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BATTERY 2030+ and its Research Roadmap: A Bibliometric Analysis

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In this bibliometric study, we analyze two of the six battery research subfields identified in the BATTERY 2030+ roadmap: *Materials Acceleration Platform* and *Smart functionalities: Sensing*. In addition, we analyze the entire research field related to BATTERY 2030+ as a whole. We (a) evaluate the European standing in the two subfields/the BATTERY 2030+ field in comparison to the rest of the world, and (b) identify strongholds of the two subfields/the BATTERY 2030+ field across Europe. For each subfield and the field as a whole, we used seed articles, i.e. articles listed in the BATTERY 2030+ roadmap or cited by such articles, in order to generate additional, similar articles located in an algorithmically obtained classification system. The output of the analysis is publication volumes, field normalized citation impact values with comparisons between country/country aggregates and between organizations, co-publishing networks between countries and organizations, and keyword co-occurrence networks.

1 Introduction

Uppsala University is coordinating an EU-funded Horizon 2020 large scale research initiative, BATTERY 2030+, which started already in 2018. This initiative is a long-term European effort with a "longer-than-ten-year perspective", which early published a manifesto[1] followed by a battery research roadmap.[2,3] In this roadmap, six battery research subfields are identified: *Battery Interface Genome, Materials Acceleration Platform, Recyclability, Smart functionalities: Self-healing, Smart functionalities: Sensing*, and *Manufacturability*.

One of the aims of the BATTERY 2030+ initiative is to monitor the progress of a cohort of EU projects towards the goals set out in the roadmap, as well as emerging areas, opportunities and challenges. The monitoring has resulted in a bibliometric report, in which the six battery research subfields mentioned above are analyzed.[4] In this paper, in order to maintain a reasonable scope of our manuscript, we focus on two of these subfields considered to be most representative for all: Materials Acceleration Platform (MAP) and Sensing. Moreover, with this selection, a fairly new subfield that is growing a lot (MAP) is included, along with a more established subfield (Sensing). In addition to analyzing MAP and Sensing, we analyze the BATTERY 2030+ field as a whole.

The work is based on the report by Ahlgren et al.[4] Compared to the report, we do not present new results. However, in addition to limiting ourselves to two of the subfields, we provide a description of battery research with the roadmap as starting point, present related bibliometric research and provide a more detailed discussion of the results for the two subfields. The overarching aims of the analysis are:

(a) to evaluate the European standing in the two subfields/the BATTERY 2030+ field in comparison to the rest of the world,
(b) to identify strongholds of the two subfields/the BATTERY 2030+ field across Europe.

The output of the analysis is indicated in the following list:

- Publication volumes.
- Field normalized citation impact values with comparisons between country/country aggregates and between organizations.
- Co-publishing networks, both between countries and organizations.
- Keyword co-occurrence networks.

The country/country aggregates referred to above and used in the work are defined in Table 1.

The remainder of this paper is structured as follows. In Section 2, battery research from the point of view of the roadmap is treated, and related bibliometric research is presented. Section 3 deals with data and methods, whereas Section 4 reports the results of the analysis. In Section 5, we

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Table 1. Definitions of country/country aggregates.

Country aggregate	Included
EU & associated	EU 27 + Horizon 2020 associated countries[5]
China	China
JKS	Japan, South Korea, Singapore
North America	Canada, US

reflect on the results, put forward limitations and give conclusions.

2. Battery Research with the Roadmap as Starting Point and Related Bibliometric Research

In this section, we briefly treat battery research from the point of view of the roadmap, and we review a selection of bibliometric studies on battery research.

2.1. Battery research with the roadmap as starting point

A long term-roadmap for forward looking battery research in Europe has been established within BATTERY 2030+ with the vision to radically transform the way we discover, develop, and design ultra-high-performance, durable, safe, sustainable, and affordable batteries. The overarching goal is to "reinvent how we invent the batteries of the future". Although the focus herein is set on MAP and Sensing, all six fields of research mentioned above are highly promising and may dramatically influence how we produce, apply, and experience rechargeable batteries. BATTERY 2030+ and the research subfields outlined in the roadmap are essentially based on a chemistry neutral approach even though references to Li-ion battery terminology are frequently made herein.

MAP aims to develop methodologies capable of transforming the battery materials research processes of today. The vision is to establish autonomous, "self-driving" laboratory for the accelerated discovery and optimization of battery materials, interfaces and cells. In practice, the research relies on combining approaches from high-throughput automated synthesis and characterisation, materials and interface simulations, autonomous data analysis and data mining, as well as Artificial Intelligence (AI) and Machine Learning (ML). Thereby, the end-to-end discovery time for future high-performance batteries can be shortened.

Sensing sets out to explore sensor technologies to monitor key battery cell parameters during operation with unparalleled spatial and temporal resolution. For instance, battery sensors could determine battery state of charge (SoC), state of heath (SoH), state of power (SoP), modes of battery failure, or even identify defective areas or components within the cells that need to be repaired by activating/adding self-healing functions. Fundamental insights into chemical and electrochemical reactions can be gained by tracking them with a sensor "in situ" directly inside a battery cell in real-world applications. A further important aspect in this subfield is battery safety in which a sensor can survey critical management aspects, e.g. battery heating, and detect early signs of adverse processes, e.g. thermal runaway, which is not only hazardous but may otherwise prevent practical realization of future battery technologies.

2.2. Related bibliometric research

Below, we briefly present a selection of earlier research publications, which bibliometrically address battery research.

Schiebel, using 7761 publications published 2004–2010, detected and visualized research fronts (groups of publications with common references) and knowledge bases (groups of co-cited publications) in battery research.[6] For the former, a front of materials research for battery electrodes was detected with many publications on lithium metal oxides and their properties. For the latter, one of the detected bases was "Si-based composite anodes for Li-ion batteries", where the name was obtained from reading titles and abstracts of citing publications. Vignarooban et al., as a part of a review of electrolytes for sodium-ion batteries, used publications from 1990–2015 and showed that there was a significant and unprecedented growth of publications on electrolytes for sodium-ion batteries.[7]

Questions pertaining to the socio-environmental impacts of lithium mineral extraction and use were addressed by Agusdinata et al.[8] Research hotspots and emerging research agendas were identified by mapping the evolution of research focus and themes with regard to a smaller publication set. Li et al., as part of their review, used a smaller set of publications on recovery of spent lead-acid battery.[9] It was shown that the organic acid leaching-calcination process was the most frequently published technology in hydrometallurgical processes, and that leady oxide and lead oxide were the most recovered products. An analysis of Li–O_2 battery research, where 1803 publications were used, was carried out by Torayev et al.[10] The authors focused on three main challenges of Li–O2 battery chemistries-the stability-cyclability, the low practical capacity and the rate capability-and found, for instance, that publications dealing with these issues represented 86% of the used publications.

Cabeza et al. investigated research trends in the field of thermal battery management system.[11] The authors analyzed 1,926 publications published 1997–2019. The publications were analyzed in terms of publications per year, top countries and journals where the research is published. Further, a keyword network analysis was performed. It was concluded that the study of the thermal management of batteries other than lithium-ion ones constitutes a research gap. Liu et al. studied 5260 publications on lithium–sulfur batteries regarding contributions of countries, institutions, corresponding authors and journals.[12] For instance, a substantial increase of China's publications from 2012 compared to that of US and South Korea was found. An analysis of the development tendency

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about the recycling methods of spent lithium-ion batteries was performed by Hu et al.[13] A sample of 383 publications was used, and the authors analyzed country contribution, country co-publishing, institution contribution, institution co-publishing, journals, highly cited publications and involved topics (in terms of term frequencies).

Liu et al. mapped research on thermal hazards of lithium ion batteries, using 826 publications from 1996–2019.[14] The analysis concerned annual publications, countries, institutions, authors, terms, and references. The results show, for instance, that China and US were the most productive countries, and that these two countries co-published frequently. Wali et al. mapped research on lithium-ion battery energy storage systems, where 100 publications (the 100 most frequently cited publications in a set of 1333 publications), published 2010–2021, were used.[15] Distributions of articles in terms of publication year, country origin, journal, study type, and subject area were obtained, and a keyword analysis was performed in order to identify more recent research topics. Finally, recycling characteristics and trends of spent lithium-ion batteries were studied by Zhao et al.[16] 1,041 publications, published 1995–2020, were used in the analysis. China made the largest contribution with 528 publications and basically co-published with all other countries. "Metal value" was identified as the most frequently occurring keyword.

3. Data and Methods

In this section, the main data source of the analysis is described, as well as the used methods and indicators.

3.1. Data source

The data source of the analysis is the KTH Library database Bibmet, a relational database that constitutes a bibliometric version of WoS. Bibmet contained about 64 million publications at the time for the analysis, with the earliest publication year equal to 1980, and is updated quarterly. The publication period of the analysis is 2010–2019, and the WoS document types taken into account are "Article" and "Review". In the remainder of this work, we use the term "article" to stand for articles and reviews.

Bibmet involves a classification system, algorithmically obtained by use of a methodology proposed by Waltman and van Eck.[17] The system is hierarchical and has four levels of clusters, where, for each level, the clusters are pairwise disjoint. Only articles are clustered, based on direct citation relations between them, and the clustering technique used is similar to modularity-based clustering.[18,19] 35.7 million articles were included in the system at the time for the analysis. Each cluster, regardless of hierarchical level, has been algorithmically assigned three labels, where a label is an author keyword, a journal name, a WoS subject category name or a word derived from author addresses. The purpose of these labels is to indicate the subject orientation of the clusters.

