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Patent-Based Technology Entropy Analysis Method and Its Application to Emerging Technology Monitoring: A Case Study of Carbon Capture Technology (Postprint)

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Abstract

【Objective】Based on the characteristics of technological systems, a technical entropy analysis method is proposed. Through patent literature data, dynamic and effective monitoring of the development and evolution of emerging technologies is conducted to validate the effectiveness of the technical entropy analysis method. 【Method】A multi-dimensional technical entropy patent model is constructed in a patent-based technological system. Using carbon capture technology as a case study, technical monitoring and evaluation analysis is conducted from both macro and micro perspectives. 【Results】The effectiveness of the technical entropy analysis method is confirmed. China' s carbon capture technology has experienced stages of technological germination, low-speed development, and high-speed leap, and although not yet mature, it has entered a crucial development stage; technology R&D is dominated by universities, with research primarily focused on absorption and adsorption materials, etc. 【Limitations】The selection of sample data needs improvement, with interfering data present. 【Conclusion】The technical entropy method is a scientifically effective analytical approach for analyzing evolution trends in technological fields from a technological system perspective, providing a feasible analytical tool for issues such as technological evolution, technological evaluation, technological foresight, and related technology management problems.

Full Text

Preamble

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Research on Patent-Based Technology Entropy Analysis Method and Its Application in Emerging Technology Monitoring—A Case Study of Carbon Capture

Technology

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Abstract

[**Objective**] This paper proposes a technology entropy analysis method based on the characteristics of technological systems. Using patent literature data, it dynamically and effectively monitors the evolution of emerging technologies to validate the effectiveness of the technology entropy analysis method. [**Methods**] We construct a multi-dimensional technology entropy patent model within a patent-based technological system. Taking carbon capture technology as an example, we conduct monitoring and evaluation analysis from both macro and micro perspectives. [**Results**] The validity of the technology entropy analysis method is confirmed. China's carbon capture technology has experienced stages of technological germination, low-speed development, and high-speed leap, and although not yet mature, has entered a crucial development phase. Research and development are primarily led by universities, focusing mainly on absorption and adsorption materials. [**Limitations**] Sample data selection needs improvement, with interfering data present. [**Conclusions**] The technology entropy method is a scientifically effective analytical approach for analyzing evolutionary trends in technology fields from a technological system perspective, providing a feasible analytical tool for issues related to technological evolution, evaluation, foresight, and associated technology management.

Keywords: Technology Entropy, Patent Model, Technology Monitoring, Carbon Capture
Classification Number: G350

1. Introduction

Technology monitoring has become a critical means of tracking technological evolution and obtaining competitive technical intelligence. Generally based on scientific and technical information and data analysis, it employs cutting-edge information science technologies such as data mining, information extraction, knowledge discovery, and data visualization to dynamically monitor, analyze, and evaluate scientific and technological activities. Real-time dynamic tracking of emerging technologies through technology monitoring not only holds significant practical value for enterprises in formulating technology development strategies and patent layouts, but also provides important guidance for national, provincial, and regional science and technology development planning and for enhancing technological innovation capacity and core competitiveness.

Currently, analyzing technology evolution based on patents through information visualization and data mining constitutes an important means of technology monitoring research and application, while some studies also identify and

monitor emerging technology evolution through patent indicators and mathematical models. However, few existing studies monitor and analyze technology development from the perspective of technological systems and their characteristics. Entropy, as a crucial parameter characterizing system disorder, has been exploratorily applied across major scientific fields since its inception, leading to generalized entropy theories in natural and social systems such as statistical entropy, information entropy, maximum information entropy, black hole entropy, management entropy, and economic entropy. Due to the consistency between technological systems' characteristics of synergy, self-organization, and mutation and other systems to which entropy theory applies, entropy theory is equally applicable to technological systems. This paper proposes the concept of technology entropy and its related criteria from a technological system perspective, presents a technology entropy analysis method based on patent literature data, and constructs one-dimensional and two-dimensional patent models. Taking carbon capture technology as an example, we analyze patent literature information downloaded from the National Intellectual Property Administration to monitor and evaluate the overall development of China' s carbon capture technology, providing an objective and effective technical means and method for technology monitoring research and offering predictive suggestions for comprehensively advancing the industrialization of carbon capture technology in China.

