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Battery research and innovation – a study of patents and papers

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Executive Summary

This study of patent applications and scientific publications related to batteries is unique as it includes the volume of as well as and qualitative indicators for both types of publications. The results show that China's dominance in publication volumes increases and that research with Chinese involvement is highly cited whereas the patent applications are slightly less valued than the world average. Quality-related indicators for Canada and the United States are very high for both scientific publications and patent applications. National differences in the proportions of patent applications and scientific publications are large, with Japan in the one end with three patent applications per scientific paper and Canada in the other end with almost seven scientific papers per patent application. Finally, it is noted that this new approach to study a technological field appears promising as it gives new perspectives of relevance for policy actors and others.

Keywords: battery, research, patents, innovation, scientometrics.

1 Introduction

Battery business is expanding rapidly. There is a global race to gain leadership along the whole battery value chain. Interestingly, even though production capacity is being scaled very rapidly, the investments in research are still also expanding dramatically. Many companies and countries try to gain market shares by developing competitive battery solutions. One decisive aspect is knowledge. With superior knowledge and associated intellectual property rights, the chances to gain and maintain a strong position increase.

The purpose of this study was to develop and test a method to analyze battery-related research and innovation. Through the use of two types of publications, patents and papers, this study addressed two steps in the value chain; research and innovation. By patents we mean patent applications as well as granted patents, and papers are here equal to articles, conference papers, books, book chapters and reviews indexed in Scopus.

Compared to other studies of patents or papers [1-6], this study is unique as it includes both the volume of and qualitative indicators relating to the publications.

2 Methodology and data

Critical for the study was to identify relevant publications. Patents were selected based on a method described and used in an ambitious recent project led by IEA [7]. The Swedish Intellectual Property Office was in April 2022 commissioned to retrieve all battery patents, which then were further analysed in a database for patent value assessment. Patent data until and including 2019 was considered sufficiently complete to be used in the analysis.

Papers were selected using search terms in Scopus to be matched in the title or abstract of the paper. Scopus is the broadest abstract and citation database [8]. The query was developed in an iterative process, involving manual scrutiny of randomly selected papers to ensure that only relevant papers were selected. Papers from six productive battery researchers in Canada, the United States, Japan and Sweden were used to test if the query covered a sufficiently large share of these researchers' battery-related papers. The iterative process is described with some details in [9]. At the time of the study (June 2022), volume data for papers was almost complete until and including 2021.

The resulting query included hundreds of search terms, whereof a few terms in closely related fields were not allowed to be mentioned, such as "fuel cells". This approach led to an unexpected problem, as the standard query looks for matches in the title, abstract and keywords. It was noted that the keywords include both the keywords given by the author(s) and other keywords, probably added by the journal. The latter keywords were in some cases broader, thus covering related fields not addressed in the paper. They did not work in combination with the "AND NOT" part of the query and thus a query only looking in the title and abstract was used.

It is very difficult to capture all "battery-related" papers as blue sky research, for example, is not always mentioning potential applications. Therefore, the resulting query underestimates the total volume and has a bias towards more applied battery research. A team of three battery experts from academy, business and government supported in the development of the query.

The technical and economic value of patents was assessed using a composite index, the Technology Business Index (TBI), which combines several indicators, among them the patent's scope, family size, originality, generality, and backward and forward citations [10-12]. Percentiles were used to differentiate the patents, top 30% and top 10%.

For papers, standard citation indicators such as percentiles and the field-weighted citation impact were used. The latter is a normalised indicator based on the field, year and type of publication. An average paper has FWCI 1.00 and if the paper has FWCI equalling 1.50, it is cited 50% more than the average publication.

Given the sponsor of the project, the analysis had a focus on Sweden and the selection of countries for comparison was made from a Swedish perspective. In total 11 countries were covered, whereof some are not included in this paper, as they have relatively low patent volumes. Also, below are only results on country level presented. The study did also include attempts to study institutions and individuals. For example, do the researchers with many papers also have patents? This part of the study was associated with a lot of manual work and it was only carried out for Sweden. The main reason why this was laborious was the patent data quality, which made it difficult to identify people and institutions, as the names were indicated in many different ways.