3.2. Article sets for the subfields and the BATTERY total 2030+ field

For each subfield (also the four ones that are not included in this work), and the BATTERY 2030+ field as a whole, we used the classification system to define a set of articles to analyze. BATTERY 2030+ roadmap includes, for each subfield, a publication list. These lists were used as starting points in the process of defining article sets for the subfields. Let S be a subfield. The following five steps were carried out to define a set of articles for S:

1. From the publication list for S in the BATTERY 2030+ roadmap, the subset of articles covered by Bibmet was selected. Let S_r be this subset. If deemed desirable, S_r was expanded with additional articles selected by the BATTERY 2030+ consortium.
2. For each article x in S_r, each article cited by x and covered by Bibmet was added to S_r. Let S_a be the resulting set. The articles in S_a were considered as *seed articles*: articles that can be used in order to obtain additional, similar publications.
3. The articles in S_a were located in the classification system with respect to the most fine-grained level of the system, level-1 (with 158,783 clusters) and the next to most fine-grained level, level-2 (with 5053 clusters). For both levels, Excel sheets were created, in which the identified clusters were ordered descending after the number of articles in S_a, i.e. the number of seed articles for S that a cluster contains. Besides information on number of seed articles were, for instance, cluster labels included in the sheets. Moreover, sheets with bibliographic information on the articles belonging to the identified clusters were created.
4. For the clusters with the highest frequencies of articles from S_a, keyword co-occurrence networks and co-publishing networks of countries and organizations were created. The networks were visualized, and the visualizations stored in image files.
5. At least one subject expert, with regard to the subfield S, analyzed the sheets from step 3 and the image files from step 4. The subject expert(s) marked the clusters that in her/his view are relevant, i.e. should be included in the analysis, and provided this and other feedback to the authors of this report.
6. The union of the clusters that were marked as relevant by the subject expert(s), say U_S, was obtained, and U_S constitutes the set of articles assumed to represent the subfield S in the analysis.[20]

Thus, the execution of steps 1–5 for each subfield yielded six article sets, where each such set is our operationalization of the corresponding subfield.

In the study by Ahlgren et al.,[4] and with respect to the BATTERY 2030+ field as a whole, two operationalization approaches were taken. In the first approach, the union of the six article sets (the U_S sets) was used as an operationalization of the field.[21] Let POOL denote this set. However, since POOL may represent the BATTERY 2030+ field quite narrowly, we used a larger set of articles (compared to POOL) in the second approach. This set, say WIDE, is based on a wider selection of larger level-2 clusters, which cannot necessarily be directly tied to the specific subfields of BATTERY 2030+, but which are relevant to the broader battery field as defined from the articles in the six sets of seed articles. Further, the selected level-2 clusters are ranked high, with respect to the number of seed articles they contain, for at least one of the six subfields. More precisely, for each included level-2 cluster *C*, (1) there are at least two subfields *S* and *S′* such that *C* belongs to the five highest ranked clusters in both *S* and *S′* with respect to number of seed articles, or (2) *C* has been selected by subject experts for at least one subfield. In this work, we only use the set WIDE.

3.3. Indicators

The indicators used in this study concern publication volume, international collaboration and citation impact. Regarding volume, *P full* is the number publications, *P frac* the number publication fractions. For international collaboration, *IntColl%* is the share of articles that has been co-published between two or more countries. We used four citation-based indicators. The indicators *cf* and *Ptop10%* are field normalized publication-level indicators, whereas *jcf* and *Jtop25%* are field-normalized journal-level indicators (*jcf* is a counterpart to the well-known Journal Impact Factor). In the next section, we describe the citation analysis of the study.

3.3.1. Citation analysis

The four citation-based indicators are calculated by the use of fractional counting. An author's fraction of an article is counted as 1/*n*, where *n* is the number of authors of the article. A unit's (e.g. an organization's) fraction of the article is then given by the sum of the author fractions of the authors affiliated to the unit in the article. However, if an author is affiliated to more than one unit in the article, the fraction of the author is distributed uniformly across these units. Fractional counting yields a more proper field normalization of citation impact indicators compared to full counting.

cf is the mean field normalized citation rate. This indicator normalizes for the variation of citation patterns between subject fields. Each article is compared to a reference group of articles. In our case, for an article *a* in the set U_S (the set of articles assumed to represent the subfield *S* in the analysis), the reference group consists of all articles in U_S published the same year as *a*. The number of citations of *a* is divided by the average number of citations across the articles belonging to U_S and published the same year as *a*, which results in a field normalized citation rate for *a*. Hence, the field-normalization used in the study is based on the specific subfields defined in our study. For a given country/country aggregate/organization represented in U_S and a given publication year, the *cf* value expresses the average field normalized citation rate of the country's/country aggregate's/organization's articles in U_S that are published in the year. The weighted average of the *cf* values of all countries/country aggregates/organizations for a given year, where the weight of a country/country aggregate/organization is given by its fractionalized number of articles, is equal to 1. Therefore, a citation rate above 1 for a country/country aggregate/organization indicates that its set of articles is cited above world average, e.g. a citation rate of 1.2 indicates that its articles are cited 20% above world average.

Ptop10% is the share of articles among the 10% most frequently cited. The same reference group as for the field normalized citation rate is used for the indicator (see above). Articles can partly belong to the 10% most cited articles if several articles have the same citation value as the percentile limit. The weighted average of the *Ptop10%* values of all countries/country aggregates/organizations for a given year, where the weight of a country/country aggregate/organization is given by its fractionalized number of articles, is equal to 10.

Jcf is the mean field normalized citation rate for journals. This indicator shows the citation impact of the journals in which the unit has published. It is calculated as an average of the field normalized citation rate of the set of journals in which the analyzed unit has published. If the unit has published multiple articles in the same journal, the journal's field normalized citation rate is counted multiple times. This journal indicator is normalized for field differences by the same principles as the mean field normalized citation rate (*cf*). However, in this case the Web of Science Subject Categories for journals are used as a basis for obtaining reference groups. For an article *b* in a given journal *J*, the reference group consists of all articles appearing in the journals belonging to the same Web of Science Subject Category (or categories) as *J* and published the same year as *b*. For an article *a* in the set U_S and published in the year *y*, the value of the journal of *a* is based on the years *y*-5 to *y*-1. The weighted average of the *jcf* values of all countries/country aggregates/organizations for a given year, where the weight of a country/country aggregate/organization is given by its fractionalized number of articles, is equal to 1.

Jtop25% is the share of articles that have been published in journals, which are among the 25% most frequently cited. The same reference group as for the mean field normalized citation rate for journals (*jcf*) is used for the indicator. The journals in the top 25 category publish 25% of the articles in the reference group. A journal can partly belong to the top 25% if it stretches over the percentile limit or if it has been classified into multiple fields with different percentile limits. The weighted average of the *Jtop25%* values of all countries/country aggregates/organizations for a given year, where the weight of a country/country aggregate/organization is given by its fractionalized number of articles, is equal to 25.

Above, and regarding *cf* and *Ptop10%*, we only describe the reference group of articles for an article in a given U_S, corresponding to the subfield *S*. For POOL as an operationalization of the BATTERY 2030+ field and an article *a* in POOL, *a* belongs to exactly one U_S. The reference group of articles for *a*, with respect to the two indicators, is U_S. For WIDE as an operationalization, and an article *a* in WIDE, the reference group of articles for *a*, with respect to the two indicators, is WIDE, regardless of if *a* belongs to an U_S or not. Note that the calculation of the two journal-level citation impact indicators, *jcf* and *Jtop25%*, is not affected by whether subfields or the BATTERY 2030+ field are analyzed.

Notice that for the citation analysis, the last considered publication year is 2018. The rationale for this was to avoid an improperly short citation window for the last publication year of the study (i.e. 2019). Citations are counted with an open window until the time for the analysis, hence all citations from articles registered in the database at this point in time were counted. For all citation statistics, author self-citations are excluded, defined as citations where any of the author names are the same in the citing and cited article.

For a more formal description of the calculation of the two publication-level citation impact indicators and the two corresponding journal-level indicators, see Ahlgren and Kennerberg[22] and the openly available document "Formal definitions of field normalized citation indicators and their implementation at KTH Royal Institute of Technology",[23] respectively.

4. Results

In this section, we present the results of the analysis. Each of the Sections 4.1–4.3, which correspond to the two subfields and the BATTERY 2030+ field (operationalized as the article set WIDE), has three subsections. The first subsection treats the country/country aggregate level. A table with indicator values by country/country aggregate is put forward, as well as line graphs for publication volume (*P full*) and citation impact (*cf* and *Ptop10%*). In these graphs, the horizontal axis corresponds to publication year. For all *cf* and *Ptop10%* graphs, a dashed, grey line indicates world average. The second subsection concerns the organization level and contains a table that corresponds to the table in the first subsection. 13 organizations are taken into account in the table: the top 10 organizations among EU & associated with respect to publication volume (the indicator *P full*), and the top 1 organization from China, North America and JKS regarding the same indicator. The subsection also gives information on the frequency of occurrence of companies in the articles of the subfield/field. Note that identifying organizational types in bibliometric studies can be difficult. This is especially the case for companies. Therefore, highlighted companies constitute samples, which do not give the complete picture.

In the third subsection, three bibliometric networks are visualized. First, a co-occurrence network with regard to author keywords is visualized, where the visualization was done using VOSviewer, a publically available program from CWTS, Leiden University.[24] Unification of keywords was done by VOSviewer based on manually created thesaurus files: files in which keyword variants are mapped to a standard variant. In the network, the nodes represent keywords, and the larger a node is the higher is the weight of the node, where *weight* in this case is defined as the number of articles in which the keyword occurs. A link between two nodes indicates that the corresponding two keywords co-occur in at least one article. Moreover, the thicker the link is the higher its strength, where *strength* in this case is defined as the number of articles in which the two keywords co-occur. The distance between the nodes approximately indicates the strength of the co-occurrence relation between the corresponding keywords. Note that VOSviewer cluster the keywords. VOSviewer uses modularity-based clustering,[18,19] where co-occurrence relations between keywords are utilized in the clustering. All nodes in a given cluster have the same color, whereas nodes in different clusters have different colors.

The third subsection further contain visualizations of co-publishing networks for both the country level and the organization level. Here, the nodes represent countries (organizations), and a link between two nodes indicates that there is at least one article in which the corresponding two country names (organization names) co-occur. In this case, the weight of the node is defined as the number of articles in which the country name (organization name) occurs, whereas the link strength in this case is defined as the number of articles in which the two country names (organization names) co-occur. The distance between the nodes approximately indicates the strength of the co-occurrence relation between the corresponding countries (or organizations). The nodes were clustered by VOSviewer with the same methodology as in the author keywords clustering.

Table 2 reports the number of articles per subfield and for the BATTERY 2030+ field (i.e. for WIDE) over the whole publication period 2010–2019.

4.1. Materials acceleration platform (MAP)

In this section, we give the results for MAP. The section has three subsections. The first one, which concerns results for country/country aggregates, puts forward one table and three graphs. In the second subsection, in which we deal with results for the organization level, one table is given. The third subsection visualizes three bibliometric networks.

4.1.1. Country/country aggregates

In Table 3, indicator values by country/country aggregate and for the whole publication period are given. MAP is clearly a very strong subfield for North America: regardless of citation impact indicator, North America has by far the best performance among the four units. China and JKS perform poorly for *cf* and *Ptop10%*, and China is lagging compared to Sensing (Section 4.2.1).

