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Visualization of corporate R&D capabilities: Patent data analysis of major EV-related firms

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Abstract
Purpose: This paper focuses on the battery industry and the research and development activities of EV companies and battery manufacturers in relation to this industry where competition has intensified in recent years. and looks at the R&D activities of EV companies and battery manufacturers. This paper aims to clarify how each company has changed the extent of strengths they have gained, and the technology of each company that has an advantage over others.
Design/methodology/approach: In this study, we use patent information to derive the index that measures strengths of each company in the field of technological development. In addition to the number of patents, we use text analytics based on each company's patent information to digitalize the strengths of each company. Furthermore, by analyzing the technologies in which the companies have strengths, we will clarify their specific efforts and responses to the latest trends and next-generation technologies.
Findings: In recent years, it was found that Japanese firms have been losing out to technological developments in other countries. The analysis was also conducted using elemental information for the technologies in which these companies have strengths. As a result, we could visualize the efforts made in the solid-state batteries being developed for practical use, the zinc anode batteries that can be considered next-generation technology, and the presence or absence of strengths in these fields.
Research limitations/implications: In this research, only patent information was used to identify areas in which each company has strengths. Therefore, non-patent information, such as journal papers, is not included in this analysis.
Practical implications: R&D managers can now quantitatively understand the strengths of their own technological development and the strategies of others. In addition, it can provide insight to determine the company's R&D direction.
Originality/value: The originality of this research is that it was able to use text analysis to visualize technological development trends in the battery industry as well as the strengths of

each company's technological development while such kind of research is still few in EV-related industries and in the field of innovation.

Keywords: EV battery, Patent information, Text analysis, R&D management

Introduction

Clean Technica (2023) reported that, unlike conventional gasoline-powered vehicles, electric vehicles (EVs) run on electricity and will bring about significant changes in global energy issues such as global warming and oil depletion. The number of plug-in vehicles (PHEV + BEV) registered worldwide in June 2023 reached 1.26 million, up 38% from last year. Looking at the breakdown, plug-in vehicles accounted for 19% of the total vehicle market (13% for BEVs alone). This means that the global automobile market is entering a period of EV shift. Since there are 900,000 non-plug-in hybrid vehicles, nearly one-third of the world's registered vehicles are electric vehicles, and the BEV market is expected to expand further. Bloomberg (2021) claims that the critical component of EVs is essential to the diffusion of EVs, as well as the research and development of batteries. EV batteries, after repeated discharge and charging, the maximum capacity of batteries gradually decreases, and the capacity retention rate drops. Therefore, when the capacity retention rate falls below 70-80%, the battery is considered at the end of its service life and needs to be replaced. Therefore, battery performance needs to be improved to popularise EVs. The price of Li-ion battery packs fell 89% from 2010 to 2020, reaching a volume-weighted average of $137/kWh.

For many industries, new product development is now the single most important factor driving firm success or failure. Most conclude that in order to be successful at new product development, a firm must simultaneously meet two critical objectives: maximizing the fit with customer’s needs, and minimizing the time to market. Successful firms are those that articulate their strategic intent and map their R&D portfolio to find a fit between their new product development goals and their current resources and competencies (Schilling and Hill, 1998). Strategic intent is a useful concept for purpose of continuity in an organization adopting internal and external pressure. It represents a proactive mode of strategizing, a symbol of being futuristic (Mantere and Sillince, 2007).

In order to capture strategic intent of the firm and the direction of the firm's R&D, M. E. Porter’s productivity frontier provides the analysis framework for identifying the positions of firms in the industry. Based on Porter's concept of the productivity frontier, Park et al. (2022) found the deepening trends of cooperative relationships and technological development between EV companies and battery manufacturers. However, we have not yet reached the stage of explaining how each company's strengths are expanding. Therefore, this paper inherits Park et al. (2022) framework and focuses on the R&D direction and business strategies of EV companies and battery manufacturers too, and will clarify how the degree of each company’s acquired power has changed and in which technologies it has strengths over other companies. We created an index for identifying the differences in the field of technology development and determining each company's deriving technology development strategies. by analysing the patent information of 6 companies (3 battery companies and 3 EV companies): Panasonic, LG Chem, CATL, TOYOTA, Volkswagen, and Tesla. It is our implication that such kind of research is still few in EV-related industries and in the field of innovation.