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2. Patent-Based Technology Entropy Analysis Method

Technological systems are contained within social systems and are influenced by both external factors and their own inherent attributes. From creation, development, and maturity to decline and eventual extinction, technological systems exhibit different states at different stages. The driving force behind these changes is the unified manifestation of order and disorder among internal system elements. Building upon the definition of thermodynamic entropy and according to the relevant attributes of technological systems, this study proposes the concept of "technology entropy" to describe and characterize the degree of disorder in internal relationships of a specific technological system at a particular time. Its function is to address issues related to technological evolution, monitoring, and evaluation by reflecting the changing trends or maturity levels of technological system evolution.

Based on the thermodynamic entropy formula, this study defines technology entropy calculation as follows:

$$dS = \frac{dQ}{T}$$

where dS is defined as the increment of technology entropy, dQ is the energy received by the technological system, and T is the research intensity for that technology. When $dS < 0$, i.e., negative entropy increase, the technological system tends toward orderly growth; when $dS = 0$, the technological system reaches relative equilibrium, presenting a mature state; when $dS > 0$, i.e., positive entropy increase, the technological system tends toward chaos and begins to decline.

This study establishes two criteria for the existence of technology entropy. The first is the entropy increment dS itself, which consists of two parts: one part is the entropy increment deS generated by energy exchange between the system and its external environment, which can be positive or negative; the other part is the entropy increment generated internally by the system, i.e., entropy production diS, which is always positive. In summary, the technology entropy increment dS is expressed as:

$$dS = deS + diS$$

During the technology growth stage, since the input of external negative entropy flow dominates and internal entropy production is relatively small, we have $|deS| > diS$, and because $deS < 0$, $dS < 0$, meaning the technological system evolves in an orderly direction. When the technological system evolves to a certain extent, internal entropy production shows an upward trend while negative entropy flow shows a downward trend, eventually reaching equilibrium. The period during which this state is maintained represents the mature stage of the technological system, where $|deS| = diS$. During the technology decline stage, positive entropy flow input from the external environment and internal entropy production drive system chaos, with entropy values continuously increasing, i.e., $dS > 0$.

The second criterion for technology entropy is the technology entropy increment trend value h in the calculation formula $h = -\frac{deS}{diS}$. When in the growth stage, the technological system evolves in an orderly direction with $dS < 0$, thus $h > 1$; in the mature stage, the technological system reaches a non-stable equilibrium state with $dS = 0$ and $h = 1$; in the decline stage, positive entropy flow breaks the mature stage equilibrium, making the technological system increasingly disordered with $dS > 0$ and $0 < h < 1$.

The technology entropy analysis method examines the evolution of technology life cycles based on the degree of internal chaos within technological systems from a systemic perspective. Its core idea lies in utilizing the entropy laws within technological systems to solve the systems' own problems. Therefore, its greatest advantage is "tailor-making" specific analysis methods for technological systems according to their particular problems. The technology entropy analysis method reveals the development status of technological systems during technology development, reflecting not only the current development status of technology from a macro perspective but also showing technological development changes from micro details, thereby objectively and effectively demonstrating issues such as technological shortcomings and obstacles in technology development status, and providing reference opinions for technology forecasting. Therefore, employing the technology entropy analysis method to construct a multi-dimensional technology entropy patent model enables technology monitoring and evaluation from macro to micro levels.

3. Construction of Multi-Dimensional Patent Models for Technology Entropy Method

Patents are effective carriers of technology, and the evolution of patent systems reveals the evolution of the technological systems they carry. Therefore, to verify the effectiveness of the technology entropy method in technology monitoring analysis, this study can construct a patent quantity model for the technology entropy analysis method based on relevant patent parameters. According to the technology entropy calculation formula and its existence criteria:

$$dS = deS + diS$$

where dS is the total entropy change of the system; deS is the entropy increment caused by interaction between the system and its external environment, i.e., entropy flow, which can be positive or negative; and diS is the entropy increment generated by irreversible factors within the system, i.e., entropy production, which is always positive. For research convenience, the following assumptions are proposed:

1. All external factors act on the technological system through patents, i.e., there exists a mapping relationship, ideally making patents the only means for the system to exchange technology with the external environment.
2. Only when patents expire do they automatically exit the technological system in the form of entropy production.
3. Patents from different sources and of different types have different contribution rates to the technological system, and these contribution rates are measurable.
4. Patent application volume can serve as a measure of research intensity.

