. Field normalisation is about correcting for differences in citation practices between different scientific fields. The goal of field normalisation is to develop citation-based indicators that allow for valid between-field comparisons.

In this report, we will use our in-house publication-based classification system of science to define the scientific fields that are used in this normalisation process. This system has three major advantages compared to the conventional journal-based classification systems of science: Web of Science Journal Subject Categories:

- Proper granularity in terms of fields.
- Fields are defined at the level of publications citing each other, not on allocating complete journals to field(s) where inaccuracies are introduced.
- Publications from journals like Nature, Science, PLoS ONE (multidisciplinary journals) are allocated to the field they actually belong to and not to the artificial journal field 'Multidisciplinary Sciences'.

The reasons to use this publication-based classification are furthered explained in Annex B.

Counting method

Counting methods are about the way in which co-authored publications are handled. For instance, if a publication is co-authored by researchers from two countries, should the publication be counted as a full publication for each country or should it be counted as half a publication for each of them? In this study, we use both full and fractional counting. Full counting means that if a publication is co-authored by multiple organisations, that publication counts multiple times, once for every organisation, regardless of the weight of their contribution. In this report, we use mainly the full counted publications for output and fractionalised (by number of institutions involved) for impact measures.

D Interdisciplinary research

While there are different understandings of interdisciplinarity, the definition that has gained more consensus is the one provided by the US National Academy of Sciences (2005) that states:

> "Interdisciplinary research (IDR) is a mode of research by teams or individuals that integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialised knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or field of research practice."
>
> *https://www.nap.edu/read/11153/chapter/4*

There are two key elements in this definition we consider as basic notions to articulate our proposal: the concept of integration and the idea of combining knowledge from two or more disciplines.

We characterise interdisciplinarity at the level of each individual publication, by analysing the disciplines cited by the publication. This approach will allow us to consider the citations to distinct disciplines by the same citing publication as a proxy of the integration of knowledge from different disciplines. For this analysis we consider the Web of Science Journal Subject Categories as disciplines. We analyse the degree or extent of integration through the concept of diversity. Diversity is based on three concepts: variety, balance and disparity. We operationalise interdisciplinarity using Rao-Stirling diversity, an indicator which captures the three inter-related concepts of diversity, and is computed as follows:

$$\Delta = \sum_{ij} p_i p_j d_{ij}$$

$$(i \neq j)$$

> Where pi is the proportion of cited references in the subject category i, pj is the proportion of cited references in the subject category j, and dij is the cognitive distance between the subject categories i and j

In this formula, disparity refers to the cognitive distance existing between two scientific disciplines (or subject categories, in our case). In order to compute the disparity measure, we will create a similarity matrix Sij for the WoS subject categories based on the of citation flows between them. This will be then transformed into a Salton's cosine similarity matrix in the citing dimension. In this transformed matrix, the Sij represents the similarity between each pair of WoS categories, thus the cognitive distance (d) between two subject categories can be computed as d = 1- Sij.

The indicators of interdisciplinarity will allow us to identify an institution's subject categories of a prepresenting the most interdisciplinary research.

We apply the state of the art in analysing interdisciplinarity using bibliometric techniques. However, current approaches to characterise interdisciplinary research from a bibliometric perspective remain contentious. Like any other methodology suggested so far to measure and characterise interdisciplinarity based on scientific publications, our approach is not free of limitations and therefore results of these analyses need to be interpreted with caution.