Table 2. Number of articles per subfield and WIDE, 2010–2019.

Field	*P full*
MAP	1,683
Sensing	2,818
WIDE	66,574

Table 3. Indicator values by country/country aggregate.

Region	*P full*	*P frac*	*cf*	*Ptop10 %*	*jcf*	*Jtop25 %*	*IntColl%*
EU & associated	559	420.4	0.99	11.5 %	1.36	41.3 %	56.7 %
China	228	160.4	0.63	4.8 %	1.25	36.1 %	52.6 %
JKS	254	194.3	0.47	1.8 %	1.16	31.8 %	36.2 %
North America	848	699.1	1.27	12.8 %	1.60	49.0 %	38.3 %

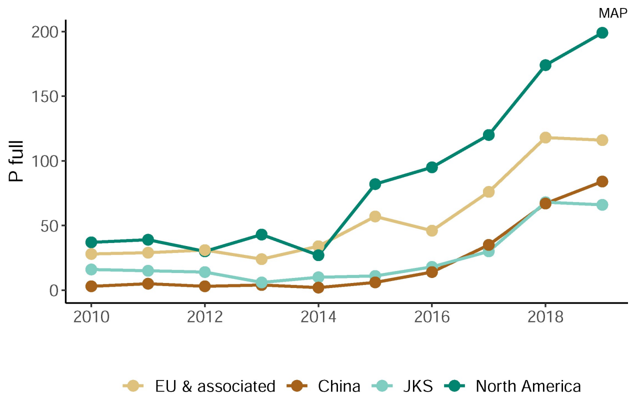

Figure 1. Publication volume (*P full*) development by country/country aggregate.

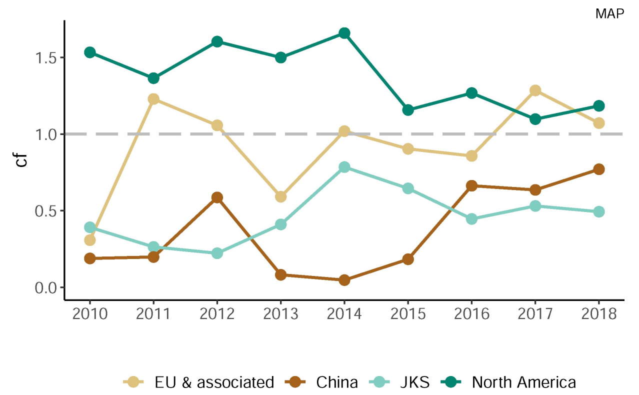

Figure 2. Publication-level citation impact (*cf*) development by country/country aggregate.

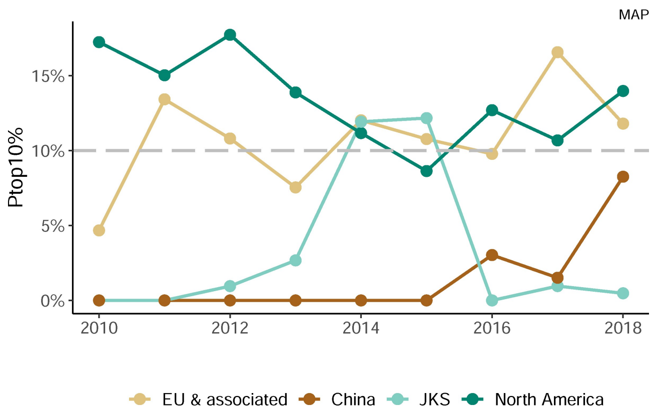

Figure 3. Publication-level citation impact (*Ptop10 %*) development by country/country aggregate.

Interestingly, MAP is growing for all four units from 2016 onwards (Figure 1). For *cf* and *Ptop10 %* trends (Figures 2 and 3), EU & associated has caught up compared to US in the later years and is relatively strong compared to China. The gap in *Ptop10 %* between North America and China is considerably less year 2018 compared to the earlier years.

4.1.2. Organizations

Table 4 puts forward indicator values for the top 10 organizations among EU & associated and the top 1 organization from China, North America and JKS with respect to *P full*. It should be kept in mind that other organizations from China, EU & associated, JKS and North America can have widely different citation impact values (the indicators *cf*, *Ptop10 %*, *jcf* and *Jtop25 %*) compared to the selected organizations.

Among the 10 organizations from EU & associated and country origin, Germany and Switzerland dominate. There is a large variability in performance among these 10 organizations with regard to *cf* and *Ptop10 %*. Technical University of Berlin has the highest values on the two indicators. Further, all 24 articles in which this organization has participated have been internationally co-authored (*IntCollab%* equal is to 100.0 %). University of California, Berkeley has the highest number of articles (*P full*) and has also a strong performance regarding the citation impact indicators. Generally, EU & associated organizations have very high values on the two journal-level citation impact indicators, *jcf* and *Jtop25 %*.

For MAP, the company publication volumes are relatively low. A notable exception is Citrine Informatics with 14 publications. This company focuses on AI in relation to material development.

4.1.3. Bibliometric networks

The network in Figure 4 gives an overview of the author keywords used in the articles selected for the MAP subfield. It is quite evident from the figure that there is a strong focus on computer science in MAP, an article set that is composed of one level-2 cluster. Several keywords, like "machine learning" and "high-throughput experimentation", are connected to AI-related subjects. This in line with the outlined vision in the BATTERY 2030+ roadmap, a vision inspired by the route of pharma industry in drug discovery processes where state-of-the-art computational schemes are coupled with combinatorial

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Table 4. Indicator values by organization. The top 10 organizations among EU & associated and the top 1 organization from China, North America and JKS with respect to *P full*.

Organization	*P full*	*P frac*	*cf*	*Ptop10%*	*jcf*	*Jtop25%*	*IntColl%*
Max Planck Society[25]	72	26.9	1.76	29.8%	1.61	58.1%	84.7%
University of Basel	49	28.0	1.45	16.4%	1.15	33.7%	73.5%
Ruhr-Universität Bochum	44	33.9	1.48	18.3%	1.14	38.0%	29.5%
Swiss Federal Institute of Technology Lausanne	32	20.2	1.05	21.1%	1.38	50.1%	62.5%
Bar-Ilan University	30	25.6	0.29	0.0%	1.29	31.3%	20.0%
ETH Zurich	29	14.9	1.93	20.3%	2.40	57.2%	69.0%
Technical University of Berlin	24	7.7	4.27	65.4%	1.79	67.8%	100.0%
Technical University of Denmark	18	13.4	2.44	28.5%	1.95	59.7%	38.9%
Université Catholique de Louvain	18	6.1	1.24	6.3%	1.10	32.5%	83.3%
Free University of Brussels	17	8.5	0.26	1.8%	1.25	43.4%	82.4%
University of California, Berkeley (NA)	78	25.5	2.23	15.5%	1.64	49.9%	24.4%
Chinese Academy of Sciences (CH)	46	23.5	0.61	3.6%	0.94	25.8%	28.3%
National Institute of Materials Science (JKS)	53	20.8	0.50	2.0%	0.99	22.7%	22.6%

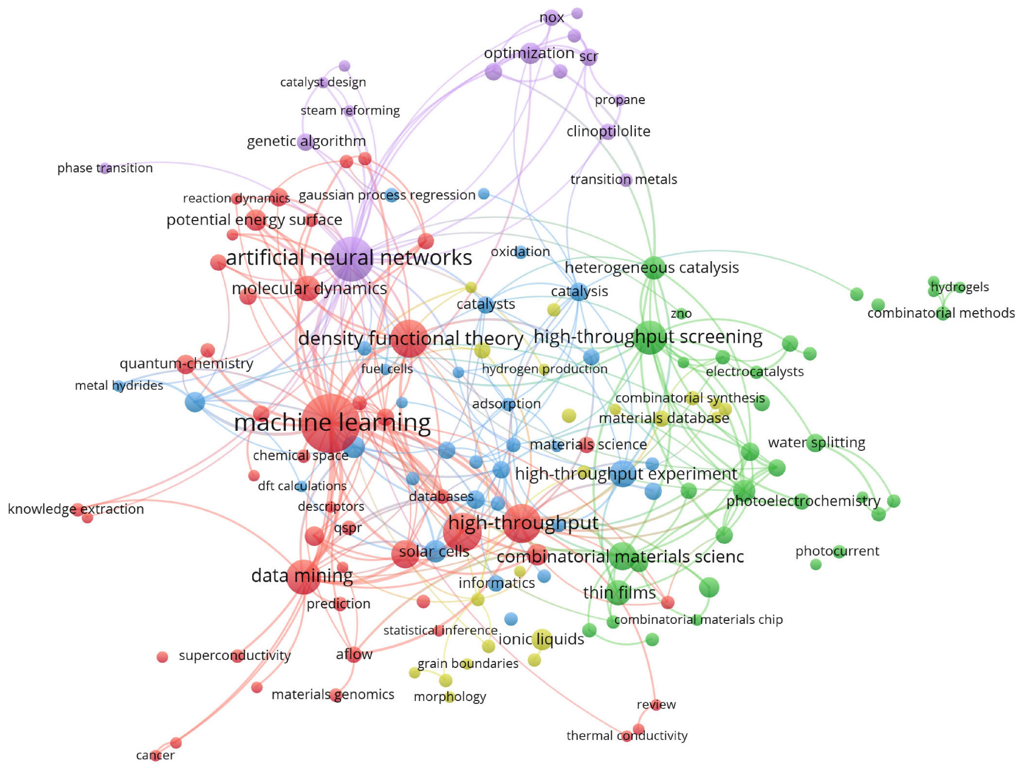

Figure 4. Author keyword co-occurrence network for MAP. Minimum node (author keyword) weight is set to 3.

material screening methodologies. The clusters are strongly nested and likely reflect that MAP is currently undergoing a strong exploratory phase in which large number of ideas are combined and evaluated.

The networks in Figures 5 and 6 show the collaboration networks between countries and organizations within MAP, respectively. As is clear from Figure 5, US is dominating MAP. Relative to what one may expect, China has rather low publication volume. For Germany and Japan, the opposite is the case.

4.2. Smart functionalities: Sensing

In this section, we give the results for Sensing.