Based on the above assumptions, the order parameters for a certain technological system can be identified as: the application volume of the first type of patent dN_1 and publication volume dn_1 within a certain time range; the application volume of the second type of patent dN_2 and publication volume dn_2; ···; the application volume of the i-th type of patent dNi and publication volume dni. Patents can be classified by source or type.

Therefore, this study provides the following expression for deS based on patent indicators:

$$deS = deSA + deSB$$

where $deSA$ is the entropy introduced into the system by authorized patents. Since it makes the system "ordered" and produces positive effects, this part of entropy is negative entropy and is always negative in quantity. $deSB$ is the entropy change caused by unpublished patents in the system. These patents enter the technological system upon application but quickly exit it. Overall, they increase the system' s chaos and should be positive in quantity. Comparing the two shows that when the negative entropy introduced by authorized patents exceeds the entropy increase caused by unpublished patents, the entropy flow manifests as overall entropy reduction and the system tends toward order. When the negative entropy introduced by authorized patents is less than the entropy increase caused by unpublished patents, the entropy flow manifests as overall entropy increase and the system tends toward chaos. When they are equal, the effect of entropy flow on the system is zero.

Define the application volume and publication volume of various patents per unit statistical time as $dN_{1-0}, dN_{2-0}, ..., dNi_0$ and $dn_{1-0}, dn_{2-0}, ..., dni_0$ respectively. Let T_0 be the research intensity of a certain technology source in the base year, then:

$$T_0 = 1 + \sum x_i \cdot dn_{i-0}$$

where $x_1, x_2, ..., x_i$ are the intensity coefficients of various patents. This paper defines the T_0 value as 1 when the inputs of $dn_{1-0}, dn_{2-0}, ..., dni_0$ are all 0, making T_0 always a real number not less than 1. According to the entropy definition $deS = -\frac{dQ}{T}$, we have:

$$deSA = -\frac{\sum \alpha_i \cdot dni_0}{T_0}$$

$$deSB = \frac{\sum \beta_i \cdot dNi_0}{T_0}$$

where $\alpha_1, \alpha_2, ..., \alpha_i$ are the contribution rates of corresponding patent types to technology development in the base year, serving as weight coefficients. Patent types with generally higher levels contribute more to technology development and have larger α values, and vice versa.

Similarly, we can calculate:

$$diS = \sum \frac{\gamma_i \cdot dNi_{-\tau_i}}{t_i}$$

where $t_1, t_2, ..., t_i$ are the validity periods of corresponding patent types. $\gamma_1, \gamma_2, ..., \gamma_i$ are the average authorization rates of corresponding patent types. $dN_{1-\tau_1}, dN_{2-\tau_2}, ..., dNi_{-\tau_i}$ are the application volumes of corresponding patent types in the $\tau_1, \tau_2, ..., \tau_i$ years before the base year. This is because there exists a review cycle from patent application to publication. Patents can be considered to have entered the technological system from the date of acceptance. After review, those not granted will exit the system, while those exiting in the base year should have been applied for before the average review cycle. Therefore, using the base year' s application volume for measurement is unreasonable. This approach not only improves the accuracy of patent measurement but also strengthens the logical connection between adjacent time nodes, thereby enhancing the overall integrity of the research.

In addition to entropy flow interaction with the external environment, the system also generates entropy production due to its internal irreversible factors. Calculation methods for entropy production are not uniform under different conditions, but the basic idea lies in calculating irreversible losses within the system. Specifically, in patent-based technological systems, the causes of entropy production can be simplified to patent expiration. On the one hand, expired patents still belong to the original technological system and exert influence internally. The patent "expiration" process is highly irreversible. On the other hand, patent expiration is fundamentally different from patent non-authorization. The former has fully become a system component during its validity period and has long played a substantive role, while the latter only enters and exits the system in the form of entropy flow without playing a substantive role internally. Therefore, only the former is the driving potential for system entropy production. Based on the above analysis and research assumptions, the entropy production calculation method for patent-based technological systems is as follows:

$$diS = \sum \frac{\gamma_i \cdot dNi_{-\tau_i}}{t_i}$$

where $t_1, t_2, ..., t_i$ are the validity periods of corresponding patent types. $\gamma_1, \gamma_2, ..., \gamma_i$ are the average authorization rates of corresponding patent types. $dN_{1-\tau_1}, dN_{2-\tau_2}, ..., dNi_{-\tau_i}$ are the application volumes of corresponding patent types in the $\tau_1, \tau_2, ..., \tau_i$ years before the base year.

