Low-carbon electricity technology transformation in Chinese universities

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Abstract

Purpose – With the growing climate problem, it has become a consensus to develop low-carbon technologies to reduce emissions. Electric industry is a major carbon-emitting industry, accounting for 35% of global carbon emissions. Universities, as an important patent application sector in China, promote their patent application and transformation to enhance Chinese technological innovation capability. This study aims to analyze low-carbon electricity technology transformation in Chinese universities.

Design/methodology/approach – This paper uses IncoPat to collect patent data. The trend of low-carbon electricity technology patent applications in Chinese universities, the status, patent technology distribution, patent transformation status and patent transformation path of valid patent is analyzed.

Findings – Low-carbon electricity technology in Chinese universities has been promoted, and the number of patents has shown rapid growth. Invention patents proportion is increasing, and the transformation has become increasingly active. Low-carbon electricity technology in Chinese universities is mainly concentrated in individual cooperative patent classification (CPC) classification numbers, and innovative technologies will be an important development for electric reduction.

Originality/value – This paper innovatively uses valid patents to study the development of low-carbon electricity technology in Chinese universities, and defines low-carbon technology patents by CPC patent classification system. A new attempt focuses on the development status and direction in low-carbon electricity technology in Chinese universities, and highlights the contribution of valid patents to patent value.

Keywords Electricity technology, Low-carbon, Transformation, Valid patent mining

Paper type Case study

1. Introduction

With continued economic development and population growth, global carbon emissions have increased, and global warming, sea level rise and extreme climate events are frequent occurrences (Zhang *et al.*, 2021). For these reasons, dealing with climate change and solving

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the emerged problems to achieve sustainable development have become an urgent issue for the whole society (Pan *et al.*, 2022a). As the world's largest carbon emitter, China has set a goal of peaking carbon emissions by 2030 and achieving carbon neutrality by 2060 (Pan *et al.*, 2022b; Fang *et al.*, 2019). The USA, the European Union, the UK, Japan and other major developed countries have also announced carbon-neutral plans. They have started to support the development of green and low-carbon technologies through the active deployment of "net zero strategies" and "carbon neutral strategies". In the energy sector, the transformation of fossil energy into new energy is actively promoted, mainly including wind energy, solar energy, low-carbon hydrogen energy, energy storage and other key technologies. However, emerging economies with a relative shortage of energy such as China and India use a large amount of fossil energy to maintain a high rate of economic growth. They mostly use nonrenewable energy sources such as thermal electricity and coal-fired electric generation, which produce a large amount of carbon dioxide. The technology and financial level of these countries are not yet able to effectively curb carbon emissions and address the serious consequences of carbon emissions. It is urgent to promote the development of low-carbon technologies in these emerging economies. In this context, the development of low-carbon technology has become a new focus and direction of China's economy (Pan *et al.*, 2022c).

The electricity industry is the basic industry of the national economic construction. It is a typical traditional industry as well as a talented-, technology- and capital-intensive industry with great innovation potential. The electricity sector accounts for 35% of global greenhouse gas (GHG) emissions, far ahead of any other sector as the leading carbon emitter (Xiang *et al.*, 2022). More and more countries are considering or formally announcing their carbon neutrality goals, and there is an urgent need for the global electric sector to act and play a role in the low-carbon transition of the energy system. According to the *Energy Technology Outlook 2017* published by the International Energy Agency (IEA, 2017), at least 50% of the carbon reduction potential can be obtained from the electricity sector. The largest GHG emitter in China is the electricity sector (Zhang *et al.*, 2022). China's electricity generation accounts for nearly one-third of the national GHG emissions (Liu, 2016). In 2018, the United Nations Intergovernmental Panel on Climate Change (IPCC) released the *IPCC Global Warming 1.5°C Special Report*. The report pointed out that controlling the temperature rise within 1.5°C requires higher requirements for the energy transition (Pan *et al.*, 2022d). Renewable energy will supply 70%–85% of the world's electricity by 2050. Global electricity demand is expected to increase by 90% by 2040 (IEA, 2017). The expansion of electricity demand has also increased the pressure on the electric industry to reduce emissions, and the development of new low-carbon technologies will drive a major shift in the way electricity is generated. Low-carbon technology is a new technology concept proposed along with the construction of an ecological economy and green revolution. Existing research usually equates low-carbon technology, green technology and environment-friendly technology as alternative concepts (Pan *et al.*, 2023). The development of low-carbon technologies is one of the effective ways to slow down global warming (Su and Hu, 2022).

With the continuous development of economic and technological globalization, the core competitiveness and comprehensive development capabilities of countries or organizations are facing a severe situation to improve and guarantee. Independent innovation, independent research and development to obtain scientific and technological achievements and acquisition of intellectual property rights have become the top priority. As an important part of intellectual property rights, patents are an important indicator to measure technological innovation (Lowe and Veloso, 2015). A valid patent usually refers to a patent that is in maintenance status as of the end of the reporting period. Valid patents not only reflect the legal status of technological innovation achievements and the survival period of patents, but also reflect the quality of technological achievements, which is an important indicator of the innovation ability and

market competitiveness of patent owners. Therefore, compared with other patent statistical indicators, valid patents better reflect the quality of patents. In 2009, for the first time, valid patents were included in the *National Economic and Social Development Statistical Bulletin*, marking that valid patents have officially become an important indicator of the comprehensive evaluation system of China's economic and social development.