Research Background and Literature Review

1) EV and Battery Market

IEA (2022) reports that few areas in the world of clean energy are as dynamic as the electric car market. Sales of electric vehicles (EVs) doubled in 2021 from the previous year to a new record of 6.6 million. Tables 1 and 2 show that Tesla, Volkswagen, CATL, LGES, and Panasonic are significant players in the EV industry. Therefore, these five companies, including Toyota, were selected for this study

Table 1 EV Market Overview: Sales by Maker (2021)

Model	Brands	Battery Maker	2020H1 Sales	2021H1 Sales	Y-O-Y
Tesla Model 3	Tesla	CATL, LG, Panasonic	142,346	243,753	71.20%
Wuling HongGuang Mini EV	SAIC	CATL, Gotion High-tech	- - -	181,810	- - -
Tesla Model Y	Tesla	LG, Panasonic	13,415	138,401	931.70%
BYD Han EV	BYD	BYD	- - -	38,667	- - -
Volkswagen ID.4	Volkswagen	CATL, LG, Samsung SDI, Gotion High-tech	- - -	38,499	- - -
GW ORA Black Cat	GWM	SVOLT,CATL	- - -	32,013	- - -
Renault Zoe	Renault	LG,AESC	37,154	31,426	-15.40%
Hyundai Kona EV	Hyundai	SK Innovation	19,286	31,233	61.90%
Volkswagen ID.3	Volkswagen	CATL, LG, Samsung SDI, Gotion High-tech	- - -	31,079	- - -

Table 2 Global Automotive Battery Market Rankings (2020-21)

Rank	Maker	2020H1	2021H1	Growth Rate	2020M/S	2021M/S
1	CATL	7.2	28.4	295.00%	18.00%	27.00%
2	LG Energy Solution	10.3	27.9	170.40%	25.80%	26.50%
3	Panasonic	10.1	17.1	69.00%	25.40%	16.30%
4	BYD	2	7.1	261.20%	4.90%	6.70%
5	Samsung SDI	2.8	5.8	108.80%	7.00%	5.60%
6	SK Innovation	2	5.1	160.40%	4.90%	4.90%
7	CALB	0.8	3.1	315.80%	1.90%	3.00%
8	AESC	1.7	2	14.40%	4.30%	1.90%
9	Gotion High-tech	0.5	1.8	266.40%	1.20%	1.70%
10	PEVE	0.9	1.2	39.50%	2.20%	1.20%
Others		1.7	5.6	224.70%	4.30%	5.30%
Total		39.9	105.2	163.40%	100.00%	100.00%
Source: SNE Research						

2) Productivity Frontier

M. E. Porter (2008) defines the productivity frontier as the sum of all existing best practices at a given time. He explains the difference between operational effectiveness and strategic positioning with a productivity frontier map. He points out that competitive strategy is about being different. It means deliberately choosing different activities, such as non-price buyer value delivered or relative cost position, to deliver a unique mix of value.

In the case of EV batteries, we focus on the R&D direction of battery makers choosing from LFP (LiFePo4), NCM (Nickel, Cobalt, Manganese), and Solid-state batteries. We found that Tesla uses NCM batteries from Panasonic and LG Chem., which offer superior performance in the U.S. and other developed countries. In contrast, CATL's LFP batteries are cheaper and safer in the Chinese market. In other words, Tesla ensures strategic flexibility by using different leading battery makers in each region (Panasonic, LG Chem. and CATL). On the other hand, CATL, which has lagged in battery R&D, has been supplying low-cost LFP batteries to EV makers (GWM, GAC, SAIC) in its own country while moving into the development of NCM and solid-state batteries.

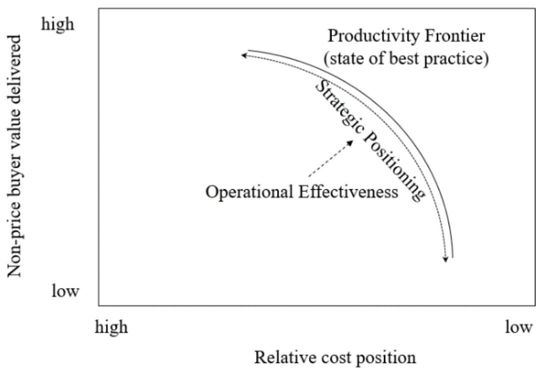


Figure 1 Operational Effectiveness Versus Strategic Positioning modified by the authors

