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Forecast and Analysis of Renewable Energy Technology Development Trend Based on Knowledge Graph and Patent Data

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Abstract. The development and utilization of renewable energy is an important part of national strategy. In this study, Cite Space was used to analyze the Knowledge Graph of relevant research literature and define the research hotspots and the key technologies in the field of renewable energy. Then, the domestic and foreign related patent data in the field of renewable energy were retrieved through the database of Wanfang, and Logistic model was used to make a comparative analysis of the life cycle of relevant technologies in this field, so as to predict the current development stage and future development trend of China's renewable energy technology.

Keywords: Renewable energy; Knowledge Graph; Patent data; Technology life cycle analysis; Development trend forecast

1. Introduction

The rational development and effective utilization of energy are related to the future of the world. Vigorously developing renewable energy is an important means for the world and China to cope with the energy resource tension, environmental degradation and global warming(Bai J H & Xin S X et al. , 2015). Therefore, a comprehensive analysis of the development status of renewable energy technology is of great significance for the scientific and rational formulation of national energy development strategy.

Knowledge Graph is to present the structure, rules and distribution of scientific knowledge by means of visualization. It is a method developed gradually under the background of scientometrics and data visualization. The visualized graph obtained through this method is called "Scientific knowledge graph", which can show the development trend of a discipline or knowledge field in a certain period and reveal the evolution process of this research field (Wang L & Li S Y, 2017). Cite Space is a visualized mapping knowledge domains software (http://cluster.ischool.drexel.edu/~cchen/citespace). Cite Space can clearly show the development trend of a certain research field in a certain period, and present the research hotspots and frontier fields in this field with vivid graphics and intuitive tables (Leydesdorff L, 2007). Therefore, it was used in this paper to analyze the domestic and foreign research literature in the field of renewable energy, present the research hotspots in this field, and find out the key generic technologies.

The technology life cycle prediction method based on Logistic growth curve uses the historical data of the technology predicted (Boretos G P, 2007), finds out its growth curve with Logistic regression model, and estimate the future by extrapolation. Its main use includes two aspects: one can be used to predict the performance of a technology to solve a problem, and the other can be used to predict how and when the technology reaches the upper limit (Harris T M & Devkotab J P, et al., 2018). Currently, Logistic growth curve has been used in many technical fields and achieved satisfactory results in technology life cycle prediction (Chen Y H & Chen C Y, et al. 2010). Therefore, from the perspective of technology life cycle, this paper makes a comparative analysis of domestic and foreign related patent technologies in the field of renewable energy, in the meantime analyzes and predicts the current development stage of China's renewable energy field.

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2. Research hotspot analysis of Renewable energy based on Knowledge Graph

Wherever According to the requirements and operational steps of Cite Space software, "title = renewable energy" was retrieved from the Web of Science database, and 11,375 records were obtained. 245 records were selected from highly cited papers in the field as the refining conditions, and 245 records were used as the source data for the visualization Knowledge Graph analysis result with Cite Space software is shown in Fig.1.

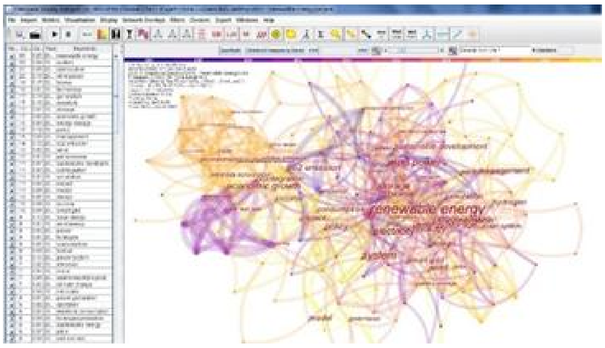

Fig. 1 Knowledge Graph analysis of relevant literature in the field of renewable energy

From the Knowledge Graph analysis results in Fig.1, it can be seen that wind energy, biomass energy, solar energy and hydrogen energy are the research emphases in the related researches in the field of renewable energy. Keywords are a high summary of the literature content, so the focus of attention in the field of renewable energy can be obtained through keyword analysis. The clustering analysis results based on keywords are shown in Fig.2.