As an important carrier of scientific research activities and technological innovation, colleges and universities are the source of technological innovation that cannot be ignored (Bachmann and Frutos-Bencze, 2022; Lei *et al.*, 2012). Innovation-driven is essentially talent-driven, and cultivating creative researchers and innovative talents is the most distinctive advantage of colleges and universities. Promoting the high-quality development of patent applications and transformation will help improve the scientific and technological innovation capabilities of colleges and universities, and play an important role in driving patent research and development and promoting patent applications (Temel *et al.*, 2021). Patent activities in universities are an important part of building an innovative country, and patent transformation is an important basis for evaluating the quality of scientific research achievements and innovation capabilities in universities. Although colleges and universities are generally considered to have no product production capacity, the scientific and technological achievements of universities can be transformed into productivity through transfer or licensing. Statistics from the State Intellectual Property Office showed that as of May 2020, the number of invention patents granted by universities accounted for 23% of the total number of invention patents granted in China, but the actual rate of patent licensing or transfer in universities was only 3.42%. The patent technology conversion rate of universities in developed countries or regions in Europe and the USA can reach 70%, but the successful transformation of patent achievements held by domestic universities is less than 10%. The transformation of scientific and technological achievements is an important link in technological innovation activities, which determines whether the innovation achievements can finally realize market value. Promoting the transformation of scientific and technological achievements in colleges and universities is the key content of China's science and technology policies.

The electricity industry, as a major carbon-emitting sector, has attracted more and more attention when energy conservation and emission reduction are mainstream. In past studies, many scholars have recognized the importance of low-carbon technology development in the electric sector. Yuan and Hu (2011) pointed out that low-carbon electricity, characterized by GDP electric intensity and CO_2 emissions per unit of electric generation, is essential for China's low-carbon development. Their research found that China could save 1.5 billion tons of energy and reduce carbon dioxide emissions by 5.7 billion tons in 2010–2030 through Integrated Resource Strategic Planning. There is also a group of scholars who studied the impact of specific low-carbon technologies on carbon emissions in the electric sector. They found that balanced portfolios made up of zero- and low-carbon baseload resources, as well as wind and solar, are the most cost-effective means of producing electricity and reducing carbon emissions (Brick and Thernstrom, 2016). Other scholars have concluded that including nuclear energy; natural gas with carbon capture and storage; and bioenergy can reduce the cost of electricity by 10%–62% in the case of complete decarbonization (Sepulveda *et al.*, 2018). Inglesi-Lotz and Dogan (2018) examined the determinants of CO_2 emissions from the top ten electric plants in Africa. Their results show that nonrenewable energy consumption intensity increases pollution, while the opposite is true for renewable energy.

Patent data is a reliable information for examining industrial technology innovation. Some scholars have used patent data to analyze the development trend of low-carbon technology (Albino *et al.*, 2014). Norhasyima and Mahlia (2018) reviewed patents on CO_2 utilization technologies for carbon capture utilization and storage applications published

between the years 1980 and 2017. Yan *et al.* (2017) used the patent data to estimate the low-carbon technology levels of 72 economies and 19 Organization for Economic Co-operation and Development (OECD) economies.

The above research lays a good foundation for this study and shows the urgency of systematically examining the low-carbon technology innovation dynamics in the electric industry. The current-related research mainly analyzes the development trend of the electric industry as a whole and the influence of innovation and cooperation on a global and national scale. Less attention is paid to the development status and development direction of Chinese universities in the field of low-carbon electric technology, and the contribution of valid patents to patent value is ignored. This paper takes Chinese universities as the main research subject and selects IncoPat patent search and analysis system to statistically analyze the patent information of Chinese universities included by the system from 2010 to 2021. From the perspective of colleges and universities, this paper analyzes the patent application trend of low-carbon technology in China's electric industry, as well as valid patents, the distribution of valid patented technologies, the status quo of valid patent transformation and the transformation path of valid patent. Based on the patent information retrieval, the valid patents of electricity in Chinese universities are mined, and then the issue of transformation strategy of scientific and technological achievements is discussed. Through the above analysis, the study clarifies the development status and direction of electricity technology in Chinese universities, so as to provide reference for the national and different regions to formulate low-carbon electricity technology patent navigation, promote the implementation and operation of low-carbon electricity patents, improve the strategic planning of low-carbon electricity technology development and provide reference for the scientific and reasonable layout of low-carbon electricity technology development construction.

The rest of this paper is organized as follows. Section 2 presents the literature review. Section 3 presents the data sources and patent searches. Section 4 discusses the development of low-carbon electricity technology patents in Chinese universities from the perspective of valid patents. Section 5 reports the transformation of low-carbon electricity technology in Chinese universities from the perspective of valid patents. Section 6 discusses the conclusions, conversion strategies and future research.

2. Methodology

2.1 Definition of low-carbon electricity technology patents

The current examination of low-carbon technology mainly relies on three patent systems: the World Intellectual Property Organization (WIPO) 2010 promulgated IPC Green Inventory; EVN-TECH issued by the OECD in 2015; and EPO and USPTO jointly released cooperative patent classification (CPC)-Y02 patents for climate change mitigation technologies or applications. The low-carbon technology patents classification of WIPO and OECD is based on the traditional IPC classification system, including more classification of specific low-carbon technology categories, and is more suitable for the study of low-carbon technology and ecological innovation. The CPC-Y02 classification system has the characteristics of systematization and structure and is more suitable for tracking and researching the overall innovation trend of low-carbon technology. More and more scholars have used the system to study low-carbon technology innovation and related issues. This paper uses the CPC-Y02 patent classification system published in October 2017 to define low-carbon technology patents.

The European Patent Office developed a new classification system for clean energy technologies in response to climate change and reclassified the entire global database, that is, the major groups under the Y02 subcategory. Based on the classification of low-carbon electricity technology in this classification, Y02E (reducing GHG emissions related to energy

generation, transmission or distribution), this paper focuses on the analysis of relevant patent data related to low-carbon electricity technology and analyzes the development direction of low-carbon electricity technology for emission reduction. The specific content is shown in Table 1.