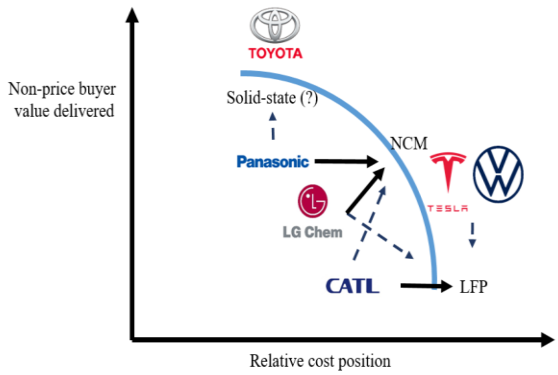


Figure2 Position of each company in the Productive Frontier

3) Patent Information

Patent analysis is one of the most effective analytical tools for analysing a company's R&D strategy since patent documents are a rich and accessible source of a company's technical and commercial knowledge. Many tools for analysing and visualising patent information, including text mining, are available, and specific methods for utilising patent information have already been implemented. In this paper, we analyse and compare the R&D strategies of various companies using doc2vec, which converts many documents derived from word2vec into vectors. The database used is the Patent Information Platform (J-PlatPat), which is collected and operated by the Japan Patent Office for all patent information in Japan. Each patent is assigned to an internationally standardised classification symbol called IPC (International Patent Classification). To extract patents related to EV battery development in this study, all patent gazettes marked in English with H01M or H02J as the IPC label among the patents filed from 2000 to 2021 are used. We make a company-by-company comparison using the information described for each company in the applicant information.

4) Research Questions

Research questions in this research are the following.

RQ1: Trends in the number of patents

As mentioned above, the EV market is becoming increasingly active, and the evolution of battery technology is required for technological innovation. Therefore, the number of patent applications companies file is expected to rise significantly. It is also well-known that Chinese companies are growing in this industry. Consequently, we will investigate the degree of their focus by examining the changes in the number of patents.

RQ2: Changes in the differentiation and strengths of each company
Each company developing technology should be innovating to gain a competitive advantage. This paper provides an index of the degree of EV battery technology's dominance and guidance on changes in competitive advantage.

RQ3: Evolution of technology and changes in fields of strength
R&D personnel are influenced by the direction of technological development at other companies and consider strategies to create new strengths. Therefore, we examine whether companies are developing exploratory technologies to lead to higher-performance batteries, such as all-solid-state batteries, which are in the process of commercialisation, and zinc anode batteries, which have the advantages of resource and environmental friendliness and safety because they do not use toxic materials or rare metals.

Methodology

1) Visualization of Differentiation and Strength Degree

In this study, we visualise the strength of each company in battery development from the abstracts of the patent documents filed by each company and clarify the annual changes in the strength of each company's battery development.

[Step 1] English Extraction and Stemming
In this study, we obtain all patents written in English under the IPC conditions described in the previous section. However, patent information filed with the World Intellectual Property Organization (WIPO) may include both English descriptions and the native languages of the companies and other countries. Therefore, it is necessary to extract only the English text in advance because it is impossible to analyse the entire summary information. Fast text can output an estimate of the number of words in each sentence, including the degree of certainty of the forecast. This study separates each summary information into sentences and is loaded into fast text for language estimation. As a result, only sentences judged to be in English are used in the analysis. In addition, stemming will be performed to restore the English text to its original form, unify strings of letters to lowercase, and remove numbers and symbols.

[Step 2] Vectorization of patent information by doc2vec
doc2vec converts each patent information into a vector that is not one-hot but can be matrix-computed meaningfully. All relevant patents for each year are used as input. This enables us to analyse the target company and the market as a whole and evaluate how strong the company is in the market.
In this study, the parameters are set as follows.
dm (Algorithm): PV-DM (PV-DM is said to be more accurate than PV-DBOW)
vector size (the number of dimensions on the output vector): 100
window (the number of words used to predict the next word): 5
min count (the minimum number of occurrences of the term to be handled): 5

[Step 3] Clustering using k-means
The vectors output in Step 2 are clustered using k-means. Clustering enables us to extract patent information with similar characteristics. The number of clusters is determined for each year based on the AIC. A schematic diagram of Steps 2 and 3 is shown in Figure 3.