4.2.1. Country/country aggregates

In Table 5, indicator values by country/country aggregate and for the whole publication period are given. It is clear from the table that JKS is lagging, both in volume and in citation impact

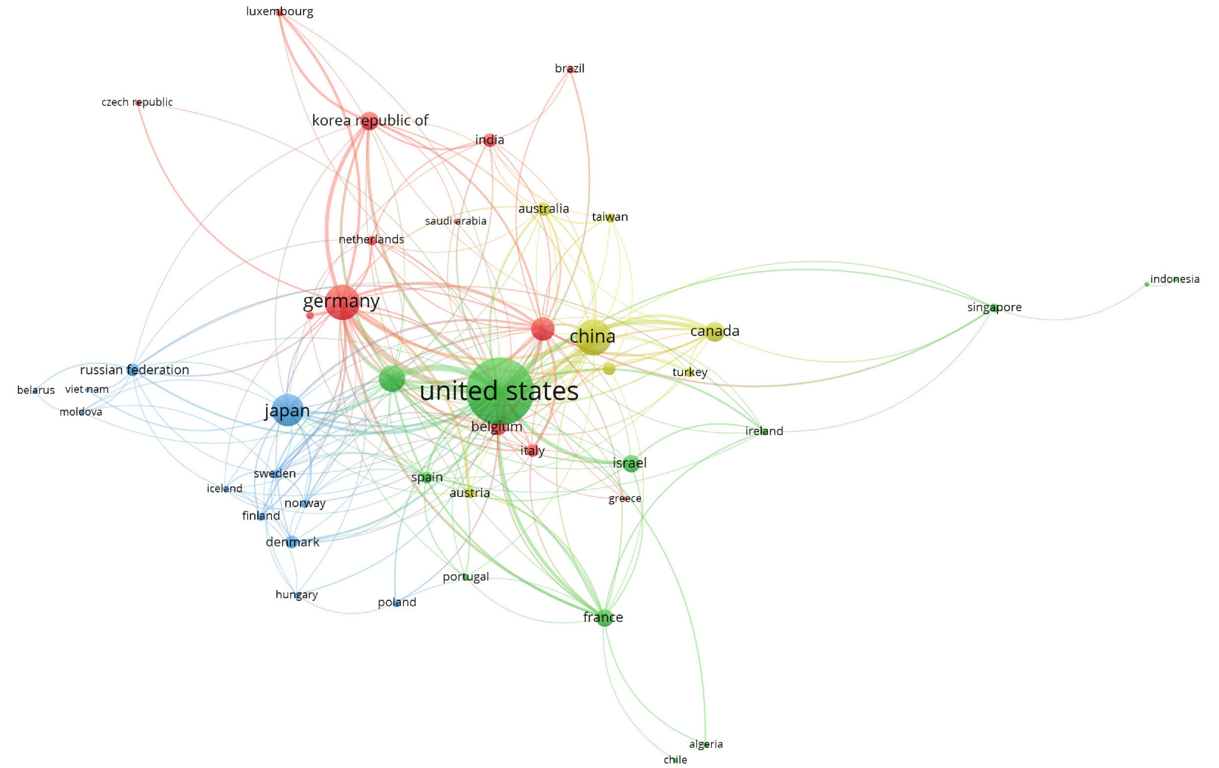

Figure 5. Country co-publishing network for MAP. Minimum node (country name) weight is set to 2.

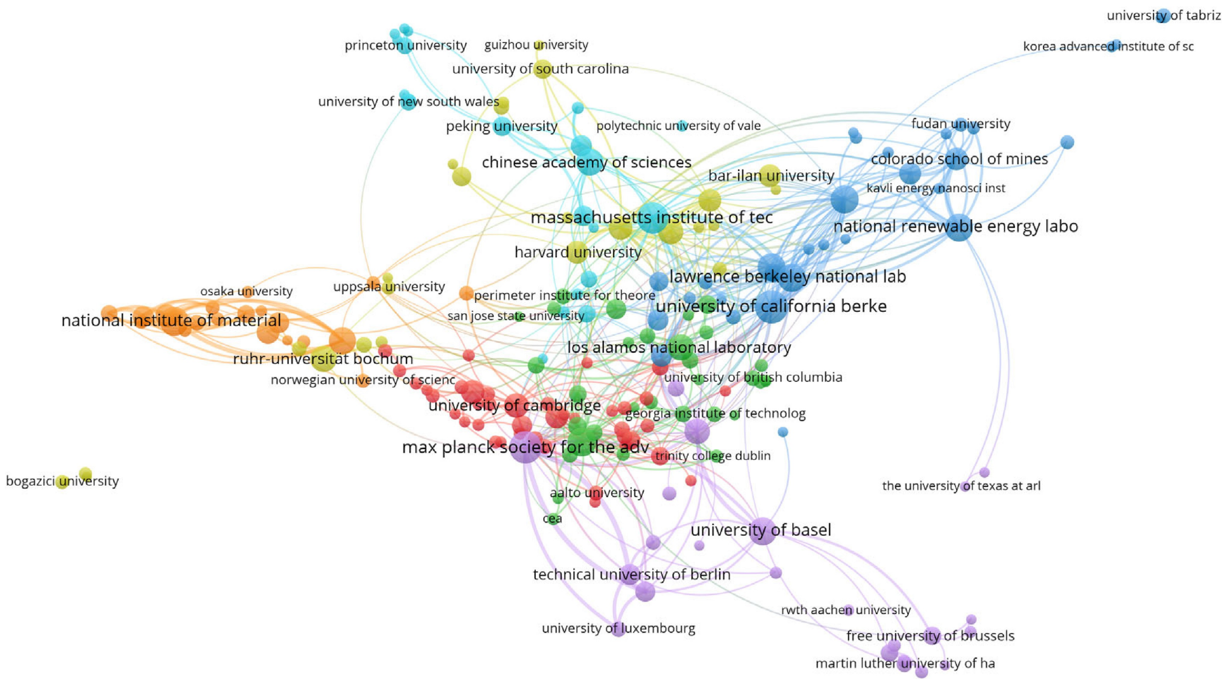

Figure 6. Organization co-publishing network for MAP. Minimum node (organization name) weight is set to 4.

(regardless of indicator). EU & associated performs worse than China and North America for the publication-level citation impact indicators *cf* and *Ptop10%*. EU & associated performs better with respect to the two journal-level citation impact indicators, *jcf* and *Jtop25%*, compared to *cf* and *Ptop10%*.

China has a remarkable increase in publication volume over time (Figure 7). However, this is a general trend for Chinese research.[26] There is a decrease in publication volume for North America in later years. This outcome is perhaps surprising. Note that China, EU & associated and North America have similar *cf*

Table 5. Indicator values by country/country aggregate.

Region	*P full*	*P frac*	*cf*	*Ptop10%*	*jcf*	*Jtop25%*	*IntColl%*
EU & associated	557	476.2	0.95	8.8%	1.31	48.0%	34.8%
China	1,338	1184.6	1.08	11.0%	1.19	42.1%	27.5%
JKS	256	206.7	0.73	6.2%	1.10	36.5%	37.9%
North America	727	575.3	1.07	11.4%	1.49	60.8%	39.9%

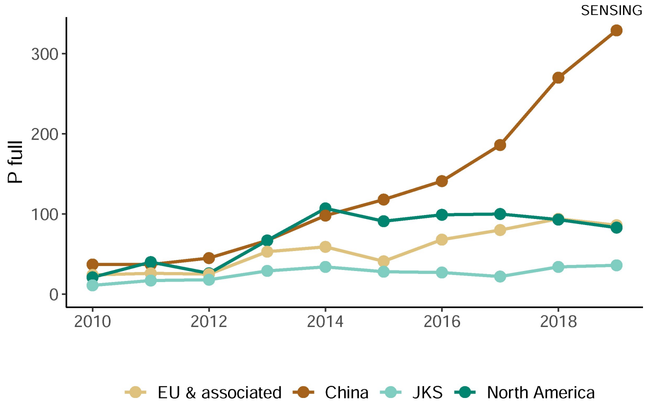

Figure 7. Publication volume (*P full*) development by country/country aggregate.

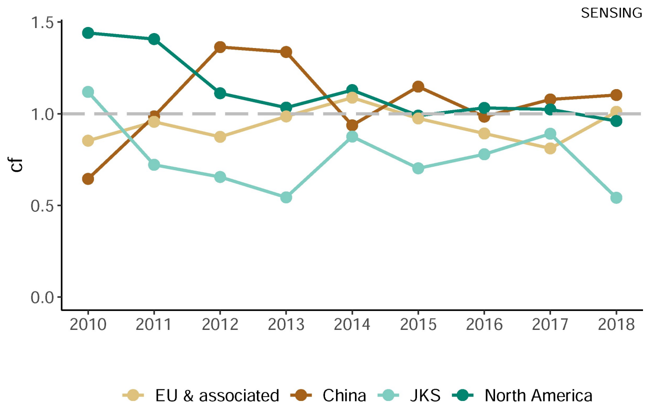

Figure 8. Publication-level citation impact (*cf*) development by country/country aggregate.

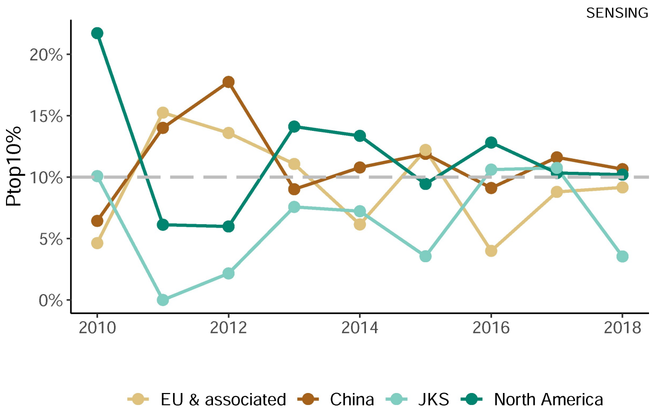

Figure 9. Publication-level citation impact (*Ptop10%*) development by country/country aggregate.

and *Ptop10%* performance for the last considered publication year, 2018 (Figures 8 and 9).

4.2.2. Organizations

Table 6 puts forward indicator values for the top 10 organizations among EU & associated and the top 1 organization from China, North America and JKS with respect to *P full*. It should be kept in mind that other organizations from China, EU & associated, JKS and North America can have widely different citation impact values (the indicators *cf*, *Ptop10%*, *jcf* and *Jtop25%*) compared to the selected organizations.

Among the 10 organizations from EU & associated, Chalmers University of Technology, Jülich Aachen Research Alliance, JARA and RWTH Aachen University all have strong citation impact performance, regardless of indicator. Perhaps somewhat surprisingly, the number of articles (*P full*) per organization in EU & associated is small. Tsinghua University, China, has a very competitive performance regarding citation impact indicators, especially for the publication-level indicators *cf* and *Ptop10%*.