2.2 Patent search, data sources and data processing

Patent information retrieval is the basis of this research and the main data source. This paper uses the IncoPat science and technology innovation intelligence platform developed by Beijing Hexiang Wisdom Technology Co., Ltd. to perform information retrieval. The platform is the world's first intelligence platform that can search and browse global patent information in Chinese. It highly integrates global scientific and technological innovation intelligence, and is also one of the few patent intelligence analysis platforms in China with rich data sources, integrating multiple functional modules such as patent search, thematic library, 3D sand table and cluster analysis, which can complete multidimensional patent search and analysis.

The retrieval time of the low-carbon electricity technology patents information in Chinese universities covered in this paper is as of August 3, 2022. The patent information with the filing date from January 1, 2011 to December 31, 2021 is the research object. And the patents collected in this paper are from the China National Intellectual Property Administration. Because invention patents generally take 18 months from the filing of the application to pass the preliminary examination before they are published. The utility model patents and design patents take at least half a year to one year from application to publication authorization, as well to the delay in the collection of this database. The patents counted in the past two years are only for reference. This study is limited to universities with application addresses in China and does not include university affiliates.

Learning from the search methods of scholars, this paper adopts the instruction search method for patent search. The overall patent search formula for low-carbon electricity technology in Chinese universities is as follows: (AP-COUNTRY = (CN) AND (AP-TYPE = (U)) AND (CPC = (Y02E)) AND (AD = [20110101 TO 20211231]))). A total of 146,175 patents related to low-carbon electricity technology in Chinese universities were retrieved. This paper constructs a database of low-carbon electricity technology patents in Chinese universities based on patent retrieval. Using the database, the patents can be divided into three categories: valid, invalid and under trial. Then, using the valid patent data, this study carries out its relevant research. The valid patent data were processed using Excel software to carry out the research related to this paper.

Classification no.	Name
Y02E	Low-carbon technologies related to energy generation, transmission and distribution
Y02E10	Renewable energy generation technology
Y02E20	Combustion technology with climate mitigation potential
Y02E30	Nuclear electric generation technology
Y02E40	Efficient generation, transmission and distribution technologies
Y02E50	Fuel production technology from nonfossil sources
Y02E60	Other technologies potentially or indirectly contribute to reducing emissions
Y02E70	Other energy conversion or management system technologies to reduce greenhouse gas emissions

Source: Author's work

Table 1. CPC-Y02E patent classification system

Patent mining and statistics is a research method for technology management decision-making based on patent information retrieval. The method is based on patent information retrieval, constructing a patent database and using a combination of quantitative statistics and qualitative analysis to extract, deduce and mine intelligence information useful for technology management decisions such as R&D innovation, patent layout, achievement utilization or risk avoidance. This paper will use this method to mine and sort out the intelligence related to effective patents, effective patent transformation and patent transformation subjects of low-carbon electricity technology in Chinese universities, so as to provide effective information support for this paper to explore the transformation paths and strategies of low-carbon electricity technology in Chinese universities.

2.3 Overall operation diagram

The overall operation steps for analyzing valid patents data are shown in Figure 1.

3. Development of valid patents for low-carbon electricity technology in Chinese universities

3.1 Analysis of valid patents for low-carbon electricity technology in Chinese universities

An invention creation has a legal status from the date of filing a patent application and being accepted. The legal status of a patent changes with each due process and legal event. The legal status of a patent application usually includes publication, substantive examination, withdrawal (deemed withdrawal), authorization, expiration of the time limit, expiration, assignment, license and pledge. All of these legal statuses can be classified into three stages: valid, invalid or under trial. A valid patent application is one in which the patent has been granted and maintained. Invalidation includes both the termination of the examination procedure by the applicant before the patent is granted and the waiver of the patent right by the patentee after the patent has been granted, while the under-trial refers to the patent application from post-application to before the grant (Ford, 2013).

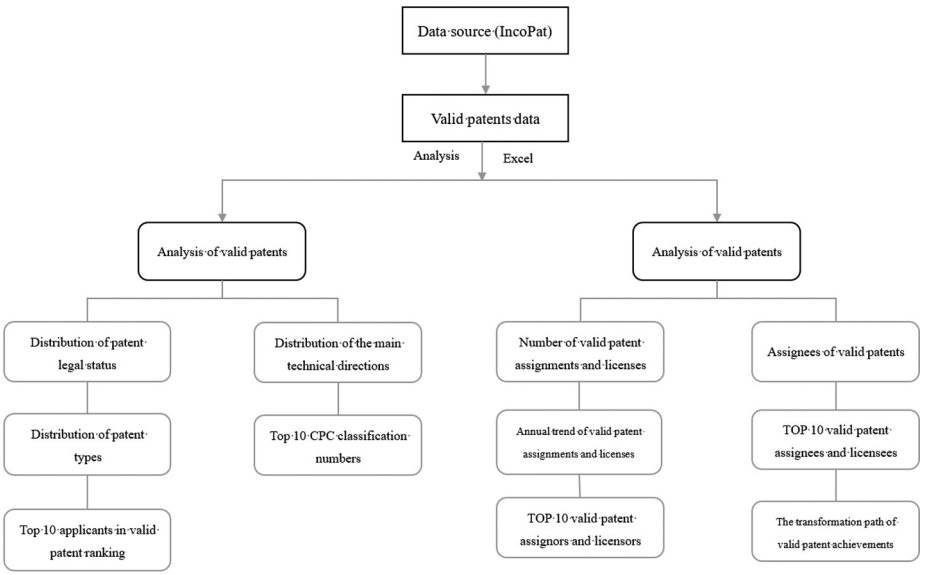

Figure 1.
Overall operation diagram of the data sources and analysis procedure

Source: Author's work

The legal status of valid patents on low-carbon electricity technology in Chinese universities is shown in Figure 2. There were 77,623 valid patents, accounting for 53% of all patents, more than half of the total. There were 43,609 invalid patents, representing 30% of all patents. A further 17% patents are pending. Through the analysis, it can be seen that more than half of the valid patents for low-carbon electricity technology in Chinese universities have been authorized and maintained, but 30% of patent applications have been invalidated for various reasons. This shows that the degree of innovation of low-carbon electricity technology patents in Chinese universities is relatively high, and the right holder is willing to apply for and maintain the patent, reflecting the patentee's motivation to protect the achievements of technological innovation (Liu *et al.*, 2018). At the same time, it is also necessary to pay sufficient attention to the invalid patent and understand the reasons why the patentee gave up the patent, to better protect the technological innovation results.