Combining formulas (1) through (5), the expression for total entropy change in the technological system is:

$$dS = -\frac{\sum \alpha_i \cdot dni_0}{T_0} + \frac{\sum \beta_i \cdot dNi_0}{T_0} + \sum \frac{\gamma_i \cdot dNi_{-\tau_i}}{t_i}$$

4. Monitoring and Evaluation of Carbon Capture Technology

To further verify the effectiveness of the patent-based technology entropy analysis method, this study takes carbon capture and storage (CCS) technology as an example. CCS technology refers to the technical means of capturing, separating, and permanently sequestering carbon dioxide from relevant emission combustion sources, which can be divided into three major technical fields: carbon capture, transportation, and storage. Among them, carbon capture can significantly reduce direct CO2 emissions and mitigate their threat to global climate, and is considered an important technical pathway for deep greenhouse gas emission reduction. In recent years, the United States, Australia, Japan, and EU member states have conducted relevant basic research and feasibility technology tests, yet a series of technical bottlenecks still constrain the development of carbon capture technology. China faces enormous pressure for CO2 emission reduction. Although it is actively restructuring its energy mix, fossil fuels represented by coal are generally believed to remain dominant in energy consumption in the short term. Therefore, carbon capture technology may become one of China' s important pathways for reducing carbon emissions. In fact, China began researching carbon capture technology as early as 2003, achieving major progress not only in theoretical research but also supporting the construction of several demonstration projects. While still imperfect, these efforts have attracted widespread attention from all sectors of society. Carbon capture technology is currently in a rapid development period in China, with core technologies not yet mature and uneven development among related technologies, making it a typical emerging technology.

Relying on the National Intellectual Property Administration' s Key Industries Patent Information Service Platform, we searched for patents using "carbon dioxide and (adsorption or absorption or capture)" as search elements in patent abstracts, obtaining 2,861 data entries [Figure 1: see original paper]. We conducted technology entropy analysis on 2,716 patent applications from 1985 to 2013 to accurately and objectively monitor and analyze carbon capture technology.

[Figure 1: see original paper]

4.1 One-Dimensional Technology Entropy Analysis of Carbon Capture

The patent model based on technology entropy has strong applicability. To macroscopically 梳理 the development trajectory of China' s carbon capture technology, we employ the one-dimensional form of this model for technology entropy analysis.

Since only the one-dimensional form is used, the original model can be simplified to:

$$dS = -\frac{dni_0}{T_0} + \frac{dNi_0}{T_0} + \frac{dNi_{-\tau}}{t}$$

where x is the patent intensity coefficient, which is 1 here; α is the contribution rate of base-year patents to technology development, which is also 1 here due to the absence of comparison objects; ε is the average patent authorization rate; and τ is the average patent application cycle, both calculated from patent application and acceptance data publicly released by the National Intellectual Property Administration.

[Figure 2: see original paper] shows the analysis results of research intensity of China' s carbon capture technology from 1985 to 2013. This reveals that China' s carbon capture technology research can be divided into three stages: Stage 1 (1985-1995): technological germination stage; Stage 2 (1996-2005): technological initiation stage; and Stage 3 (2006-2013): high-speed leap stage.

Based on the T_0 calculation results, this study further conducts technology entropy analysis on the low-speed development stage and high-speed leap stage, as shown in [Figure 3: see original paper].

[Figure 3: see original paper]

As seen in Figure 3, although the low-speed development period (1996-2005) of carbon capture technology showed an overall significant increase in patent volume and approximately linear growth in research intensity, internal oscillations actually occurred within the technological system. In 1996, patent input higher than previous years provided excessive negative entropy for the carbon capture technology system, introducing disturbances that promoted system ordering. However, because the negative entropy input was still relatively small at the beginning and insufficient to generate macro-level movement, the technological system' s inherent self-organization manifested as offsetting external influences. Consequently, significant entropy production began to appear around 1999, but the slowly strengthening negative entropy flow was insufficient to counteract its effects, causing the technological system to tend toward stable equilibrium and manifest as stagnation.