3 Results

3.1 Volumes of patents and papers

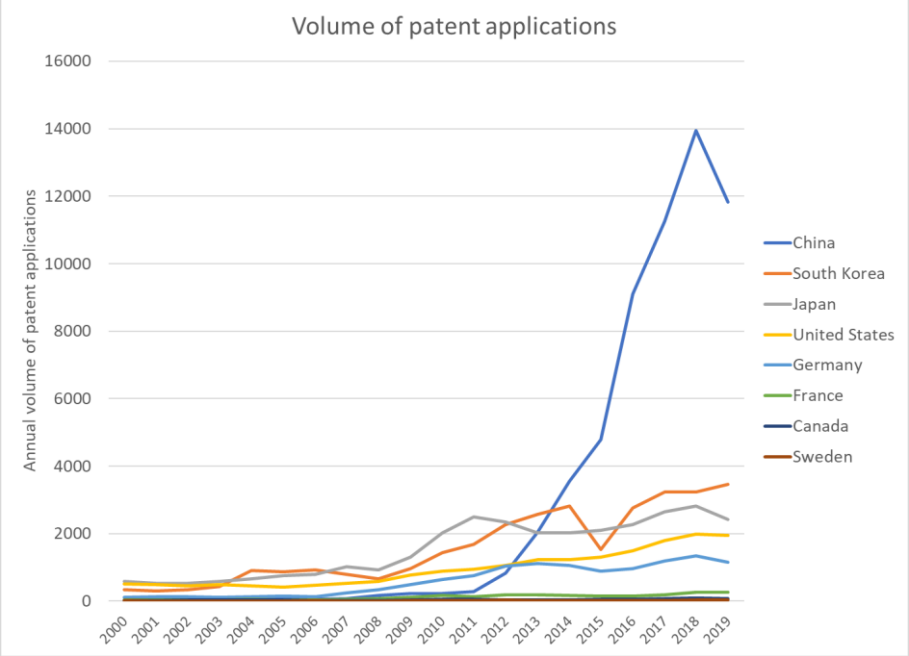

Figure 1: Development of patent volumes

The volumes of publications increase rapidly over the period studied, as Figure 1 and Figure 2 show. Interestingly, the volumes of patents and papers are relatively similar, which facilitates comparisons. China dominates in both types of publications. It has been the largest producer of battery papers since 2005 and patents since 2014. The dip for China in 2019 in Figure 1 might be due to incomplete patent data.

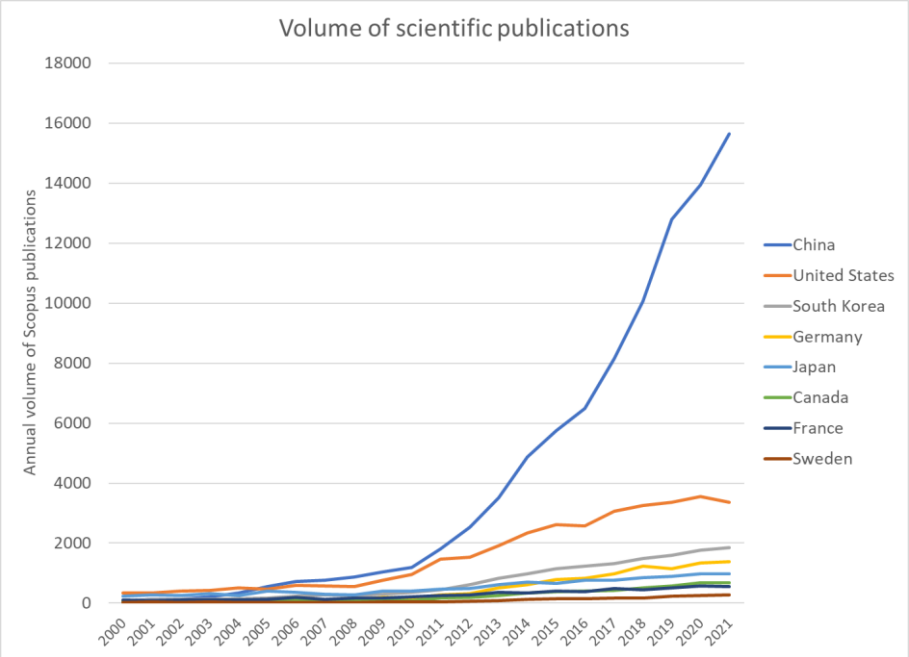

Figure 2: Development of paper volumes

Three six-year periods were used to obtain a sufficient volume of patents for each period. In Table 1, the volumes of patents and papers for these three periods are presented.