Nemlioglu and Mallick (2017) pointed out that the different types of innovation brought different benefits to enterprises. CNIPA used novelty and applicability to classify patents, which can be divided into invention, utility models and designs (Chen and Zhang, 2019). Invention patents perform a relatively strict examination procedure and have a long-term protection, while utility models and designs are subject to simpler examination procedures and a relatively short-term protection.

Figure 3 reflects the distribution of valid patents types for low-carbon electricity technology in Chinese universities. The valid patent applications are mainly invention patents and utility models, not including designs. There are 68,435 invention patents and 9,188 utility models. This is closely related to the characteristics of technological innovation in the industry. Low-carbon electricity technology innovation does not require innovations in shape, pattern or combination of products, as well as color, shape and pattern. Because this industry is a technology-intensive industry, a lot of manpower and material resources have been invested in innovation, resulting in a lot of original technological achievements, so the proportion of invention patents is the highest. The effective rate of invention authorization is the highest. This is closely related to the characteristics of invention patents. Compared with utility models, invention patents have more stringent examination steps, and the degree of innovation is higher. The patent rights are relatively stable, and the patentee is more willing to maintain the validity of the patent.

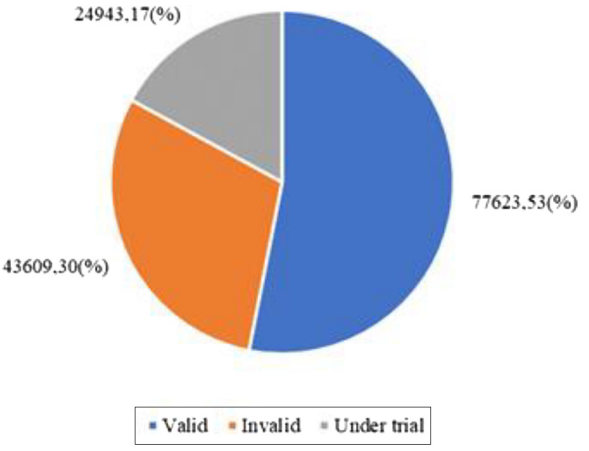

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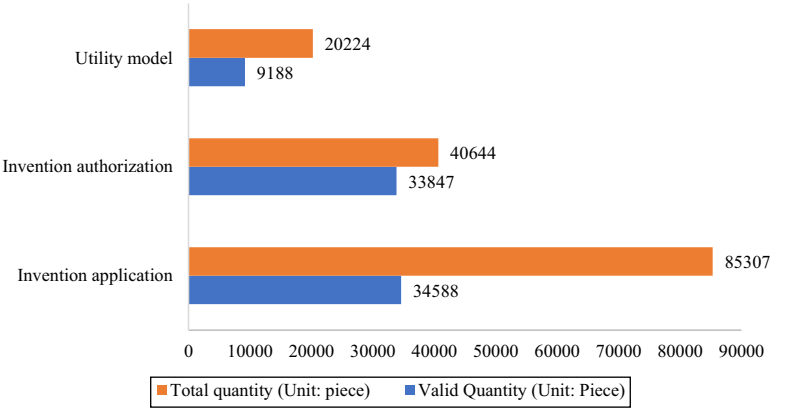
Figure 2.
Distribution of legal status of valid patents for low-carbon electricity technology in Chinese universities



Source: Author's work

Figure 3.
Distribution of patent types for low-carbon electricity technology in Chinese universities

Table 2 shows the top ten Chinese universities having valid patents of low-carbon electricity technology. Tsinghua University ranks first in the number of valid patents, far surpassing Zhejiang University, which ranks second. This is similar to the findings of Dolphin and Pollitt (2020), where the distribution of patent applications over the sample period was heavily skewed, with a small number of participants accounting for a large proportion of applications. These universities pay more attention to the innovation of low-carbon electricity technology and have more effective scientific research achievements, which are the intellectual source of low-carbon electricity technology transformation in Chinese universities.

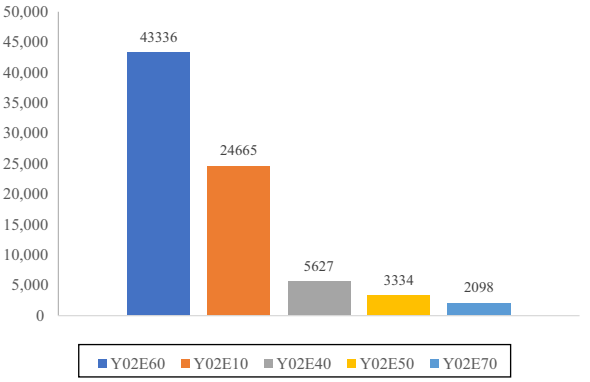
3.2 Distribution of valid patent for low-carbon electricity technology in Chinese universities

The specific distribution of valid patents is shown in Figure 4 based on the classification of Y02E. Among them, the Y02E60 classification has the highest number of patent applications, which is the use of technologies that have a potential or indirect effect on GHG emissions, that is, battery-related energy storage technologies. The number of applications was 43,336, accounting for 55.8% of the total number of valid patent applications for