During this fluctuating development, the continuously input negative entropy flow gradually brought the system to a near-critical state. Therefore, after fluctuations in 2005, disturbances in 2006 caused a qualitative change in the technological system, propelling it into a high-speed leap development stage (2006-2013). During this period, negative entropy flow continued to input and consistently exceeded internal entropy production in quantity, driving the system toward an unstable equilibrium state of technological maturity. However, it should be noted that in 2013, negative entropy flowing into the technological system decreased while entropy production suddenly increased, pulling the system back to a relatively balanced critical state. To identify future development directions for carbon capture technology, this paper conducts further research.

4.2 Two-Dimensional Carbon Capture Technology Entropy

Considering that the one-dimensional form of our model inadequately reflects micro-level detail fluctuations and is mainly used for trend analysis, we introduce the two-dimensional form of the patent model based on technology entropy here, analyzing invention patents and utility model patents as the first and second types respectively. The original model becomes:

$$dS = -\frac{\alpha_1 \cdot dn_{1-0} + \alpha_2 \cdot dn_{2-0}}{T_0} + \frac{\beta_1 \cdot dN_{1-0} + \beta_2 \cdot dN_{2-0}}{T_0} + \sum_{i=1}^{2} \frac{\gamma_i \cdot dNi_{-\tau_i}}{t_i}$$

[Figure 4: see original paper] shows the analysis results of research intensity of China's carbon capture technology from 1985 to 2013 under the two-dimensional system. Comparing Figures 2 and 4 reveals that the two model forms yield basically the same results for research intensity analysis. However, the two-dimensional model shows more pronounced 曲折上升 trends during the low-speed development stage and exhibits different characteristics during the high-speed leap stage, particularly the fluctuation in research intensity that appeared in 2013, which warrants greater attention.

Using the two-dimensional technology entropy model to analyze the low-speed development stage and high-speed leap stage, [Figure 5: see original paper] presents the development history of China' s carbon capture technology from three perspectives: deS, diS, and dS.

[Figure 5: see original paper]

From the perspective of deS, since 1996, the entropy flow introduced into the system by new patents in China has generally manifested as negative entropy, with its growth increasing year by year. During the low-speed development stage, because research intensity was still relatively low, small patent inputs could bring significant entropy changes to the system, resulting in large negative entropy flow in certain years (such as 1997). Meanwhile, since this stage had not yet formed stable patent input, some years (such as 1998) showed very small negative entropy flow or even positive values. This well reflects the characteristics of 曲折上升 during the low-speed development stage. During the high-speed leap stage, the annual patent volume input into the technological system grew steadily, and research intensity increased year by year. Except for individual years, deS generally showed an upward trend, revealing that carbon capture not only became a new research hotspot but also that China' s related research indeed achieved certain results.

From the perspective of diS, China' s carbon capture technology system maintained a basically stable level during both the low-speed development and high-speed leap stages, with little variation between different years and values comparable to deS. This reflects that the internal effects of this technology system are not yet strong enough, which is a typical characteristic of not having reached maturity.

From the perspective of dS, the boundaries between China' s carbon capture technology' s low-speed development stage and high-speed leap stage are clear. According to technology entropy theory, carbon capture technology during the high-speed leap stage experienced complete development and maturity stages, achieving important development (see Figures 5 and [Figure 6: see original paper]). However, comprehensive consideration of deS, particularly diS, leads to the conclusion that carbon capture technology has not yet matured.

[Figure 6: see original paper]

In summary, China' s carbon capture technology is not yet mature. The important progress achieved during the high-speed leap stage has provided necessary basic research and technical reserves for technological maturity. The reason why dS tended toward 0 in 2013 is that although substantial research effort was invested, it did not yield high-level outputs comparable to previous levels. This indicates that China' s carbon capture technology development has entered a crucial stage where key technologies await breakthroughs, technology promotion needs strengthening, and industrialization capacity requires enhancement.