Sunwoda Electronic Co, which is a battery producer also for the vehicle industry, is the company with the highest publication volume (21). In general, many car companies publish in Sensing, for instance General Motors Company and Mitsubishi Corporation.

4.2.3. Bibliometric networks

The network in Figure 10 gives an overview of the author keywords used in the articles selected for the Sensing subfield. The left side of the network is dealing with applied battery performance-related aspects of sensing. The blue cluster is primarily associated with concepts related to battery charge state (i.e. state of charge, open circuit voltage). The yellow cluster relates to battery lifetime aspects (i.e. state of health), whereas the green cluster clearly represents battery safety-related topics (i.e. heat generation, fire behavior). On the other side, the purple cluster is more directly dealing with specific sensing technologies. The optical methods indicated should primarily be seen as examples (e.g. Fiber Bragg grating-based sensing).

The networks in Figures 11 and 12 show the collaboration networks between countries and organizations within Sensing, respectively. In terms of publication volume, Canada and United

Table 6. Indicator values by organization. The top 10 organizations among EU & associated and the top 1 organization from China, North America and JKS with respect to *P full*.

Organization	*P full*	*P frac*	*cf*	*Ptop10%*	*jcf*	*Jtop25%*	*IntColl%*
University of Mons	36	24.0	0.86	6.4%	1.48	57.0%	58.3%
RWTH Aachen University	34	18.5	1.88	18.3%	1.52	67.3%	8.8%
Free University of Brussels	32	24.0	1.19	13.2%	1.21	43.5%	34.4%
Chalmers University of Technology	30	11.3	1.87	33.0%	1.56	67.7%	53.3%
Technical University of Munich	21	16.6	0.46	0.0%	0.90	20.3%	28.6%
Karlsruhe Institute of Technology	15	12.0	0.74	0.0%	1.47	72.2%	13.3%
Aalborg University	15	8.6	0.95	2.3%	1.15	33.3%	80.0%
Jülich Aachen Research Alliance, JARA	15	6.7	2.14	15.2%	1.64	81.9%	6.7%
RISE – Research Institutes of Sweden	11	5.0	1.12	20.1%	1.11	47.1%	0.0%
Ikerlan	10	5.3	1.57	8.7%	1.52	65.4%	30.0%
Tsinghua University (CH)	134	81.2	1.91	20.2%	1.30	52.6%	26.9%
Nanyang Technological University (JKS)	37	22.6	1.26	14.9%	1.48	45.2%	62.2%
Carleton University (NA)	68	42.0	0.93	10.8%	1.45	60.4%	58.8%

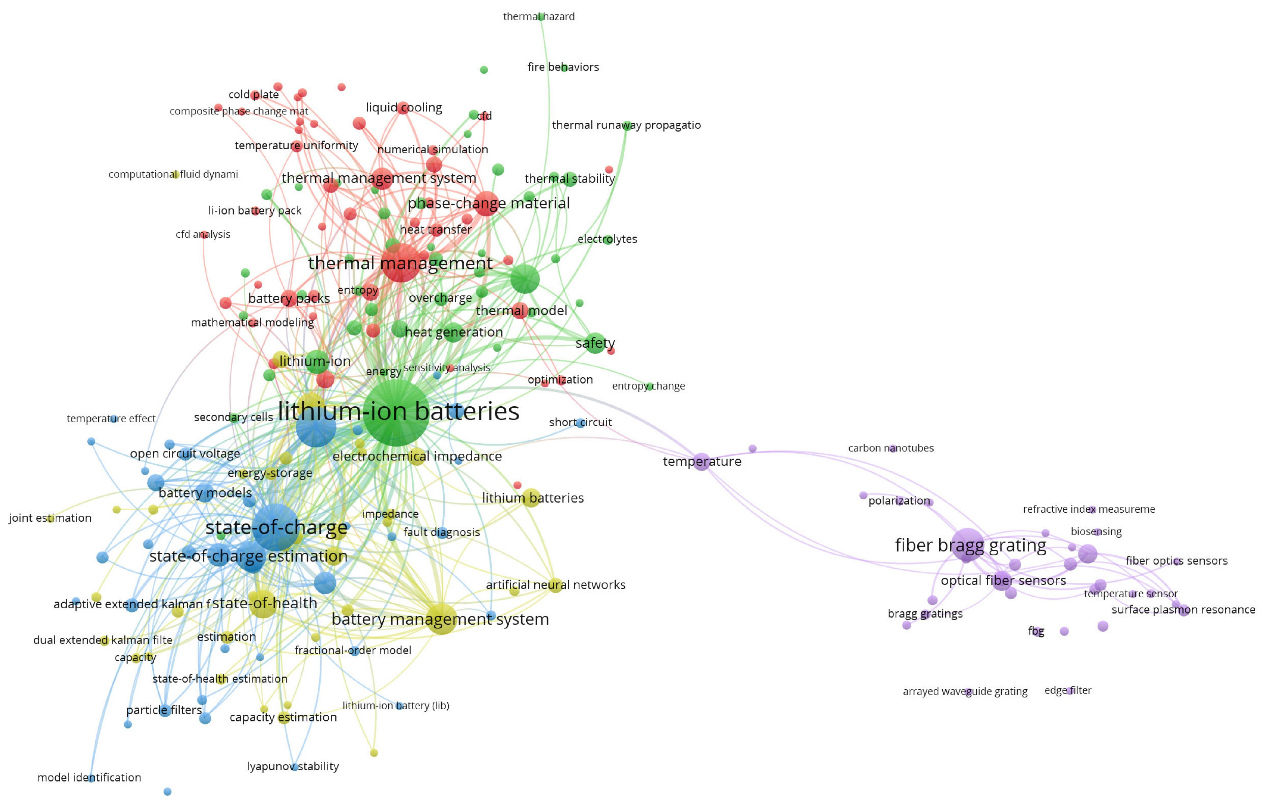

Figure 10. Author keyword co-occurrence network for Sensing. Minimum node (author keyword) weight is set to 6.

Kingdom are more prominent in relation to China and US in comparison to the subfield MAP (Figure 11; the node for Canada is the relatively large, green node near the node for US). The network of Figure 12 is somewhat unstructured but dominated by Chinese organizations. Most of the European organizations seem to be located in the lower part of the map, close to several Canadian organizations.

4.3. The BATTERY 2030+ field-WIDE

In this section, we give the results for the BATTERY 2030+ field as a whole, operationalized as the article set WIDE.

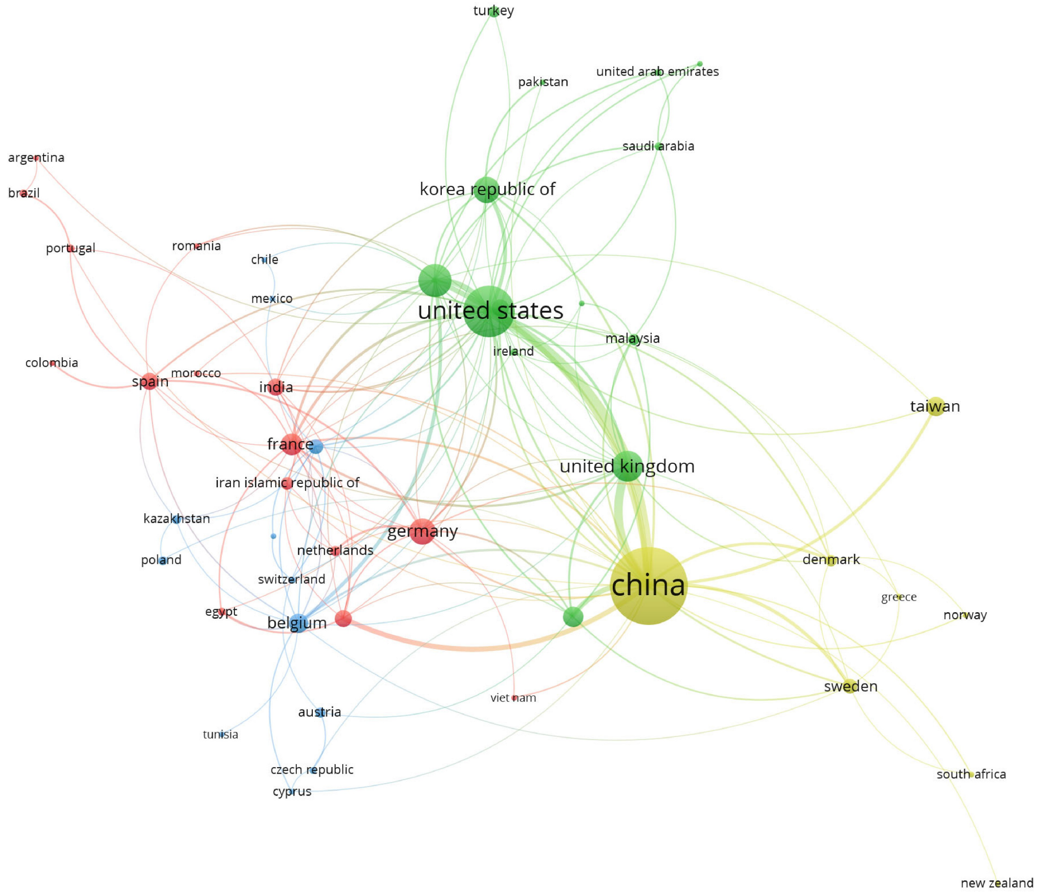

Figure 11. Country co-publishing network for Sensing. Minimum node (country name) weight is set to 3.

4.3.1. Country/country aggregates

In Table 7, indicator values by country/country aggregate and for the whole publication period are given. It is clear from the table that North America is very strong in all four citation impact indicators. EU & associated, China and JKS have a similar overall citation impact performance. Regarding volume and *P full* values over time (Figure 13), China has a remarkable increase. Moreover, for each considered year, China has a higher *P full* value than North America. For *cf* and *Ptop10%* values over time, North America has considerably higher values than EU & associated, China and JKS for all considered years (Figures 14 and 15). EU & associated exhibits a weak *Ptop10%* trend from 2014 onwards. For international co-publishing (*IntColl%*), EU & associated and North America have the highest shares among the four units, 47.3% and 45.6%, respectively, whereas China has the lowest, 23%.