Applicant	No.
Tsinghua University	3,168
Zhejiang University	2,258
Central South University	2,029
Xi'an Jiaotong University	1,900
South China University of Technology	1,840
Huazhong University of Science and Technology	1,684
Shanghai Jiaotong University	1,399
Southeast University	1,348
Shan Dong University	1,312
Tianjin University	1,237

Source: Author's work

Table 2.
Top ten Chinese universities having valid patents of low-carbon electricity technology



Source: Author's work

Figure 4.
Distribution of valid patents for the main technical directions in Chinese universities

low-carbon electricity technology in Chinese universities. Y02E10, which is the production of energy through renewable energy, that is, the use of photovoltaic, tidal energy and wind electric generation-related technologies, stood second with 24,665 applications, accounting for 31.8% of the total number of valid patent applications for low-carbon electricity technology in Chinese universities during this period. The top two technologies account for 87% of the low-carbon electricity technology in Chinese universities. Innovative energy storage technology and alternative electric generation energy technology will be the focus of low-carbon electricity technology development in the future. The number of applications for transmission and distribution and fuel technologies related to traditional electric generation, such as Y02E40 and Y02E50, can only rank third and fourth, with a total proportion of only 11.5%. The application of traditional technology is gradually decreasing, and it is bound to be replaced by more advanced technology.

To further analyze the specific development direction of future technologies, this paper further counts statistics on the subgroups under each CPC classification group, and the results are shown in Table 3. The use of technologies with a potential or indirect effect on GHG emissions has become a current development hotspot. Among them, the battery

CPC classification no.	Classification no. interpretation	No. of patents
Y02E60/10	Accumulators	21,077
Y02E60/50	The fuel cell	7,568
Y02E60/36	Hydrogen production from non-carbon sources	5,258
Y02E10/50	Photovoltaic energy	5,008
Y02E60/13	Supercapacitors, double-layer capacitors	4,978
Y02E10/56	Conversion of electrical or electronic aspects	3,423
Y02E10/549	Organic photovoltaic cells	3,350
Y02E10/72	Wind turbines with an axis of rotation along the wind direction	2,930
Y02E10/76	Conversion of electrical or electronic aspects	2,899
Y02E70/30	Energy storage and energy production from nonfossil sources	2,098

Source: Author's work

Table 3.
Top ten CPC classification number in valid patent ranking of low-carbon electricity technology in Chinese universities

(Y02E60/10) is the most important technology application point, and the number of patent applications reached 21,077, accounting for 27% of the total number of low-carbon electricity technology patent applications in Chinese universities during this period. It was followed by fuel cells (Y02E60/50), with 7,568 applications, accounting for 9.7%. Battery energy storage technology has become a hot spot and trend in current low-carbon development. Photovoltaic is also a technology direction with relatively intensive innovation.

4. Development of valid patents for low-carbon electricity technology transformation in Chinese universities

4.1 Development process of valid patent assignment and license for low-carbon electricity technology in Chinese universities

According to Articles 10 and 12 of the *Patent Law of the People's Republic of China*, the patentee can exercise its rights through assignment and license. Statistical analysis of the annual number of patent assignment and license can reflect the development and change history and current situation of the transformation of low-carbon electricity technology in Chinese universities. Patent assignment and license are important ways for universities to spill over knowledge and transform innovative achievements (Liu *et al.*, 2016). The assignment and license of patent rights are the two main forms of the patent operation. The assignment patents are usually patents with relatively high innovation levels, technical content and application value. Therefore, the assignment rate of patents can reflect the overall quality level of authorized patents (Liu *et al.*, 2021). Analyzing the assignment and license trends of valid patents can reflect the development trend of university–enterprise transformation and technology transfer, and show the activity and recognition of its patented technologies. The statistics were conducted using the patent database constructed in this paper, and the results are shown in Table 4. During the calculation period, the number of valid patent applications and authorizations for low-carbon electricity technology in Chinese universities has been increasing since 2010, with the number of applications peaking in 2019. However, the number of authorizations reached a maximum in 2018 and has declined since then, which is similar to the search results of Xiao *et al.* (2021). The number of patent applications and grants will be affected by national policies and market

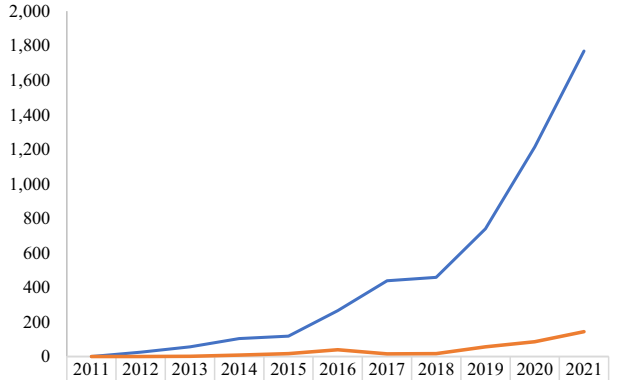
Table 4.
Number of valid patents assignment and license for low-carbon electricity technology in Chinese universities

Year	Application/ piece	Authorization/ piece	Assignment/ piece	Assignment/ authorization (%)	License/ piece	License/ authorization (%)
2011	4,629	1,529	–	–	–	–
2012	5,442	1,800	25	1.39	–	–
2013	7,405	2,668	56	2.10	2	0.07
2014	8,736	3,097	104	3.36	9	0.29
2015	10,683	3,548	118	3.33	17	0.48
2016	15,027	4,888	266	5.44	40	0.82
2017	16,573	4,938	439	8.89	16	0.32
2018	20,212	6,057	458	7.56	17	0.28
2019	21,505	5,938	740	12.46	56	0.94
2020	18,620	4,533	1213	26.76	86	1.90
2021	17,343	2,344	1769	75.47	144	6.14

Source: Author's work

environments (Li *et al.*, 2021). There has been a qualitative leap in the number of low-carbon technology patent applications in China compared with the period 1991–2010 (Peng *et al.*, 2018). Among the valid patents of low-carbon technology transformation activities in Chinese universities, the cumulative number of valid patents realized for transformation from 2010 to 2021 is 5,575, and the transformation by way of assignment involves 5,188 patents, accounting for about 93.1%, while the number of license patents is 387, accounting for about 6.9%. A total of 5,188 patents were converted by transfer, and 387 were converted by licensing.