Through further refinement of carbon capture technology-related patents, we find that the technical fields mainly involve classifications B01D, C01B, B01J, C07C, and C10L, with the total number of patents in these five fields accounting for 87% of the total, making them representative. These five fields correspond to: (1) Performing operations; transporting—physical or chemical processes—separation; (2) Chemistry; metallurgy—inorganic chemistry—non-metallic elements and their compounds; (3) Performing operations; transporting—physical or chemical processes—chemical or physical methods, e.g., catalysis, colloid chemistry and their equipment; (4) Chemistry; metallurgy—organic chemistry—acyclic or carbocyclic compounds; (5) Chemistry; metallurgy—petroleum, gas and coke industries; industrial gases containing carbon monoxide; fuels; lubricants; peat—fuels not included in other categories; natural gas; synthetic natural gas obtained by methods not included in subclasses C10G or C10K; liquefied petroleum gas; additives in fuels or fire; igniters.

Upon reviewing relevant literature, we find that all five fields are directly related to carbon capture materials but have limited association with carbon capture processes. Regarding applicant composition, patent applications from Zhejiang University, China Petroleum & Chemical Corporation, Southeast University, Toshiba Corporation, Tsinghua University, Alstom Technology Ltd., East China University of Science and Technology, and Dalian University of Technology account for 86% of the total patent volume. Domestic research institutions are mostly universities, with only one domestic enterprise. These two points indicate that China' s carbon capture research mostly concentrates on the primary stage of absorption and adsorption materials, with research institutions still dominated by universities and insufficient involvement from domestic enterprises, indicating that large-scale industrialization capacity has not yet been achieved.

4.3 Dynamic Evaluation of Carbon Capture Technology Development

According to technology entropy theory, technology development is influenced by numerous factors such as policy, economy, and market, making its real development path almost unpredictable. Therefore, this paper relies on existing data and conducts dynamic evaluation of China' s carbon capture technology development through single-variable analysis.

1. Assuming that by 2020, the application and publication volumes of China' s carbon capture technology-related patents remain at the average level of 2011-2013, the dS development situation is shown in Figure 7: see original paper. Under this scenario, deS will reach a stable level starting from 2014, but diS will increase rapidly, with dS always being positive, leading to severe system degradation and eventual extinction.

2. According to the technology entropy patent model, we relax the quantitative relationship between research intensity T and patent volume in assumption (4), i.e., maintaining high attention to carbon capture while not all technical achievements are reflected in patent growth. Assuming that from 2014 to 2020, T grows at the average growth rate of T from 2009-2013, the dS development situation is shown in Figure 7: see original paper. Under this scenario, both deS and diS will decrease year by year, but deS decreases faster than diS, with dS always being positive, causing the system to rapidly move toward extinction.

3. Assuming that by 2020, the application and publication volumes of China' s carbon capture technology-related patents grow linearly at the average growth volume of 2009-2013, the dS development situation is shown in Figure 7: see original paper. Under this scenario, both deS and diS will accelerate growth at basically the same rate, with dS fluctuating near 0, causing the technological system to re-enter a low-speed development stage similar to 1996-2005, making it difficult to achieve substantive progress.

4. Assuming that by 2020, the application and publication volumes of China' s carbon capture technology-related patents grow exponentially at the average growth rate of 2009-2013, the dS development situation is shown in Figure 7: see original paper. Under this scenario, both deS and diS will accelerate growth, but deS grows at a significantly higher rate than diS, with dS showing negative values that effectively drive technology toward maturity.

Through single-variable analysis, we find that China' s carbon capture technology is at a critical development period, and its development in the coming years will directly affect the entire technological system' s growth. Since the technological system itself is still in the development stage, if negative entropy input is lower than internal entropy production, the technological system will rapidly degrade until extinction, with the technology accumulated over the previous decade dispersing into different technology fields rather than forming a carbon capture technology system. If negative entropy input is comparable to internal entropy production levels, the system will maintain an unstable equilibrium state but cannot reach maturity. In this case, increasingly more negative entropy is needed to maintain the system' s own dissipation, at increasingly higher costs. Once negative entropy flow decreases, the system still faces the risk of rapid degradation, resulting in a high-input, low-return situation. If negative entropy input exceeds internal entropy production, the system will enter a new development process, depending on a series of technological innovations driven by breakthroughs in core technologies to push technology toward maturity, with the degree of evolution directly determining the industrialization potential of China' s carbon capture technology.