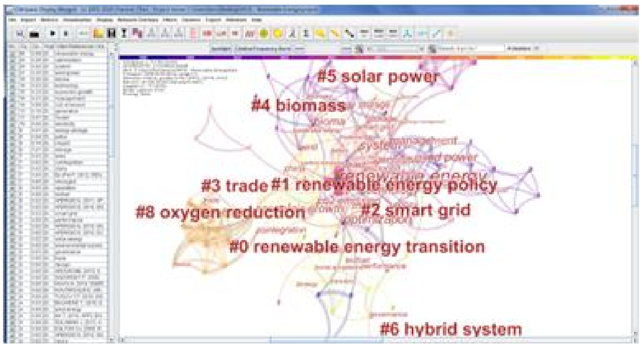

Fig. 2 Keywords based research hotspot analysis results in the field of renewable energy

According to Fig.2, the focus in this field are: renewable energy transition, renewable energy policy, smart grid, trade of renewable energy, biomass, solar energy, and hybrid system.

3. Key renewable energy technology development forecasting based on patent data

3.1 The forecasting method of S-curve and Logistic model

Research shows that a particular trajectory of technological progress follow a specific path, the overall trend is similar to the human life cycle (Wang Y H & Trappey A J C, et al., 2015). It will experience the germination period, growth period, mature period and decline period, namely, the life cycle curve. Because its shape is similar to S, it is also called the S curve (Ghinea C & Dragoi E N, 2016). Logistic model was first proposed by Verhulst in 1838, and the most common equation to describe logistic model is as follows:

$$p(t) = \frac{k}{1 + e^{-\frac{\ln(81)}{dt}(t - t_m)}} \quad (1)$$

Where, P(t) is the cumulative number of the patents; k is the growing saturation level (saturation); dt is defined as the time interval length of [k ×10%, k× 90%], i.e., the length of time from growth period to maturity period.

There are three important parameters in Logistic model (Liu C Y & Wang J C; 2010): (1) Saturation (saturation point): the largest utility produced by using a technique that estimates the value of the maximum value of the cumulative number of patents;(2) Growth time (growth period): said a technology produces maximum utility value of 10%~90% time; (3) Midpoint (inflection point): S curve inflection point, i.e. zero point of two differential from positive to negative.

The s-shaped curve starts from a low production plateau, undergoes a near exponential increase until flattening out into near linear growth through the cycle's midpoint, then follows a near exponential decrease in growth until reaching a high production plateau (known as the carrying capacity when modeling population) (Miranda L C M & Lima C A, 2010). It has been discovered that renewable energy sources tend to produce an s-shaped production trend as the source of energy is not depleted once utilized, but rather is renewed on a periodic basis (Harris T M & Devkotab J P et al., 2018). Therefore, in this study, the logistic model analysis software named Loglet Lab, which developed by Rockefeller University, is used to fit the S curve based on the related domestic and foreign patents data. According to the fitting results, the development stage of the relevant technologies, which include solar energy, nuclear power, marine energy, bio energy, hydropower, and hydrogen energy are predicted.

3.2 Technology development forecasting of renewable energy

In this study, the cumulative number of patent data is the main technical indicators, Wanfang patents database (http://g.wanfangdata.com.cn/) is used as a patents data source, and foreign patents and domestic patents data related to wind energy, solar energy, bioenergy and hydrogen energy are retrieved and analyzed respectively. However, due to the consideration of the length of the report, only solar energy is introduced here as an example.

3.2.1 Solar energy technology development forecasting based on foreign patents data analysis.

The cumulative number of foreign patents related to solar energy technology is shown in Fig.3.