Figure 5 depicts the annual trend of assignments and licenses of valid patents for low-carbon electricity technology in Chinese universities. The transformation of valid patents for low-carbon electricity technology in Chinese universities mainly occurred in 2013, before which no patent licenses had occurred. For patent assignments, there was a clear growth trend after 2013. Since the establishment of the first National Low Carbon Day in 2013, carbon-related topics have already entered daily life. Shenzhen has launched the country's first carbon trading market. Shenzhen is one of the seven pilot cities for carbon emission trading in the country. Its opening also reflects the urgent need of China to promote enterprises to consciously save energy and reduce emissions through market means. With the release of the *National Intellectual Property Strategy Implementation Promotion Plan* in 2013, the number of assignments exceeded 100 in 2014 and is currently maintained at 1,500–2,000 patents. Universities have also actively promoted the application and industrialization of their intellectual property rights. According to the development strategy of Chinese electricity industry, by 2020, China will form a unified joint electric grid that covers the whole country. In this process, cross-interval interconnected transmission lines will play a key role in energy transfer, which is a prerequisite for the large-scale development and utilization of renewable low-carbon energy sources such as hydropower and wind electricity and has significant low-carbon benefits. Under the combined effect of industrial innovation needs and national policies, low-carbon electricity technology transformation in Chinese universities has shown an increasingly active development trend, indicating that the overall quality level of China's patents is improving.



	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Transfer execution date	0	25	56	104	118	266	439	458	740	1213	1769
License year	0	0	2	9	17	40	16	17	56	86	144

Source: Author's work

Figure 5. Annual trend of valid patent assignments and licenses for low-carbon electricity technology in Chinese universities

4.2 Analysis of the execution subjects of valid patents assignment and license of low-carbon electricity technology in Chinese universities

By analyzing the implementation of the execution subjects, it can help to understand the demand of the superior universities and low-carbon electricity technologies, thus helping to improve the efficiency of patent conversion. This study refers to the contractual parties of a valid patent assignment or license, i.e. the patentee and the assignee or licensee, as the executing subjects, which represent the technology supply side and demand side, respectively.

4.2.1 Technology supply-side subject analysis. Universities in the field of low-carbon electricity technology are the main supply side of the technologies in this study. Table 4 shows the top ten valid patent assignors and licensors of low-carbon electricity technology in Chinese university. From the perspective of transferring universities, the number of assignment from the top ten universities accounted for 26% of the total number of assignment, with a total of 1,372. Tsinghua University has the largest number, with a total of 245 valid patents, involving mainly H01M (methods or devices for directly converting chemical energy into electrical energy, such as battery packs). Central South University followed closely, transferring a total of 201 patents, involving the main technical field of H01M. Shanghai Jiaotong University, Changzhou University and Harbin Institute of Technology also transferred a certain number of patents, 154, 133 and 131, respectively. From the perspective of assignment rate, the assignment rates of top ten universities are higher than the average assignment level of 5% in the field of low-carbon electricity in Chinese universities. Except for South China University of Technology, the assignment rates of the remaining nine universities are over 10%. The status of the top ten universities with assignment patents is listed in Table 5. First, these universities have obvious advantages in technological innovation abilities, and the quality of technological innovation is relatively high. Second, most of these universities are double-first-class universities under the ministry, and the support of national finance and policies is relatively large. Third, after combing the specific conditions of the above universities, we found that most of these universities have set up technology transfer and transformation institutions. For example, Tsinghua University has set up the Office of Achievements and Intellectual Property Management and the Technology Transfer Research Institute to promote the patent transformation. Shanghai Jiaotong University has established a leading group for the transfer and transformation of scientific and technological achievements, which is especially responsible for the transformation of scientific and technological achievements.

From the perspective of licensed universities, the largest number is Jiangsu University of Science and Technology, with a total of 36 valid patents, mainly involving H01M (methods or devices for directly converting chemical energy into electrical energy, such as battery packs). Wenzhou University followed closely, transferring a total of 32 patents, and the main technical field involved was also H01M. Nanjing Forestry University, Nanjing University of Posts and Telecommunications and Jiangsu University also transferred a certain number of patents, 28, 25 and 22, respectively. On the whole, as a way to temporarily transfer patent rights to patent technology transformation, patent licensing is also an important way for universities to realize patent value through patent technology transfer. Compared with the transfer of patents, the scope of exclusive or exclusive rights enjoyed by a patent licensee in a specific technology market is greatly limited because there is no change in the subject of rights in a patent license. From the current practice point of view, universities in Jiangsu and Zhejiang and other regions, where the economy is more developed and technological innovation activities are relatively active, attach more importance to or are good at using patent licensing to transform patent technology.