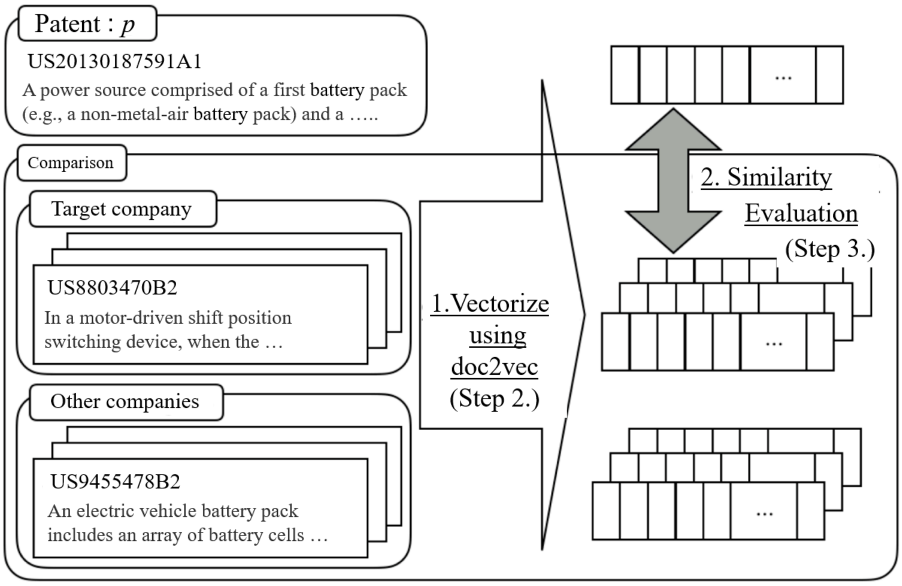


Figure 3 Schematic diagram of Steps 2 and 3

[Step 4] Visualization process by creating a graph
In Step 3, it became clear to which cluster each patent belongs. The number of patents in each company's cluster on the horizontal axis and the number of patents belonging to each company's cluster divided by the total number of patents in each cluster on the vertical axis are expressed in a scatter diagram. In this study, the score on the vertical axis is called the dominance. A cluster in the upper right corner of the graph means that the company has a high degree of dominance and a large number of patents and thus can be considered an advantage in the industry.

2) Visualization of Differentiation and Strength Field
The method described in the previous section can be used to evaluate whether or not each company's technology has strengths. However, we have not yet reached the point where we can evaluate which technologies are the strengths of each company. Therefore, we will use the information on materials and elements in each patent to consider what kind of technology each company's strength area consists of. The method is described in the following steps.

[Step 1] Definition of strengths
For this evaluation, a definition of strengths is necessary. In this study, the following conditions are used.
1. The degree of dominance is more than 0.05.
2. The number of patents belonging to each cluster is 50 or more.
3. If no more than three clusters satisfy the above two conditions, up to three clusters with the highest dominance among the clusters with at least one patent are considered to have strengths.

Patents in clusters that meet these requirements are extracted as technologies with strengths.

[Step 2] Element extraction for each cluster
We evaluate what materials (elements) are used in each cluster. Specifically, we count the number of patents in each cluster where the elements and the words "solid-state" appear and extract the top 10 words in each cluster.

[Step 3] Extraction of strengths of each company
The ratio of the appearance of the top elemental information obtained in Step 2 in the strength clusters obtained in Step 1 is calculated and visualised in a heat map. The characteristics of technological development in which each company has acquired strengths are derived.

Results

1) An approach based on the number of patent publications

Before investigating the details of technological development, we first analyze the number of patents in this area for each company to understand the trend of technological development in the industry. Figure 4 shows the number of patents held by each company. In the 2000s, when HV vehicles, rather than EVs, were the primary type of battery-powered vehicles, the Japanese companies Toyota and Panasonic led the industry in terms of the number of patents. However, Korean firm LG's patent number increased in the 2010s. Furthermore, the number of CATL patents has grown rapidly since 2016, indicating that technological development in the industry has been revitalized. On the other hand, the number of patents by Japanese companies, which initially led the industry in technological development, has not increased, suggesting that their relative position in the industry is declining.
Tesla, the leader in the EV market, has not been active in the industry in terms of the number of patents it holds, which may be because it has not adopted a strategy of issuing a large number of patents in the industry.