5. Conclusions

This paper introduces the concept of entropy into patent-based technological systems and proposes a technology entropy analysis method. Taking China's emerging carbon capture technology as an example, we construct one-dimensional and two-dimensional patent technology entropy models to monitor and evaluate the overall development of China' s carbon capture technology, verifying the effectiveness of the patent-based technology entropy analysis method in emerging technology monitoring and evaluation applications. Through analysis of carbon capture technology, we reach the following main conclusions:

1. From 1985 to 2013, China' s carbon capture technology research experienced technological germination, low-speed development, and high-speed leap stages. Although the low-speed development period (1996-2005) showed overall significant increases in patent volume and near-linear growth in research intensity, internal oscillations actually occurred within the technological system, representing a 曲折上升 process. Around 2006, carbon capture technology began rapid development based on the previous stage, entering a critical development period by 2013.

2. From the perspective of deS, carbon capture technology has not only become a new research hotspot but has also achieved certain results. From the perspective of diS, the technology system still exhibits typical characteristics of not having reached maturity. Therefore, China' s carbon capture technology is not yet mature. The important progress achieved during the high-speed leap stage has provided necessary basic research and technical reserves for technological maturity. However, the substantial research investment in recent years has not yet yielded high-level outputs comparable to previous levels, confirming that China' s carbon capture technology development has entered an important stage where key technologies await breakthroughs, technology promotion needs strengthening, and industrialization capacity requires enhancement.

3. Analysis reveals that 87% of China' s carbon capture technology-related patents are mainly related to carbon capture materials, and among the 86% of patent applicants, only one is a domestic enterprise. This indicates that China' s carbon capture research mostly concentrates on primary stages such as absorption and adsorption materials, with research institutions still dominated by universities, insufficient involvement from domestic enterprises, and large-scale industrialization capacity not yet achieved.
4. Single-variable analysis shows that development in the coming years will directly affect the entire carbon capture technology system' s growth. Breakthroughs in core technologies and the resulting series of technological innovations can effectively drive technology toward maturity, with the degree of evolution directly determining the industrialization potential of China' s carbon capture technology.
5. To comprehensively promote the development of China' s carbon capture technology, research management departments should focus more on concentrating efforts to tackle key technologies that urgently need solutions to open up new situations. Researchers could attempt to conduct equipment and process studies to eliminate technological shortcomings and prepare technically for industrial implementation of carbon capture. Enterprises should not only closely monitor relevant research trends but also appropriately increase R&D investment to develop technologies more closely connected with enterprise needs and improve the applicability of patented technologies.

Based on these research conclusions, the patent-based technology entropy analysis method, starting from the perspective of technological systems, reveals the evolutionary trends of technology fields by analyzing changes in various system elements and judging the technology life cycle, serving as an effective tool for monitoring technological systems.

References

[1] Porter A L, Jin X Y, Gilmour J E, et al. Technology Opportunities Analysis: Integrating Technology Monitoring, Forecasting and Assessment with Strategic Planning [J]. Society of Research Administrators Journal, 1994, 26(2): 21-31.

[2] Jun S, Park S S, Jang D S. Technology Forecasting Using Matrix Map and Patent Clustering [J]. Industrial Management & Data Systems, 2012, 112(5): 786-807.

[3] Cho T S, Shih H Y. Patent Citation Network Analysis of Core and Emerging Technologies in Taiwan: 1997-2008 [J]. Scientometrics, 2011, 89(3): 795-811.

[4] Érdi P, Makovi K, Somogyvári Z, et al. Prediction of Emerging Technologies Based on Analysis of the US Patent Citation Network [J]. Scientometrics, 2013, 95(1): 225-242.

[5] Zhao Huanfang, Zhu Donghua. Application of Information Visualization in Technology Monitoring [J]. Journal of Intelligence, 2005, 24(12): 46-48.

[6] Lv Yibo, Kang Yuhang. Mapping and Empirical Study of Science and Technology Monitoring Map Based on Co-occurrence Analysis [J]. Studies in Science of Science, 2010, 28(10): 1459-1466.

[7] Sun Taotao, Tang Xiaoli. Research on Method and Application of Technical Fronts Monitoring in Patent Literature [J]. Journal of Medical Informatics, 2011, 32(10): 40-44.