Table 5.
Top ten valid patent assignors and licensors of low-carbon electricity technology in Chinese universities

		Assignment					License			
Rank	Assignor	No. of assignment	Authorization	Assignment rate (%)	Major IPC	Licensor	No. of license	Authorization	License rate (%)	Major IPC
1	Tsinghua University	245	1803	13.59	H01M	Jiangsu University of Science and Technology	36	206	17.48	H01M
2	Central South University	201	1085	18.53	H01M	Wenzhou University	32	120	26.67	H01M
3	Shanghai Jiaotong University	154	814	18.92	H02J	Nanjing Forestry University	28	148	18.92	F03D
4	Changzhou University	133	308	43.18	H01M	Nanjing University of Posts and Telecommunications	25	203	12.32	H02J
5	Harbin Institute of Technology	131	689	19.01	H01M	Jiangsu University	22	479	4.59	H01M
6	Xi'an Jiaotong University	126	1155	10.91	H02J	Hangzhou University of Electronic Science and Technology	19	184	10.33	H01M
7	Jiangsu University	112	479	23.38	H01M	Xi'an Jiaotong University	18	1155	1.56	H01M
8	South China University of Technology	98	1059	9.25	H01M	Shan Dong University	16	757	2.11	H02J
9	Nantong University	87	148	58.78	H02J	Huaiyin Institute of Technology	16	66	24.24	H01L
10	Shaanxi University of Science and Technology	85	520	16.35	H01M	Southeast University	14	765	1.85	H02J

Source: Author's work

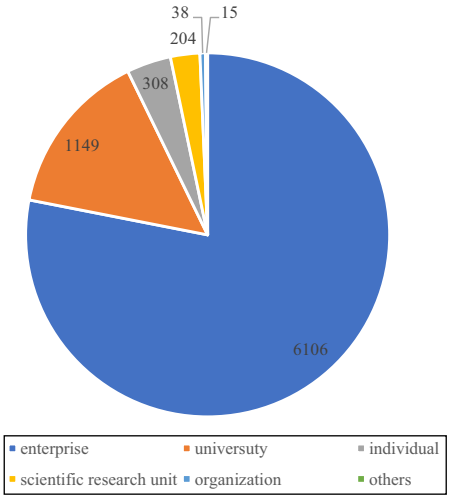
In both transferred and licensed top ten universities, their major IPCs are mostly concentrated in H01M and H02J, which is similar to the findings of Hu *et al.* (2022). They used green invention patent data for China's electric industry between 2000 and 2021 and found the top three IPC categories in the electric industry as H02J7/00, H01M10/44 and H01M4/86.

4.2.2 Technology demand-side subject analysis. Technology demanders are mainly enterprises engaged in production and operation or R&D in this field, which not only have practical demand for relevant patent technologies but also have good patent technology accumulation themselves. Analyzing the main parties of technology demand designed in this study, it can be seen that the assignees of 7,820 valid patents involved various types of enterprises, universities, individuals, scientific research units, organizations and others (as shown in Figure 6).

Table 6 shows the top ten assignees and licensees of low-carbon electricity technology valid patents in Chinese universities from 2010 to 2021. Only four of the top ten assignees are universities, namely, Tsinghua University, Shanghai Jiao Tong University, North China University of Electric Power and South China University of Technology, while the rest are enterprises. And the assignees of low-carbon patents transferred by universities are still mainly enterprises.

4.3 Analysis of the transformation path of valid patent of low-carbon electricity technology in Chinese universities

The transfer process of university patents is often accompanied by changes in the patentee and the ownership of rights. As for the assignment, the assignee sees the innovative value of the patented technology, so he hopes to claim the "exclusive right" of the patent in his name, to achieve a "monopoly" of the specific technology market. As for licensing, it shows the "exclusive" right of the patent subject to temporarily transfer the patent, reflecting the game between the licensor and the licensee for the value of the patented technology.



Source: Author's work

Figure 6.
Assignees of valid patents for low-carbon electricity technology in Chinese universities

Rank	Assignment		License	
	Assignee	No.	Licensee	No.
1	Tsinghua University	112	Technology Transfer Center of Jiangsu University of Science and Technology	22
2	China Nuclear Energy Technology Co.	70	Guangxi Yang Sheng New Energy Co.	18
3	Southern Power Grid Scientific Research Institute Co.	69	Tianjin Tianmai Technology Co.	16
4	Hefei Kyushu Longteng Technology Achievement Co.	64	Guangxi Refa Energy Technology Co.	16
5	State Grid Corporation	63	Jiangsu South Post Internet of Things Technology Park Co.	14
6	Huzhou Youyan Intellectual Property Service Co.	62	Hubei Benxing Carbon Material Co.	14
7	Shanghai Jiaotong University	58	Wenzhou Juyuan Lithium Battery Technology Development Co.	12
8	North China University of Electric Power	54	Nanjing Rongchuan Environmental Protection Engineering Co.	10
9	South China University of Technology	49	Guangxi Chaoxing Solar Energy Technology Co.	10
10	Changshu Intellectual Property Operation Center Co.	49	Shenzhen Huaxinhui Technology Co.	10

Source: Author's work

Table 6. Top ten valid patent assignees and licensees of low-carbon electricity technology in Chinese universities

Through the analysis of the types and transfer paths of patent transformation in Chinese universities, there are mainly the following five paths: universities–enterprises, such as Tsinghua University, transferred the patent "a control method for connecting a dynamic reactive electric compensation device to the electric transmission network" to Beijing Zhizhong Energy Internet Research Institute Co., Ltd.; Universities/enterprises–enterprises, such as Foshan Zhengde Biological Engineering Co., Ltd. and Jinan University, transferred the joint patent "a method for preparing biodiesel using high acid value oils and fats" to the company Foshan Zhengde Machinery Equipment Co., Ltd.; universities–scientific research institutes, such as Harbin Institute of Technology, transferred the "space folding mechanism derived from the five-rotation sub-unit" to the Harbin Institute of Technology Electric Engineering (Jiashan) Research Institute as a whole; universities–natural persons, such as Hohai University, transferred the "wave energy generator" to the natural person Weiping Peng; and university–intermediary-enterprise model, such as Soochow University, transferred the patent of "AZO coated lithium manganate secondary lithium battery cathode material and its preparation method" to Huaibei Tianmao Recycling Energy Co., Ltd. The company was re-transferred to Anhui Boshi Hi-Tech New Materials Co., Ltd. through market behavior. Judging from the current operation of patent industrialization, the models of universities–scientific research institutes, universities–intermediaries and universities–natural persons are not the main body of the market with good patent industrialization in most cases, and patent transfer is only the re-ownership of patent rights. It is difficult to truly commercialize and industrialize university patents in the short term. Chinese universities mainly carry out patent transformation activities based on technology transfer institutions, school–enterprise cooperation and government technology transformation platforms. Most universities have not yet set up special intellectual property operation agencies.