4.3.2. Organizations

Table 8 puts forward indicator values for the top 10 organizations among EU & associated and the top 1 organization from China, North America and JKS with respect to *P full*. It should be kept in mind that other organizations from China, EU & associated, JKS and North America can have widely different citation impact values (the indicators *cf*, *Ptop10%*, *jcf* and *Jtop25%*) compared to the selected organizations.

Germany has a strong foothold in the WIDE: five out of ten in EU & associated are German universities or research institute.

Table 7. Indicator values by country/country aggregate.

Region	*P full*	*P frac*	*cf*	*Ptop10%*	*jcf*	*Jtop25%*	*IntColl%*
EU & associated	10,624	8,573.5	0.88	7.8%	1.49	47.0%	47.3%
China	32,837	29,718.4	0.95	9.4%	1.43	44.9%	23.0%
JKS	11,682	9,739.1	0.90	8.8%	1.49	48.3%	33.2%
North America	14,491	10,865.3	1.52	17.1%	2.01	63.4%	45.6%

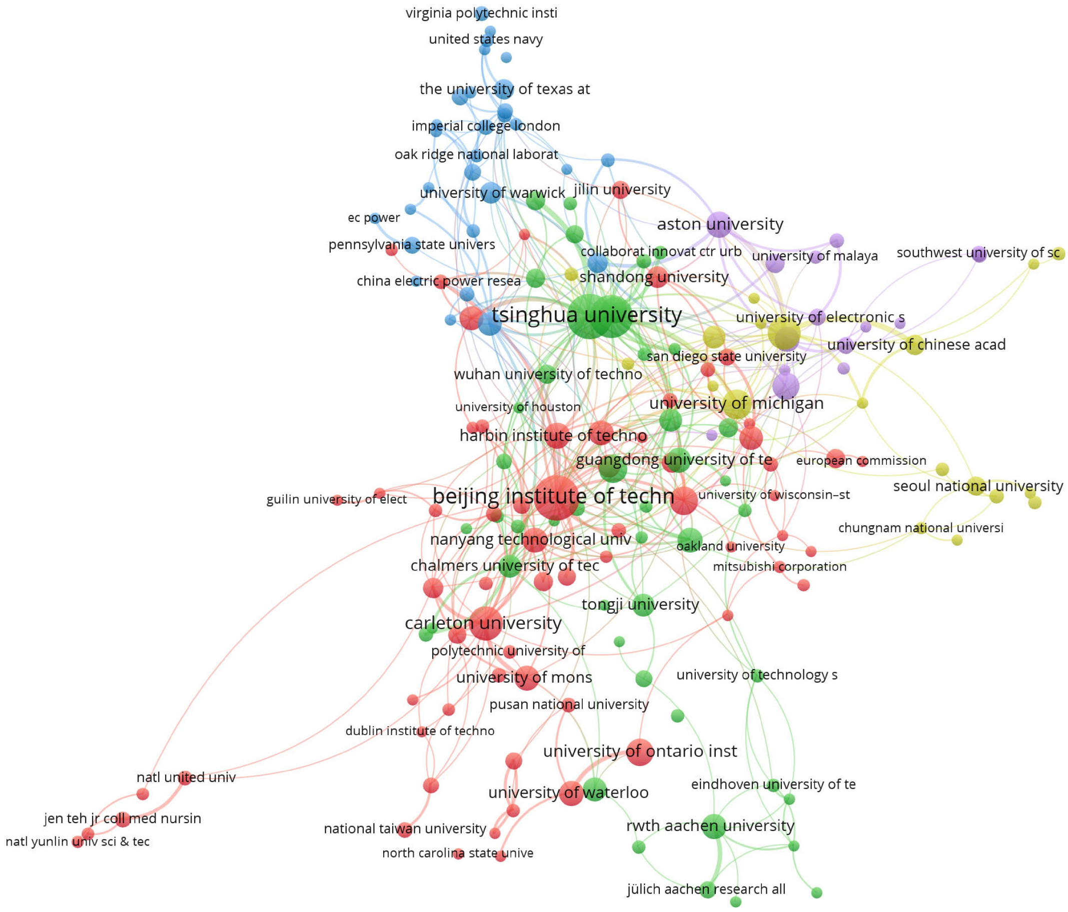

Figure 12. Organization co-publishing network for Sensing. Minimum node (organization name) weight is set to 6.

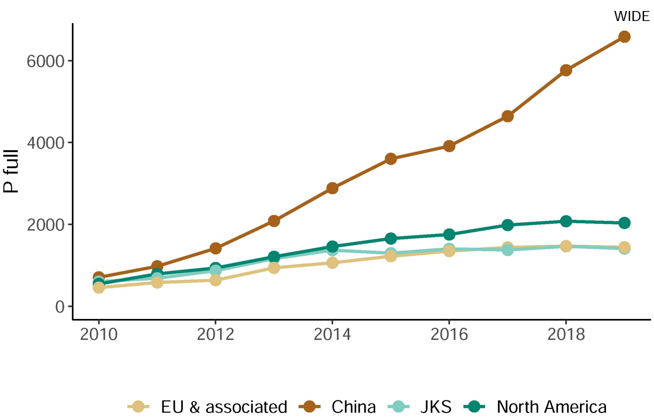

Figure 13. Publication volume (*P full*) development by country/country aggregate.

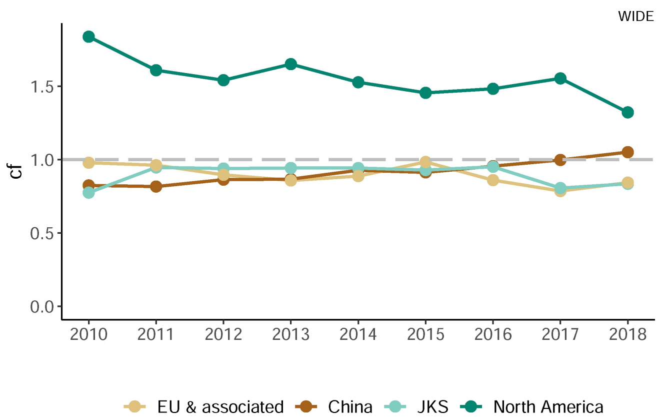

Figure 14. Publication-level citation impact (*cf*) development by country/country aggregate.

When it comes to companies in WIDE, and based on publication volume, many of the most prominent ones are represented by research activities in US. The four companies with the highest publication volumes are Samsung (324), Toyota (223), General Motors Company (213) and BASF[27] (150). Among the top 15, two EU companies are represented, based on research activities from within Europe, both in Germany: BMW Group and Daimler AG.

4.3.3. Bibliometric networks

The network in Figure 16 gives an overview of the author keywords used in the articles selected for WIDE. In this relatively wide operationalization of the BATTERY 2030+ field as a whole, we observe that the network is not very differentiated. The green cluster seems to be related the negative electrode and possibly to the next-generation electrodes. The blue cluster

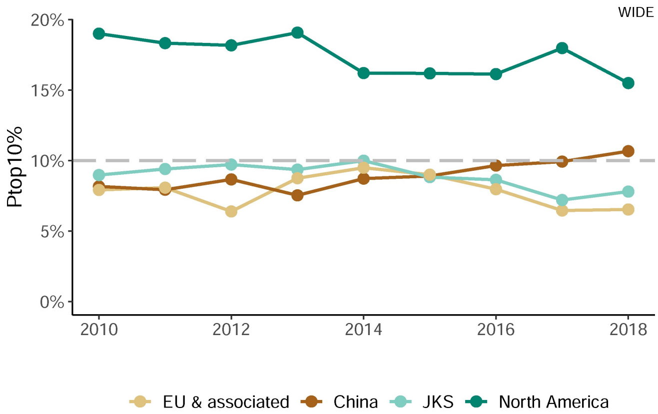

Figure 15. Publication-level citation impact (*Ptop10%*) development by country/country aggregate.

deals more with classical Li-ion batteries with a focus on the positive electrode. The red cluster seems to focus on the electrolyte but is less material-oriented compared to the blue and green clusters. In the red cluster also the link between electrolyte concepts and the topics in BIG and MAP, such as machine-learning and neural networks, is discerned, as well as topics related to Sensing (e.g. thermal management, state-of-health and state-of-charge). The yellow cluster mainly captures self-healing. This network provides a broad, general overview of battery research, especially related to lithium batteries.

The networks in Figures 17 and 18 show the collaboration networks between countries and organizations within WIDE, respectively. As in the Sensing subfield, China and US dominate the country network (Figures 17 and 11). Regarding EU & associated, the countries with the largest publications volumes are Germany and France, and the two corresponding nodes are positioned close to each other. For the organization network (Figure 18), the different regions are fairly separated. There are, however, many collaboration links between Chinese organizations (green and yellow nodes) and US organizations (blue nodes).

5. Discussion

In this work, we have used bibliometric methods to analyze battery research with the BATTERY 2030+ roadmap as point of departure. We focused on two of the six battery research subfields identified in the BATTERY 2030+ roadmap: Materials Acceleration Platform (MAP) and Smart functionalities: Sensing. Moreover, we analyzed the BATTERY 2030+ field as a whole. In the following list, we repeat the overarching aims of the analysis:

(a) to evaluate the European standing in the two subfields/the BATTERY 2030+ field in comparison to the rest of the world,

(b) to identify strongholds of the two subfields/the BATTERY 2030+ field across Europe.

In the remainder of this section, we reflect on the results, put forward methodological limitations and give conclusions.

5.1. Reflections on the results

For point (a) above, EU & associated has similar but slightly lower publication volumes compared to North America for WIDE and for Sensing. However, in MAP, the publication volume from North America stands out as considerably larger. North America has been a very early adopter of data-driven methodologies (AI/ML) in materials sciences with large-scale research initiatives, such as Material Genome Initiative,[28] which is believed to be reflected in their higher publication volumes in the field. Also note that in MAP, but not in Sensing, North America and EU & associated have a higher volume than China, which has yet to catch up. The citation performance (cf and Ptop10%) of EU & associated is similar to China and JKS and

Table 8. Indicator values by organization. The top 10 organizations among EU & associated and the top 1 organization from China, North America and JKS with respect to *P full*.