Table 1: Comparison paper and patent volumes

	2002 - 2007			2008 - 2013			2014 - 2019		
	Paper	Patent	Paper/ patent	Paper	Patent	Paper/ patent	Paper	Patent	Paper/ patent
Canada	389	194	2.01	849	240	3.54	2,619	390	6.72
China	2,717	479	5.67	10,937	3,772	2.90	48,138	54,485	0.88
France	778	274	2.84	1,452	845	1.72	2,572	1,188	2.16
Germany	499	915	0.55	1,582	4,391	0.36	5,604	6,608	0.85
Japan	1,862	4,349	0.43	2,621	11,117	0.24	4,643	14,300	0.32
South Korea	1,076	4,267	0.25	2,813	9,590	0.29	7,788	17,026	0.46
Sweden	159	43	3.70	284	97	2.93	988	149	6.63
United States	2,984	2,818	1.06	7,182	5,489	1.31	17,216	9,796	1.76
World	13,775	14,939	0.92	33,831	38,541	0.88	102,132	111,518	0.92

Globally, the number of battery patents is slightly higher than the number of papers leading to a ratio around 0.9. A similar ratio applies for China in the last period included. In some countries, the patent production dominates, among them Japan, South Korea, and Germany. In other, the volumes of papers are clearly larger. Canada, Sweden, France and the United States appear to focus more on research than patenting. For China, the share of patents per paper has increased over the periods, whereas in Canada and the United States, the trend has been in the opposite direction. Globally, the ratio has been rather stable.

Another type of innovation indicator is academic-corporate co-publications, which are defined as scientific publications with at least two co-authors, whereof at least one with an academic and one with a corporate affiliation. A high share of such publications is considered positive for innovations to materialise.

Table 2: Academic-corporate collaboration (2014 – 2019)

Academic-corporate co-publ. (share of)		
Papers:	Batteries	All
Canada	9.0%	4.3%
China	2.0%	2.7%
France	8.3%	6.3%
Germany	11.4%	6.5%
Japan	11.8%	6.4%
South Korea	5.9%	4.9%
Sweden	9.3%	7.5%
United States	5.8%	4.7%

In Table 2, all countries except China have a higher share of academic-corporate papers within the battery field than the average for all papers in the country. In Canada, Germany and Japan, the share is around twice as high.

3.2 Quality-related indicators

In Table 3, two citation-based indicators for papers are presented as well as TBI percentiles for patents. These indicators are explained above in the Methodology and data section. Among the listed countries, battery papers are clearly more cited than all papers. The United States has the highest FWCI as well as the highest share of papers in the top 10% citation percentile. Canada has the second highest FWCI and China the second highest share of papers in the top 10% percentile.

Table 3: Comparison quality-related indicators for papers and patents (2014 – 2019)

	Paper citation data		Patent TBI value	
	FWCI	Top 10%	Top 10%	Top 30%
Canada	2.47	43%	25%	54%
China	2.30	44%	7%	28%
France	1.89	32%	9%	24%
Germany	2.10	37%	6%	16%
Japan	1.60	29%	12%	34%
South Korea	1.89	39%	8%	25%
Sweden	2.24	40%	16%	29%
United States	2.79	46%	23%	50%

The patent TBI values differ more between the countries than the citation impact indicators. Canada has the highest TBI values in both percentiles followed by the United States. Germany and China have the lowest TBI values.

A high share of academic-corporate papers is as stated above considered positive for innovation and it is also of interest to study whether the papers are cited. In Table 4, the citation impact for all battery papers and battery papers with academic-corporate collaboration are compared.

Table 4: Comparison of different types of battery papers

Field-weighted citation impact 2014 - 2019		
Battery papers:	**All**	**Academic-corporate collaboration**
Canada	2.47	2.89
China	2.30	1.89
France	1.89	2.20
Germany	2.10	2.85
Japan	1.60	1.54
South Korea	1.89	2.17
Sweden	2.24	1.49
United States	2.79	2.68

On a global level, academic-corporate co-publications are typically more cited [13]. In the battery field, this is also the case in four of the eight countries, with Germany exhibiting the largest positive difference. Sweden has a relatively large difference in the other direction, here the academic-corporate collaboration did clearly not bring citation benefits.

4 Discussion – what do the numbers tell?

Quantitative studies have limitations and should be interpreted with care. It is often a good idea to use them as an input to generate an informed discussion among the actors in the field. The participation at EVS36 is one attempt to allow for such a discussion.

From a methodological perspective, the chosen approach appears promising. It is important to select a technological field that is large enough to result in reasonable volumes of publications. Analyses based on small numbers of publications do seldom lead to solid results. One critical ingredient in the method was to involve experts in the battery field.