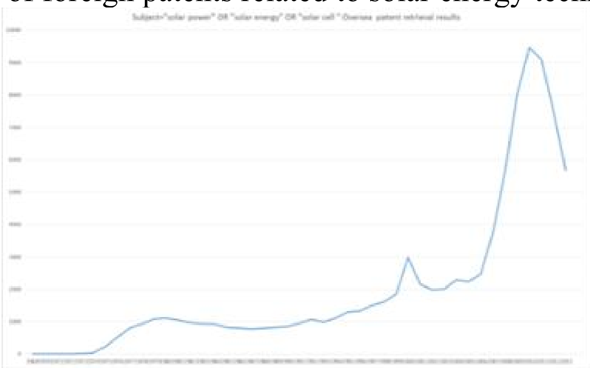

Fig. 3 The cumulative number of foreign patents related to solar energy technology

It can be seen from Fig.3, the number of foreign patents related to solar energy showed slow growth, rapid growth, slow down and Rapid growth again. Related study found that the S curve fitting must be segmented, and the segmentation data selection will have a great impact on the accuracy of the predicted results. When predicting the technology life cycle with S curve must carry on the reasonable section of relevant patent data, only in this way, the life cycle of relevant technologies can be predicted and judged accurately (Zhao Xiuxu & Ke Wei et al., 2015). Therefore, three stages are selected for the S curve fitting by using LogLet Lab, the results are shown in Figure.4.

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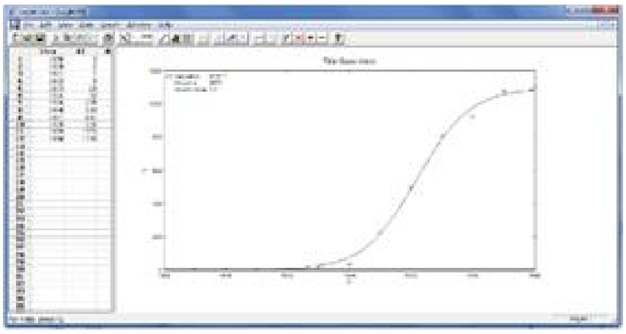
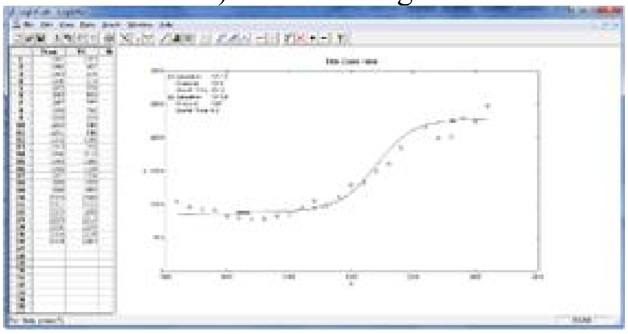
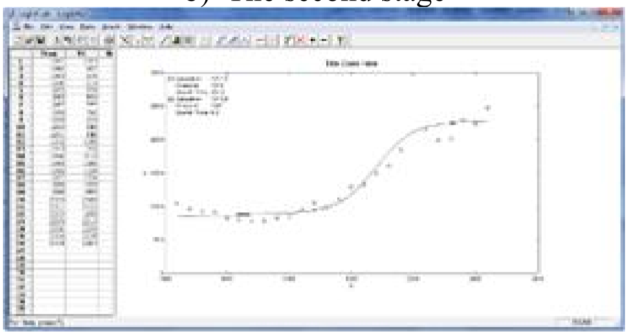


a) The first stage



b) The second stage



c) The third stage

Fig.4 S curve fitting result of the first stage of foreign solar energy

According to above fitting results, foreign solar technology development can be predicted, as shown in Table 1.

Table 1. Technology development forecasting result of the development of foreign solar technology

Variable	The turning point from the embryonic period to the growth period	The turning point from the growth period to maturity	The turning point from mature stage to the recession period
Midpoint	1976	1997	2008
Growth time(years)	3~4	6~7	2~3

The above analysis shows that the growth period of foreign solar technology started from the mid-1970s, and it experienced two periods of rapid growth from the late 1970s to the early 1980s, and from the late 1990s to the early 2000s, and then began to mature around 2008.

3.2.2 Solar energy technology development prediction based on domestic patents data analysis

The number of domestic patents related to solar energy technology is shown in Fig.5.