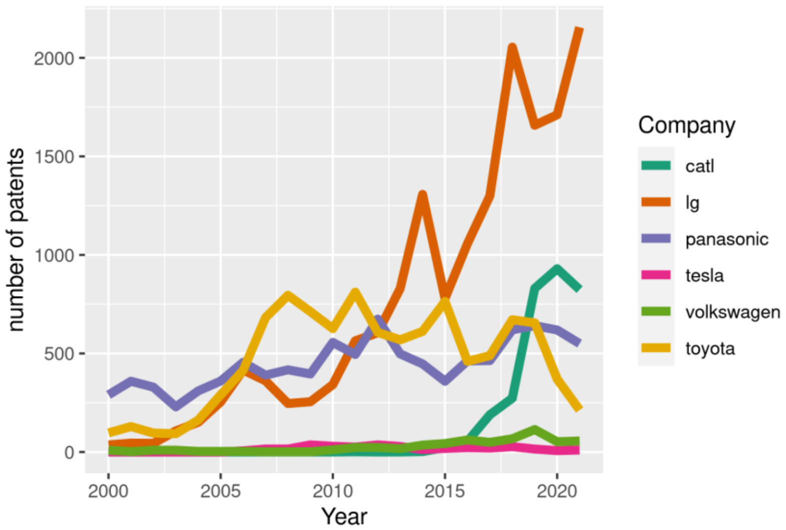
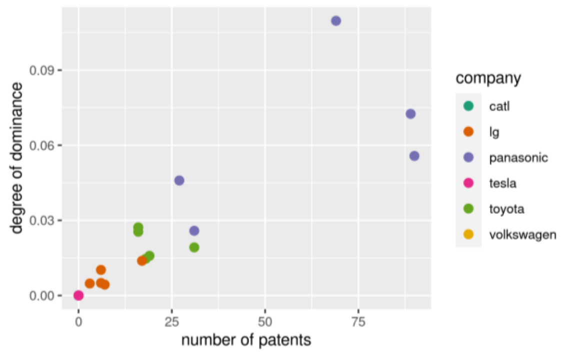


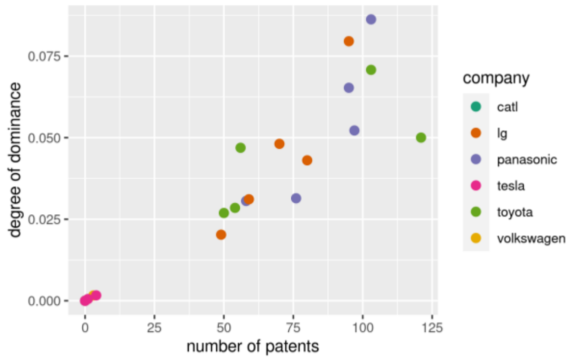
Figure 4 Trends in the number of patents in this field

2) An approach based on Differentiation and Strength Degree

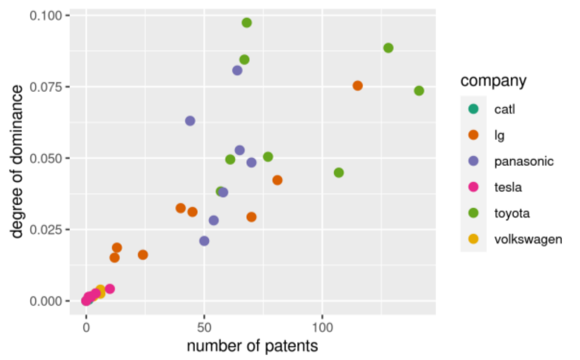
Figure 5 shows a scatter plot of the strengths of each company for each year using the method for determining and visualizing the degree of differentiation and strengths described in the previous section. This study's degree of differentiation was visualized for all years, but the 2001, 2006, 2011, 2016, and 2021 results are selected as examples. The dots in the figure indicate the number of patents and the degree of dominance in each cluster for each company. It can be seen that the number of clusters is not significant in the 2000s because the overall number of patents is small. In other words, the technological development related to batteries has not spread. In 2016, LG had several clusters with high numbers and dominance, indicating that LG's technological development has gained a competitive advantage over its competitors in a wide range of areas. The figure for 2021 also shows that LG has many clusters with a high level of dominance, indicating that its superiority has not changed. In addition, the rise of CATL is conspicuous in that there are four clusters with a higher degree of dominance than that of Japanese companies. In addition, the fact that Tesla does not have many patents is an influence, and it was impossible to find an advantage over the other companies.