5. Conclusion, conversion strategies and future research

5.1 Conclusion

Based on patent information retrieval, this paper searches and excavates the valid patents of low-carbon electricity technology in Chinese universities, discusses the transformation of low-carbon technology and obtains the following research conclusions:

- The patent analysis shows that the output of low-carbon electricity technology in Chinese universities started late but developed rapidly. Since 1990, China has attached importance to the significant role of universities in technology transformation and innovation, and has issued a series of policies with clear requirements for technology transformation in universities. The 20th Party Congress further emphasized the need to promote high-quality development of universities and transform more scientific and technological achievements into reality. This study shows that the transformation of low-carbon electricity technology patents in Chinese universities mainly occurred after 2013. The resulting transformation activities of low-carbon electricity technology patent transfer and licensing in Chinese universities have become increasingly active in recent years, which indicates that the overall quality level of Chinese patents is improving.
- The transformation of low-carbon electricity technology patents in Chinese universities is dominated by assignment. The assignment and license of patents can reflect the transformation of low-carbon technology of universities. This study shows that patent assignment dominates the transformation of low-carbon technology patents in Chinese universities. And most of the universities with high level of patent technology transformation adopt the strategy of technology transformation mainly by assignment, and there are almost no universities mainly by license. According to the change trend in recent years, the growth rate of the number of patent licenses is much smaller than that of assignments, and this status quo of mainly patent assignments may continue to be maintained for a long time in the future. Wen (2014) used the visualization method of social network analysis to conclude that most universities have a low level of participation in patent licenses. Combined with the removal of the condition of exclusive licensing method in 2016 in the recognition of high-tech enterprises in China, the license of low-carbon electricity technology patents in universities has significantly decreased. More enterprises or patent operators attach importance to the innovation value of domestic university patent technology in the low-carbon electricity, and choose to claim their exclusive rights in their own name to achieve absolute monopoly in the market of specific technologies.
- The level of low-carbon patent transformation of electricity in Chinese universities is significant to promote the achievement of carbon neutrality. Carbon Neutral 2060 is the first long-term climate commitment proposed by China. It is also a programmatic document for China to achieve high-quality economic transformation changes in the medium and long term. As the largest carbon-emitting sector in China, low-carbon transition from electricity sector is of global importance to achieve the goal of carbon peaking and carbon neutrality. According to the research of this paper, the low-carbon electricity technology in Chinese universities is mainly based on renewable energy sources such as electrical storage, fuel cells and hydrogen, which have reduced carbon emissions to a great extent.

5.2 Conversion strategies

In the transformation of scientific and technological achievements, universities, as the source of knowledge innovation, are an important part of the national innovation system. For this reason, this paper believes that the low-carbon electricity technology in Chinese universities should pay sufficient attention to the following aspects in the transformation of scientific and technological achievements:

- Universities should build a patent evaluation index system oriented by quality and value, improve the policy of supporting high-quality creation of patents and further optimize the patent funding and reward policy and evaluation and assessment mechanism. We should make full use of the research of electricity in universities. This will form a synergistic "industry-academia-research" mechanism for scientific and technological innovation in electricity, and increase the number and improve the quality of low-carbon technology patent applications in Chinese universities.
- Universities should improve the quality management assessment system of intellectual property rights in the electricity, and make patents reach a high level in both quantity and quality by conducting valid patent quality management assessment. Universities should also improve the number of patent applications and the overall patent quality level of low-carbon electricity technology and promote China's electricity to take the leading position in the international market at the level of core technology.
- Universities should further break through the intellectual property barriers of low-carbon electricity technology, and strengthen the research and development of related advanced technologies, such as photovoltaic, wind energy, battery and other technology fields. This could further break through the limitations of existing proprietary technologies and develop low-carbon technologies for electricity from cleaner areas.
- We make full use of the favorable policy environment for the transformation of national scientific and technological achievements, build institutional guarantee oriented to the transformation of science and technology achievements and support qualified universities to establish and improve specialized institutions integrating technology transfer and intellectual property management and operation. It also encourages universities with limited conditions to make use of the power of market-oriented intellectual property operating (IPR) institutions to add to the transformation of research results in Chinese universities.
- China can borrow some policies and regulations for carbon emission reduction from developed countries. China's low-carbon electricity technology transformation pathway can also provide lessons for other emerging economies.

5.3 Future research

This paper has studied the path of low-carbon electricity technology transformation in Chinese universities through the perspective of valid patents. Although some additions have been made to the shortcomings of related studies, there are still some areas for improvement in this study. The follow-up study can be improved from the following two aspects:

(1) The study of low-carbon electricity technology transformation paths is a complex process, and this paper only studies the transformation paths among universities, enterprises and individuals, and fails to analyze other paths in detail. The consideration of low-carbon transformation paths is not comprehensive, and the subsequent systematic analysis can be carried out more deeply for each path to build a more comprehensive transformation path network.

(2) Because the transformation of low-carbon technology results is a long and complex systematic process, the effect of a result being transformed needs long-term tracking studies and feedback to be understood. The next step can be verified through case studies.

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