Organization	*P full*	*P frac*	*cf*	*Ptop10%*	*jcf*	*Jtop25%*	*IntColl%*
Karlsruhe Institute of Technology	660	322.6	0.97	8.3%	1.54	54.7%	42.7%
University of Münster	447	301.5	0.87	6.9%	1.44	49.6%	22.8%
Technical University of Munich	325	195.8	0.99	9.1%	1.36	37.6%	41.2%
Max Planck Society	325	149.6	2.19	34.6%	2.52	73.0%	72.9%
Uppsala University	324	207.5	0.71	4.5%	1.61	57.6%	55.9%
Forschungszentrum Julich	311	94.2	0.79	4.1%	1.41	44.5%	37.0%
University of Picardy Jules Verne	289	108.8	1.26	15.6%	1.91	64.8%	55.4%
French National Centre for Scientific Research	250	73.7	1.15	5.8%	1.97	60.7%	52.4%
Bar-Ilan University	211	150.2	1.70	12.1%	1.63	51.9%	66.4%
Sapienza University of Rome	210	98.2	1.40	10.3%	1.56	54.6%	63.3%
Chinese Academy of Sciences (CH)	4,200	2,286.2	1.39	15.2%	1.73	55.8%	22.2%
Nanyang Technological University (JKS)	871	507.0	2.40	33.2%	2.15	70.0%	64.1%
Argonne National Laboratory (NA)	1,043	518.4	1.38	16.0%	2.21	69.8%	45.3%

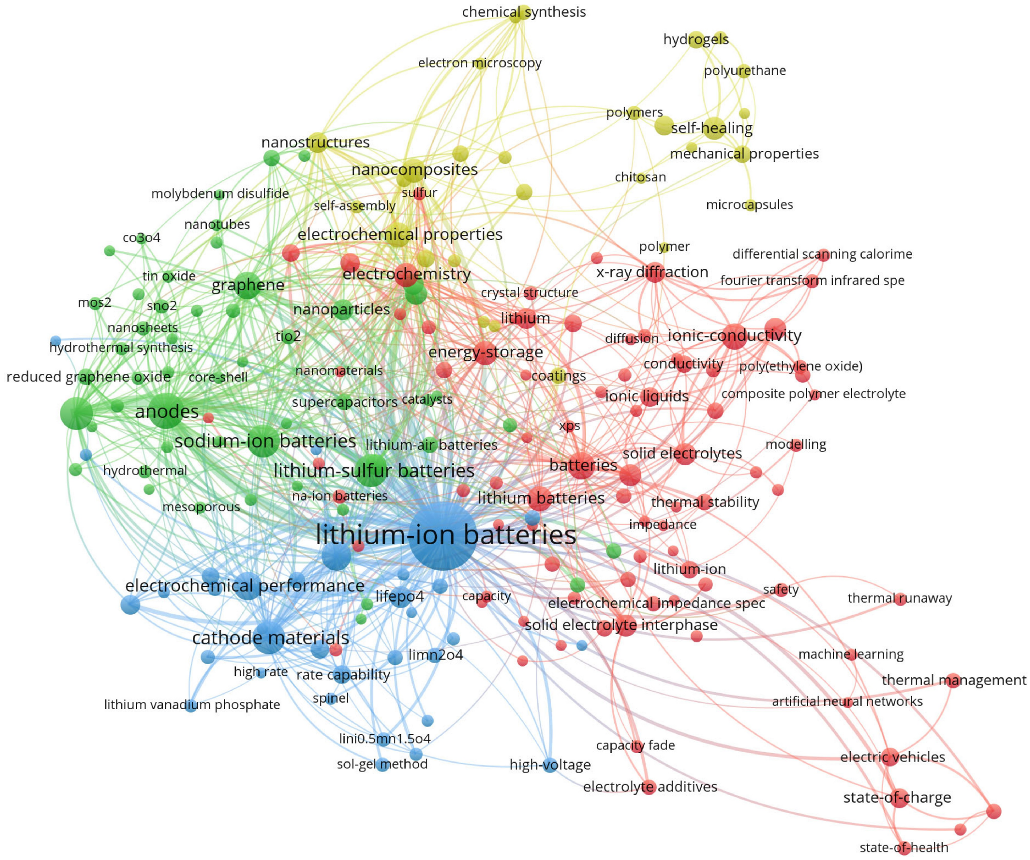

Figure 16. Author keyword co-occurrence network for WIDE. Minimum node (author keyword) weight is set to 100.

well below North America with regard to WIDE. North America, its elite universities, and national laboratories, have already had several decades of well-funded research schemes and large-scale long-term research initiatives targeting battery research involving internationally leading scientists. Europe and China are however gaining momentum, and focusing on the end of the study period, EU & associated has a stronger citation performance, in relative terms, in MAP compared to Sensing. Switzerland is well represented in MAP, likely supported by the strong international standing of its pharmaceutical industry and associated academics when it comes to integrate similar methodologies developed in MAP.

For point (b) above, Karlsruhe Institute of Technology and Max Planck Society are EU & associated organizations with high publication volumes in WIDE. Both organizations host internationally well-known and prominent scientists in the field. In the two subfields, there is a large variability in the top EU & associated organizations regarding volume. For citation impact (cf and Ptop10%), the performance of the EU & associated organizations is quite variable with some performing well above world average and some with a more modest performance. Examples of high-performing (cf and Ptop10%) EU & associated organizations are Chalmers University of Technology (in Sensing), Max Planck Society (in MAP and WIDE) and Technical University of Berlin (in MAP). Again, these institutions host well-known researchers with scientific activities in the fields of batteries and sensors.

Some subfields from the BATTERY 2030+ roadmap are easier to define from a conceptual view and other less so. For instance, aspects of Sensing are easier to pinpoint than the more process-oriented and conceptual subfield MAP. Therefore, the selection of clusters for the more forward-looking subfield MAP was more challenging.

Although the scope of BATTERY 2030+ is essentially chemistry neutral, lithium-based rechargeable battery chemistries are today associated with large publication volumes and as representative for the highest performing battery systems act as benchmark and take-off point for alternative chemistries. This up to present dominance of lithium-based chemistries is clearly reflected in the available literature in the field.

One thing to comment on is the overall scope of the study. The methodology used here, going from seed articles to potential clusters, followed by selection of clusters for subfields (with the aim of targeting these specific subfields), probably leads to a relatively narrow interpretation of the battery field, primarily targeting the perceived scope of BATTERY 2030+. However, to view the battery field as a whole, a much wider perspective could also have been utilized, compared to the perspective underlying the generation of WIDE, where not only battery research but also related research and technologies from e.g. applied physics, chemistry and recycling technology

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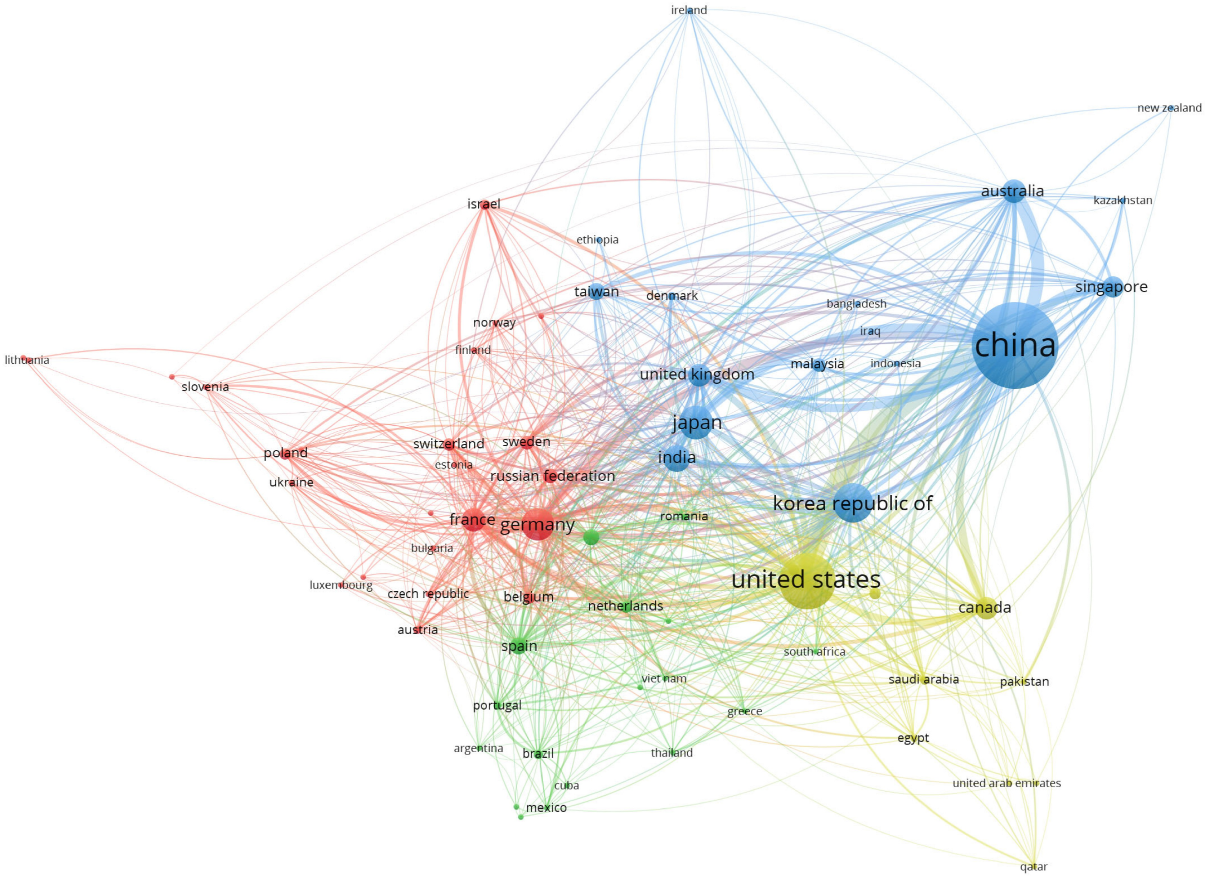

Figure 17. Country co-publishing network for WIDE. Minimum node (country name) weight is set to 15.