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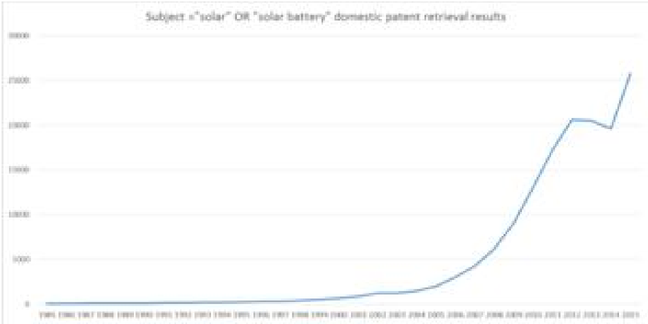

Fig.5 The number of domestic patents related to solar energy

From Figure.5, it can be found that the time of domestic solar energy development is still at the initial stage of growth. The S curve of the first stage is fitted by LogLet Lab, and the result is shown in Fig.6.

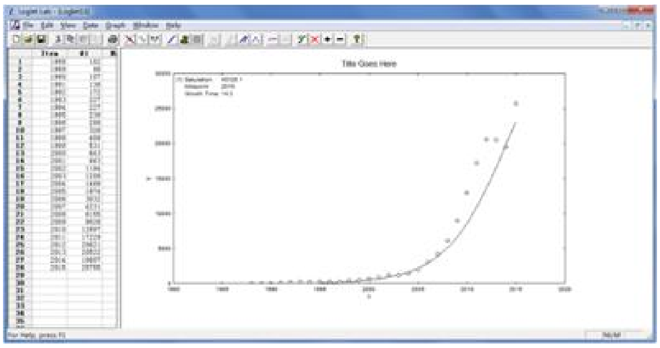

Fig.6 S curve fitting result of the 1st stage of domestic solar energy technology development

The development of domestic solar energy can be predicted, as shown in Table 2.

Table 2.Technology development forecasting result of domestic solar energy

Variable	The turning point from the embryonic period to the growth period	The turning point from the growth period to maturity	The turning point from mature stage to the recession period
Midpoint	2015	-	-
Growth time(years)	14-15	-	-

It can be seen from the predicted results in Table 4 that China's solar energy technology is currently in a period of rapid development. According to the above steps, the life cycle and development of several types of domestic and foreign renewable energy technologies are analyzed and compared. The results are shown in Table 3 and Table 4.

Table 3.Forecasting results of foreign renewable energy related technology development stages

Type	The turning point from the embryonic period to the growth period	The turning point from the growth period to maturity	The turning point from mature stage to the recession period
Wind power	1978	2005	2013
Solar energy	1976	1997	2008
Bioenergy	1992	2014	-

Type	The turning point from the embryonic period to the growth period	The turning point from the growth period to maturity	The turning point from mature stage to the recession period
Hydrogen energy	1977	1995	2003

Table 4.Forecasting results of domestic renewable energy related technology development

Type	The turning point from the embryonic period to the growth period	The turning point from the growth period to maturity	The turning point from mature stage to the recession period
Wind power	2010	2025	-
Solar energy	2015	-	-
Bioenergy	2008	-	-
Hydrogen energy	2015	-	-

4. Conclusion

In this paper, Cite Space was used as the visualization Knowledge Graph analysis tool to analyze the research focus and focus in the field of renewable energy. On this basis, the life cycle of related technologies in the field of renewable energy was analyzed and compared by patent data, and the following conclusions were drawn:

(1) Most of foreign renewable energy technologies have completed the transition from growth to maturity in the seventies of last century. Moreover, the transition from growth to maturity have been completed, and now relevant technologies are in the stage of mature. Because bioenergy related technology started later, it's turning point from the embryonic period to the growth period in the nineties of last century, now it is in a transition stage from growth to maturation.

(2) Most of the domestic renewable energy relevant technologies started the turning stage from the embryonic period to the growth period around 2010-2015. As a result, domestic renewable energy technologies will keep in a rapid increase trend for quite a long time (approximately 5 ~ 15 years). Therefore, the opportunity can be used to seize the technological advantage, so as to create greater economic and strategic value on this basis.

The research of this paper can provide scientific and reasonable basis for the development strategy of renewable energy in China, and is of great significance for the future development direction of renewable energy.

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