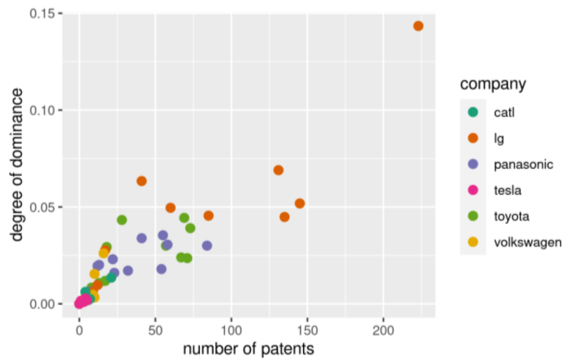
(a) 2001



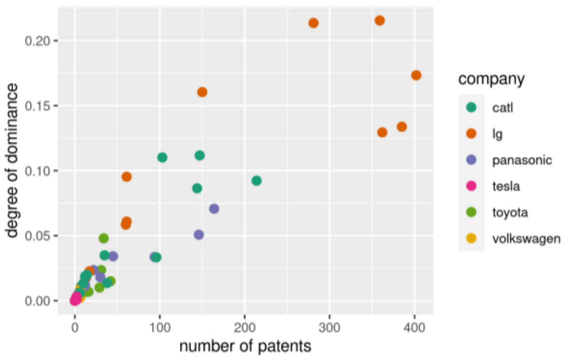
(b) 2006



(c) 2011



(d) 2016

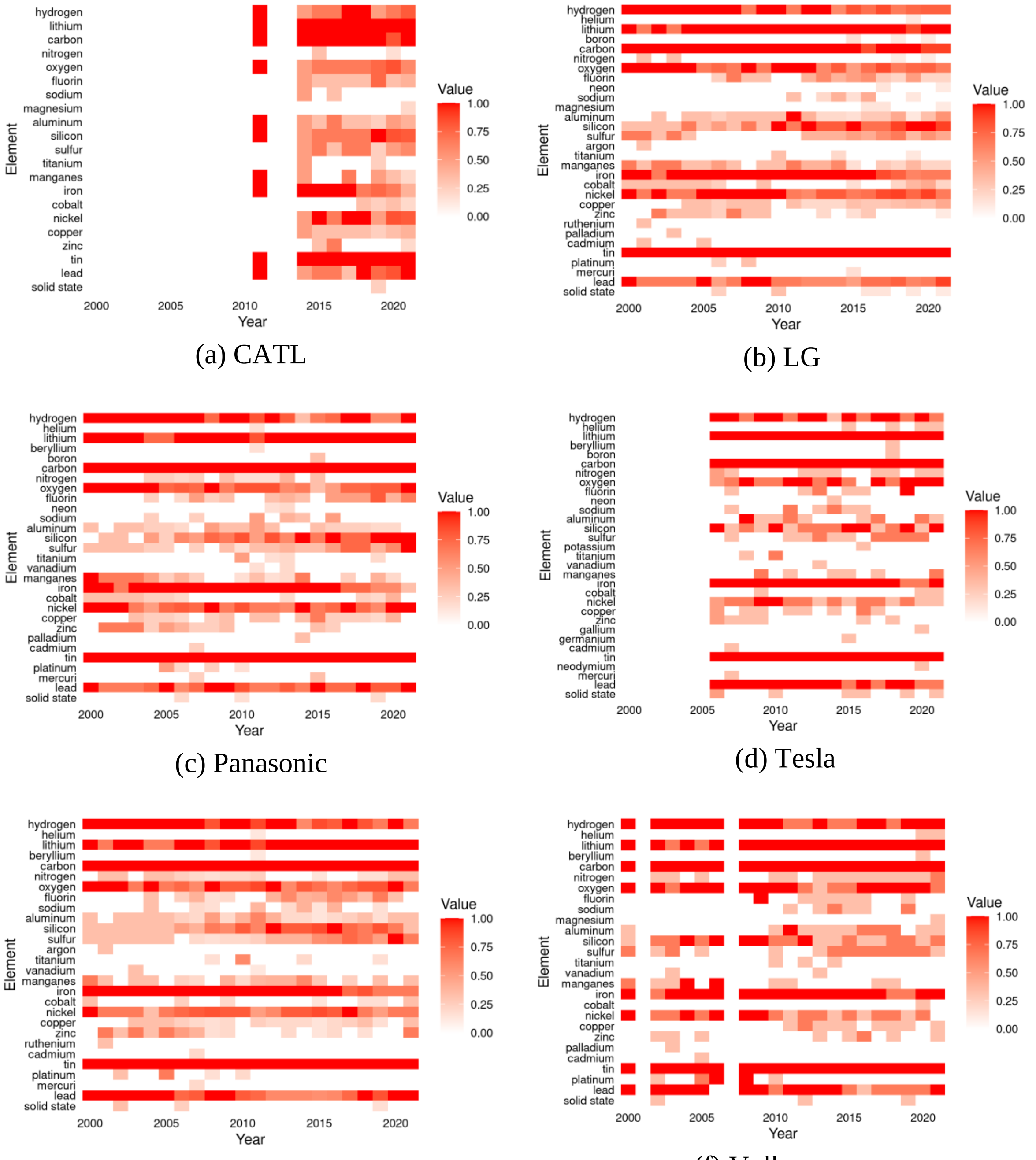


(e) 2021

Figure 5 Differentiation and strength degree in each year

3) An approach based on Differentiation and Strength Field

Using a visualization technique for areas of differentiation and strength, a heat map showing each company's strengths in each year is shown in Figure 6. LG, Panasonic, and Toyota are developing technologies using various elements to gain a competitive advantage. On the other hand, Tesla and Volkswagen use only a small number of elements in their technological development as an area of strength, suggesting that each company is pursuing technological development specialized in its field of strength.



(a) CATL (b) LG

(c) Panasonic (d) Tesla

(e) Toyota (f) Volkswagen

Figure 6 Differentiation and strength fields in each year

Findings

Based on the above results, the research questions for this study can be summarized as follows. RQ1: For a long time, Japanese companies such as Panasonic and Toyota maintained an advantage in battery technology development regarding the number of cases. However, in the 2010s, when the shift to EVs became more pronounced, they lost their advantage in the number of issues around 2014. In recent years, the rise of CATL, in particular, has been conspicuous, suggesting that competition in the industry has become even more intense.

RQ2: First, the number of clusters in this area of technological development is increasing. This can be considered to mean that the efforts of each company are becoming more diversified. In addition, as in RQ1, a company-based comparison shows that Japanese companies, which initially possessed strengths in the industry, have yet to gain strengths in the development of battery technology in recent years. In addition, it can be seen that the companies are not aiming to gain an overwhelming competitive advantage in a few clusters but to achieve strength by developing a wide range of technologies and digging deeper into areas where they have strength.