[8] Huang Lucheng, Shi Yuanyuan, Wu Feifei. Dynamic Analysis of Identification of Technological Trajectory Based on Patent Citation Network: Taking Solar Cell Technology as an Example [J]. Studies in Science of Science, 2013, 31(3): 358-367.

[9] Chang P L, Wu C C, Leu H J. Using Patent Analyses to Monitor the Technological Trends in an Emerging Field of Technology: A Case of Carbon Nanotube Field Emission Display [J]. Scientometrics, 2010, 82(1): 5-19.

[10] Breitzman A, Thomas P. The Emerging Cluster Model: A Tool for Identifying Emerging Technologies Across Multiple Patent Systems [J]. Research Policy, 2015, 44(1): 195-205.

[11] Kuang Jingming, Hu Yi, Li Bei, et al. Patent Blank Mining Technology Based on Generating Topological Mapping [J]. Information Studies: Theory&Application, 2015, 38(12): 133-136, 142.

[12] Ren Zhijun, Qiao Xiaodong, Xu Shuo, et al. An Approach for Technology Opportunities Discovery Model Based on Data Mining [J]. Journal of Intelligence, 2015, 34(6): 174-177, 190.

[13] Zhai Dongsheng, Xia Jun, Zhang Jie, et al. Research on Weak Signal Identification Method of Emerging Technology Based on Patent [J]. Journal of Intelligence, 2015, 34(8): 31-36.

[14] Zhu Donghua, Yuan Junpeng. Research and Empirical Analysis of Technical Monitoring Index [J]. Studies in Science of Science, 2003, 21(4): 419-422.

[15] Shannon C E. A Mathematical Theory of Communication [J]. Bell System Technology Journal, 1948, 27(3): 379-423.

[16] Jaynes E T. Information Theory and Statistical Mechanics [J]. Physical Review, 1957, 106 (4): 620-630.

[17] Bekenstein J D. Black Holes and Entropy [J]. Physical Review D, 1973, 7(8): 2333-2346.

[18] Ren Peiyu, Zhang Li, Song Yong. Management Entropy and Management Dissipative Structure Theory Based on Complexity Science and Its Role in the Organization and Decision Making of Enterprises [J]. Management World, 2001(6): 142-147.

[19] Wang Hengjun. Economic Energy, Economic Entropy, Economic Crisis [J]. Quantitative & Technical Economics, 2002 (2): 72-75.

[20] Zhong Ping, Peng Sizhen, Jia Li, et al. Development of Carbon Capture, Utilization and Storage (CCUS) Technology in China [J]. China Population, Resources and Environment, 2011, 21(12): 41-45.

[21] Zhang Weidong, Zhang Dong, Tian Kezhong. Carbon Capture and Sequestration Technology [J]. Sino-Global Energy, 2009, 14(11): 7-14.

[22] Gan Zhixia, Liu Xuezhi, Shang Yuetong. The Challenge and Suggestion of Developing CCS Technology in China [J]. Forum on Science and Technology in China, 2012(4): 135-138.

Author Contributions

Hou Jianhua: Proposed research ideas, designed research plan, wrote paper and revised final version;
Guo Shuang: Retrieved and processed data, designed case studies and conducted analysis.

Conflict of Interest Statement

All authors declare no conflict of interest.

Supporting Data

Supporting data is self-archived by the authors, E-mail: houjianhua@dlu.edu.cn.
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Analyzing Emerging Issues with Technology Entropy Method Based on Patents: Case Study of Carbon Capture

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Abstract: [Objective] This paper proposes a patent-based technology entropy analysis method, aiming to effectively monitor the development of emerging issues from the patent data. [Methods] First, we built a multi-dimensional technology entropy model for the patent-based system. Second, we analyzed the carbon capture technology from the macro and micro perspectives. [Results] We found that the technology of carbon capture in China was at the crucial development stage. Most of the studies were conducted by universities, which focused on materials with absorption and adsorption abilities. [Limitations] The data collection method needed to be modified to remove the irrelevant ones. [Conclusions] Technology entropy method could effectively analyze the evolution trends of technologies. It provides a feasible tool for us to manage and evaluate the evolution and prediction of new technologies.

Keywords: Technology Entropy, Patent-based Models, Technology Monitoring, Carbon Capture

Note: Figure translations are in progress. See original paper for figures.

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