The study confirms the massive development of Chinese patenting and research within the battery field. It is somewhat surprising how different the proportions of patents versus papers are in the countries studied and the diverging trends. The linear innovation model suggests a gradual development from research towards innovation, which in terms of patents and papers would mean that the ratio patent per paper increases over time as the field matures. Data does not indicate such a trend, even though some countries, not least China, clearly had an increasing share of patents from 2002 - 2019. One possible interpretation is that the battery

field still develops rapidly with many new questions arising relating to everything from new chemistries to production methods.

The citation indicators and TBI percentiles highlight that the United States and Canada are strong in both patents and papers. China is stronger in papers, whereas Japan is somewhat stronger in patents. It should be noted that high quantity does not necessarily mean low quality. China, which made almost 50% of the global volume of battery papers in 2014 – 2019, did it with a high citation impact. Japan, which made three times more patents than papers in the same period also managed to get higher TBI values than the global average.

Academic-corporate collaboration is more frequent in the battery field than in general, at least when it comes to such co-publications. The associated citation impact varies between countries, some result in higher values, some in lower than for all battery papers. As the citation impact is an important indicator for researchers, countries with lower citation impact for academic-corporate papers might consider a closer study of how the collaborations are performing.

5 Conclusions

The purpose of this study was to develop and test a method to analyse the volumes of as well as qualitative aspects of patent applications and scientific publications. Battery development in several countries was used as a case. One conclusion is that this approach gives perspectives on battery research and innovation that are new and constitute a valid starting point for further discussions on policy level. The results show that China during 2014 – 2019 dominated quantitatively and increasingly in both types of publications with a development towards higher ratio of patent applications per scientific publications. The quality-related indicators show that the United States and Canada during the same period made highly cited scientific publications as well as patent applications with leading Technology Business Index values.

Acknowledgements

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References

[1] Barbosa W., Prado T., Batista C., Câmara J.C., Cerqueira R., Coelho R., Guarieiro L. (2022) Electric Vehicles: Bibliometric Analysis of the Current State of the Art and Perspectives, *Energies*, 15, 395, https://doi.org/10.3390/en15020395

[2] Chen L., Feng J., Tian Y., An Y. and Dong G. (2021) Knowledge mapping analysis of lithium secondary batteries research based on bibliometrics, *Energy Storage Science and Technology*, 10(3), pp 1196-1205

[3] Dutta B. and Kumarb S. (2021) Scientometric study of lithium ion battery research in India during 1989 to 2020, *Annals of Library and Information Studies*, 68, pp 430-441

[4] Wang S. and Yu J. (2021) A Bibliometric Research on Next-Generation Vehicles Using CiteSpace, *Recycling*, 6(14), https://doi.org/10.3390/recycling6010014

[5] Hammarfelt, B. (2021) Linking science to technology: the "patent paper citation" and the rise of patentometrics in the 1980s, *Journal of Documentation*, 77(6), pp 1413-1429

[6] Marx M. and Fuegi A. (2020) Reliance on science: Worldwide front-page patent citations to scientific articles, *Strategic Management Journal*, 41, pp 1572–1594

[7] IEA and EPO (2020) Innovation in batteries and electricity storage: A global analysis based on patent data, September 2020

[8] Burnham J. F. (2006), 'Scopus database: a review', *Biomedical Digital Libraries* 3(1). https://doi.org/10.1186%2F1742-5581-3-1

[9] Pohl H., Karlström M. (2023) Academic and Corporate Vehicle Electrification Research. *World Electr. Veh. J.*, 14, 71. https://doi.org/10.3390/wevj14030071

[10] OECD (2015) Enquiries Into Intellectual Property's Economic Impact

[11] Donato C., Lo Giudice P., Marretta R., Ursino D. and Virgili L. (2019) A well-tailored centrality measure for evaluating patents and their citations, *Journal of Documentation*, 75(4), pp 750-772. https://doi.org/10.1108/JD-10-2018-0168

[12] Williams H. (2015) HOW DO PATENTS AFFECT RESEARCH INVESTMENTS? Working Paper 23088, http://www.nber.org/papers/w23088

[13] Pohl H. (2021) Internationalisation, innovation and academic-corporate co-publications. *Scientometrics,* 126, 1329–1358.

Presenter Biography

Hans Pohl (PhD) is Project Manager and researcher at Lindholmen Science Park. Pohl's research interests are vehicle electrification, innovation and scientometrics. Previous positions include Analyst at Sweden's Innovation Agency, and Area Manager at ABB Switchgear. EVS13 in Osaka was Pohl's first.