RQ3: The heatmaps show the elemental information of each company's technology and indicate that CATL is not developing technology using many elements but specializing in technology using a few elements due to the short period since its start-up. On the contrary, LG, Panasonic, and Toyota are developing technologies using various elements. In particular, LG is the strongest among the three companies in the “solid-state battery technology” field, developed in recent years with the aim of commercialization. In 2021, Toyota will have strengths in several clusters of technologies used for zinc anode batteries, which are the most advanced technology. Therefore, Toyota is making efforts to develop next-generation technologies. On the other hand, Tesla and Volkswagen show no significant changes in the elemental information used in the clusters where they have strengths. Therefore, it can be considered that they are developing technologies to maintain their bargaining power with battery companies.

Discussion and Conclusion

In this paper, we analyzed textual information on patents and applications for EV battery technology development, which has been the focus of much attention in recent years, to derive the efforts of each company to develop related technologies.

As a result, it was found that although Japanese firms were strong in this technological area in the 2000s, they have been pushed back by the technical development of other countries since the shift from gasoline-powered vehicles to EVs became clear. Toyota needs to catch up in the EV market and to compensate for this, it has been promoting the development of solid-state batteries and alliances with foreign companies (BYD, CATL, LG Chem). Meanwhile, Panasonic plans to strengthen its cooperation with Tesla and increase its production capacity to compete with rivals CATL and LG Chem. In recent years, CATL has increased its presence not only in the number of patents but also in the degree of technological dominance in the industry. In addition, the results of the analysis based on the elemental information used for the technology in which they have a strong point enabled us to visualize the wide range of areas they are dealing with and their approach to all-solid-state batteries and zinc anode batteries, which are still being developed for practical use and are still next-generation technologies.

However, since this study did not include BYD and Samsung as companies subject to analysis, it is difficult to say that the industry as a whole has been grasped. In addition, the study is still insufficient regarding parameter settings for the text analysis part and the definition of strengths. Therefore, we plan to increase the number of target companies and verify appropriate parameter settings in future research.

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