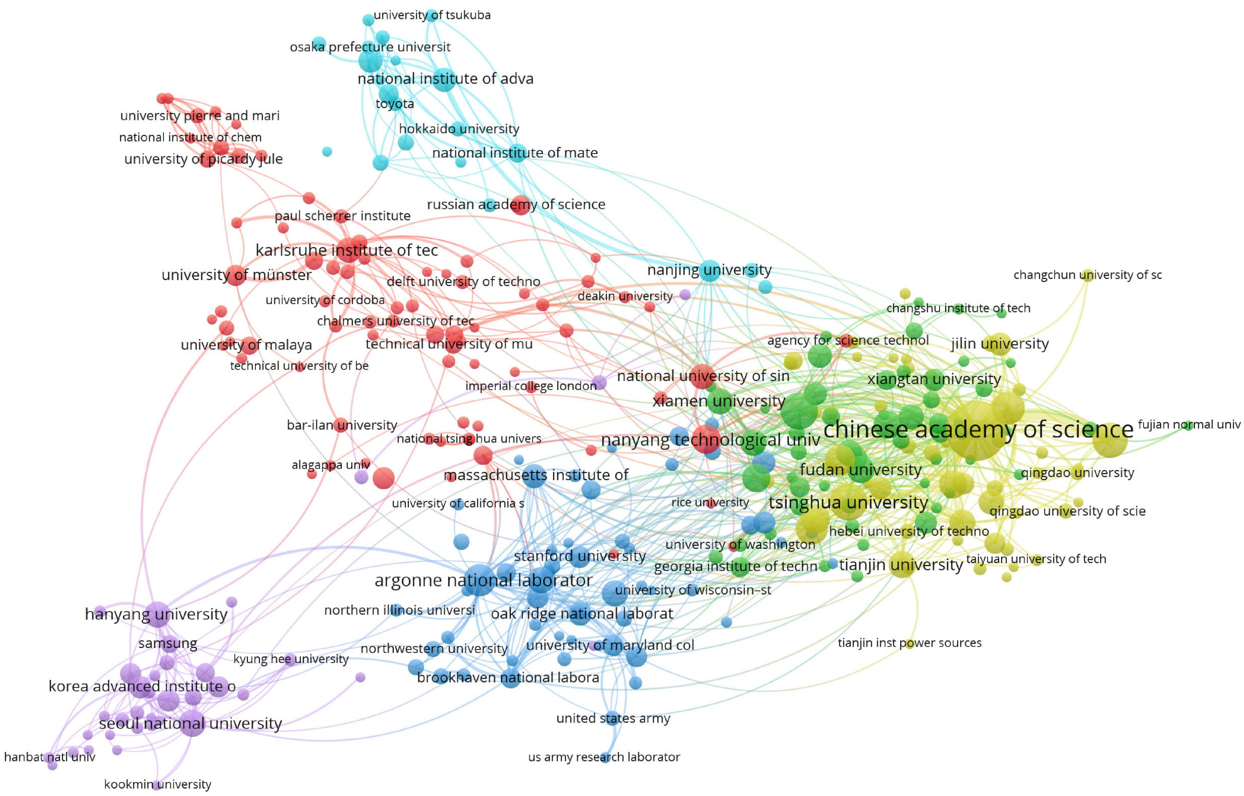

Figure 18. Organization co-publishing network for WIDE. Minimum node (organization name) weight is set to 85.

could have been included. If using the same type of cluster methodology, such a study could have selected clusters at a higher level (level-3) or pooled a much larger set of level-2 clusters. Clearly, such a study would be more loosely tied to BATTRY 2030+, but might be relevant for an even wider overview of the relative strength of different geographical regions and research organizations.

5.2. Methodological limitations

Our approach is based on publication clustering, which in turn is based on direct citation relations. This has the advantage of providing a relatively objective basis for subject delineation, and it also does not require time consuming compilation and expert curation of publication sets that are deemed relevant for different subject areas. As such, the method is not sensitive to human biases on notions of subject field relations, literature from different parts of the world etc. However, a crucial step in using clusters to represent subject fields lies in the identification and selection of clusters. In this study, we have used seed articles from the BATTERY 2030+ roadmap for identification of potential clusters and expert-based screening of clusters.

Another thing to keep in mind is that each article in the modularity-based clustering is placed in exactly one cluster. This means that articles that fall in-between two subject areas will be placed in exactly one cluster. Among many potential ways to delineate subject areas, one will also dominate, based on the citation relations within the literature. As an example, of interest in this study, sensors in batteries can be approached both from a technical point of view (i.e. sensing technology, and ways to measure aspects of battery state) or from the approach of the battery states that need to be monitored and measured (i.e. state of charge, state of health etc.). In the article clusters, the second perspective dominates, mainly because of citation practices within the fields. However, this places a clear limitation on the selection of clusters, and it also means that studies of the technical perspective in the sensor example above will be more challenging to identify.

Another approach to obtaining article sets for subfields is to use search queries. However, an advantage of the approach followed in this work compared to the search query approach is that the former is not dependent on the identification of search terms standing for the same or nearly the same concept. This is because the articles in the classification system have been clustered based on direct citation relations between them, and not based on textual similarity. The article set for a given subfield may contain articles (pertinent to the subfield) that treat a certain topic but doing this by using partially different terminologies. With the search query approach, the used query may fail to retrieve some of these articles. On the other hand, a possible advantage with search queries is the ability for fine grained control over the selection, when this is needed, for a user with deep knowledge of the subject field.

One further caveat worth mentioning is that the cluster selection for subfields has been relatively independent and can follow slightly different principles. For instance, the relevant literature can be seen in more broad terms or more narrowly, as only directly relevant to e.g. lithium-ion batteries.

5.3. Conclusions

We put forward tentative conclusions and observations in the list below.

- EU & associated are relatively well represented (as countries and organizations) in the two subfields, but is lagging North America in publication volume regarding MAP towards the end of the study period. As mentioned above, North America has been a very early adopter of data-driven methodologies (AI/ML) in materials sciences with large-scale research initiatives, such as Material Genome Initiative, which is believed to be reflected in their higher publication volumes in the field.
- Looking at the two subfields and focusing on the end of the study period, EU & associated has the strongest citation performance, in relative terms, in MAP. For WIDE, China is showing stronger citation impact than EU & associated towards the end of the study period. Clearly, battery research and development in China has massively expanded at a much higher pace during the past decade, compared EU and North America, and the results of that is now reflected in their respective publication output from Chinese scientists.
- None of the themes in BATTERY 2030+ are established but rather emerging multidisciplinary scientific fields, which vary strongly in the degree to which they are connected to traditional subfields in battery research.
- Our study clearly shows that topics in MAP, such as neural networks, are currently mostly applied to battery electrolytes, but aspects associated with the electrodes are expected to receive increasing future focus with several research constellations within the Battery 2030+ framework being proliferate.
- The clusters in the Sensing subfield are clearly divided into two parts. One related to battery performance characteristics, which are intended to be probed by sensors, and the other related to the technical aspects of sensor operation. Although optically based methods are primarily represented, there are a number of other sensing technologies gaining momentum (e.g. acoustic emission sensing) and expected to result in significantly higher future publication volumes.

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Conflict of Interests

The authors declare no conflict of interest.

Keywords: BATTERY 2030+ · batteries · bibliometric analysis · bibliometric networks · citation impact.

[1] https://battery2030.eu/.
[2] J. Amici et al., *Adv. Energy Mater.* **2022**, *12*, 2102785.
[3] https://battery2030.eu/research/roadmap/.
[4] P. Ahlgren, T. Jeppsson, E. Stenberg, E. Berg, K. Edström, *A bibliometric analysis of battery research with the BATTERY 2030+ roadmap as point of departure*, Uppsala University, Uppsala, **2022**.
[5] Albania, Armenia, Bosnia and Herzegovina, Faroe Islands, Georgia, Iceland, Israel, Moldova, Montenegro, North Macedonia, Norway, Serbia, Switzerland, Tunisia, Turkey, and Ukraine.
[6] E. Schiebel, *Scientometrics.* **2012**, *91*, 557–566.
[7] K. Vignarooban, R. Kushagra, A. Elango, P. Badami, B. E. Mellander, X. Xu, T. G. Tucker, C. Nam, A. M. Kannan, *Int. J. Hydrogen Energy.* **2016**, *41*, 2829–2846.
[8] D. B. Agusdinata, W. Liu, H. Eakin, H. Romero, *Environ. Res. Lett.* **2018**, *13*, 123001.
[9] M. Li, J. Jang, S. Liang, H. Hou, J. Hu, B. Liu, R. V. Kumar, *J. Power Sources.* **2019**, *436*, 226853.
[10] A. Torayev, P. Magusin, C. Grey, C. Merlet, A. Franco, *JPhys Materials.* **2019**, *2*, 044004.
[11] L. F. Cabeza, A. Frazzica, M. Chàfer, D. Vèrez, V. Palomba, *J. Energy Storage.* **2020**, *32*, 101976.
[12] T. Liu, H. Hu, X. Ding, H. Yuan, C. Jin, J. Nai, Y. Liu, Y. Wang, Y. Wan, X. Tao, *Energy Storage Mater.* **2020**, *30*, 346–366.
[13] Y. Hu, Y. Yu, K. Huang, L. Wang, *J. Energy Storage.* **2020**, *27*, 101111.
[14] J. Liu, J. Li, J. Wang, *J. Energy Storage.* **2021**, *35*, 102253.
[15] S. B. Wali, M. A. Hannan, P. J. Ker, M. S. Abd Rahman, M. Mansor, K. M. Muttaqi, T. M. I. Mahlia, R. A. Begum, *J. Cleaner Prod.* **2022**, *334*, 130272.
[16] S. Zhao, J. Quan, T. Wang, D. Song, J. Huang, W. He, G. Li, *Environ. Sci. Pollut. Res. Int.* **2022**, *29*, 9448–9461.
[17] L. Waltman, N. J. van Eck, *J. Am. Soc. Inf. Sci. Technol.* **2012**, *63*, 2378–2392.
[18] M. E. J. Newman, *Phys. Rev. E.* **2004**, *69*, 066133.
[19] M. E. J. Newman, *Phys. Rev. E.* **2004**, *70*, 056131.
[20] However, if the feedback given in step 5 indicated that additional articles should be added to the set S_a, S_a was expanded and steps 3–5 were iterated one time (in this case, the same subject expert(s) performed the new analysis).
[21] Recall that six subfields were analyzed in Ahlgren et al.[4].
[22] P. Ahlgren, L. Kennerberg, *Uppsala University Annual Bibliometric Monitoring 2021*, Uppsala University, Uppsala, **2021**.
[23] http://www.kth.se/polopoly_fs/1.544479!/Formal%20definitions%20of%20field%20normalized%20citation%20indicators%20 at%20KTH.pdf.
[24] N. J. van Eck, L. Waltman, *Scientometrics.* **2010**, *84*, 523–53.
[25] We use "Max Planck Society" as an abbreviation for "Max Planck Society for the Advancement of Science".
[26] C. Cao, J. Baas, C. S. Wagner, K. Jonkers, *Sci. Public Policy.* **2020**, *47*, 172–183.
[27] Based on research from their US branch.
[28] http://www.mgi.gov/.

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