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Frontiers of low-carbon technologies: Results from bibliographic coupling with sliding window

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A B S T R A C T

It is of great significance to quickly and accurately detect the current and future development trends of low-carbon technologies (LCT). However, there is a lack of detecting research fronts of low-carbon technologies based on the bibliographic data. This paper proposes a research framework integrating LCT domains and the bibliometric coupling with sliding window technique to explore the LCT research fronts in recent decade (from 2007 to 2016). Eleven research fronts matching the foresight given by LCT experts are identified, including carbon capture and storage (CCS) in power generation, technology transfer, technology diffusion, electrocoagulation, magnetic nanoparticles, critical metals application, electrocatalytic water oxidation, ionic liquids, mutually immiscible ionic liquids, electric vehicle (China), electric vehicle (UK and USA). Closer investigation of the evolution shows that CCS application in the power plants and hydrogen production from water electrolysis are two emerging fronts. Besides, bibliometric coupling with sliding window is an effective tool to detect the frontiers of low-carbon technologies. Finally, the implications of the research for LCT monitoring and development are discussed.

1. Introduction

In response to climate change, low-carbon technology innovation is getting more and more attention (Mi et al., 2015; Wang et al., 2017; Wei et al., 2017). At the same time, the innovation and diffusion of low-carbon technologies are also the important driving force for low-carbon economy development (Cong, 2013; Cong and Shen, 2014; Mi et al., 2017c). In addition, the development of low-carbon technologies and corresponding policy design play a vital role in the residential health and pollutant emission reduction (Kanada et al., 2013; Mi et al., 2017a, 2017b).

Given the importance of low-carbon technologies, it is of great significance to quickly and accurately detect the frontiers of low-carbon technologies. Some literature investigates energy issues, involving the research fronts of low-carbon technologies. In the visualization of international energy policy research, Wang et al. (2016) revealed the development trends of low-carbon technologies research. Sriwannawit and Sandstrom (2015) analyzed the development of diffusion research using the bibliometrics method, and their results included the research fronts of low-carbon technology transfer. However, from the perspective of publications, there are few studies on the frontiers of low-carbon technologies. An important research on this subject is from Albino et al. (2014) who used patent data to analyze the development trend of low-carbon energy technologies. Based on the researches above, this paper tries to explore the frontiers of low-carbon technologies in the recent decade based on the bibliographic data and bibliographic coupling technique.

Firstly, this paper obtains the highly-cited literature in the field of low-carbon technologies. Secondly, with the help of bibliographic coupling to extract the samples with the high coupling strength. Thirdly, categorizing the different research fronts of low-carbon technologies through the cluster analysis. Lastly, depicting the LCT frontiers evolution employing the sliding window technique (this technique through time interval overlapping and panning to obtain more information about the change). From the

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foregoing, some policy implications will be given according to the research findings. Generally, this study tries to answer two questions: (1) what are the research fronts of low-carbon technologies in recent years? (2) What are the evolution paths of LCT research fronts?

The remainder of this paper is structured as follows: in the following part, we highlight existing literature from three perspectives including low-carbon technologies, research front conception, and detecting methods of research fronts. In the third section, we present the research framework, methods and data. Next section are the results as well as the discussions. Finally, the conclusions and policy implications are discussed at the end of the paper.

2. Literature review

2.1. Low-carbon technologies

At present, there is no clear and unified definition of “low-carbon technology (LCT)”, which is similar to the concept of “clean technology” and “environment-friendly technology” (Lv and Qin, 2016; Renewable and Society, 2010). Dechezleprêtre and Martin (2010) equated the concept of low-carbon technology with clean technology, both of which have significant potential to reduce greenhouse gas emissions. Gillingham and Sweeney (2012) defined LCT as a kind of technologies to decrease reliance on fossil fuels and reduce greenhouse gas emissions. Albino et al. (2014) recognized LCT as fundamental means to reduce the final cost of meeting environmental policy objectives and lower the cost of stabilizing atmospheric carbon dioxide concentrations. In the document *Catalogue of low carbon technologies promoted by the state (third batch)*, the national development and reform commission (NDRC) of the People's Republic of China (2016) defined LCT as follows, based on the clean and efficient use of energy and resources, these technologies were characterized by the capability to reduce or eliminate carbon dioxide.

Generally, the classification of low-carbon technologies has two main streams (NDRC, 2016; Renewable and Society, 2010). Firstly, according to the stages of the control process, low-carbon technologies are grouped into zero-carbon technologies, carbon reduction technologies and carbon storage technologies. On the other hand, according to the technical features of emissions reduction, low-carbon technologies are categorized by non-fossil energy technologies, fuels and raw materials substitution technologies, the Non-CO_2 reduction technologies in production processes, “carbon capture, utilization and storage” (CCUS) technologies, carbon sink technologies.

Although the definition of low-carbon technologies from different scholars have different details, there is a basic consensus: on the one hand, low-carbon technologies can reduce greenhouse gases in the atmosphere. On the other hand, low-carbon technologies are essential to sustainable development (Foxon and Pearson, 2008; Kennedy et al., 2016).

2.2. Research front conception

Research front is an important concept in the field of Scientometrics, which was firstly proposed by Price in 1965. Price (1965) defined the recently published and highly-cited literature as the research front. Based on the concept introduced by Price, the concept of research front has received wide attention and expanded meaning in recent years.

Small (1973) and Griffith et al. (1974) viewed that the clustering of co-cited articles represents the research front. Garfield (1989) pointed out that the research front includes co-cited articles and citing articles. Morris et al. (2003) explored the research front using the bibliographic coupling method. Shibata et al. (2008) proposed that the high cited clustering (Direct Citation Clusters) is the research front. Chen (2006) pointed out that the research front is a set of emergent concepts and their knowledge base. In the view of Persson (1994), cited literature is the knowledge base, and citing articles is the research front. Braam et al. (1991) also has a similar view. They defined research front as citing articles clusters with common knowledge base.

In addition, five stages of research fronts are proposed by Upham and Small (2010): emerging fronts, growing fronts, stable fronts, shrinking fronts and exiting fronts, which provides one way to depict the change process of fronts in a period. The categorizing is a useful tool to track the evolution of research fronts in a timely and accurate fashion.

2.3. Research front detection methods

The research front detection methods generally include two types: subjective and objective methods. Subjective methods mainly use the expert consultation and experience judgment, which are influenced by expert knowledge in the specific field. Objective methods refer to some data-driven tools, employing bibliographic data to reveal the performance of the research front, and including the following methodologies or their combination: direct citation, co-citation (Small and Griffith, 1974), bibliographic coupling (Morris et al., 2003), science network (Shibata et al., 2008), word frequency analysis (Kleinberg, 2003), co-word (Pottenger and Yang, 2001). In the era of big data, facing with massive data and complex decision-making environment, objective methods are more and more important and popular with the advantages of accurate detection, time-saving and cost-efficient.

In some specific fields, studies on research fronts show that bibliographic coupling has slightly better performance, compared with co-citation and direct citation (Boyack and Klavans, 2010; den Besselaar and Heimeriks, 2006; Shibata et al., 2009).

Relatively speaking, the highly-cited articles have better quality and higher research value, which are often used as important basis to recognize the research front. Many researches detect research fronts using bibliographic coupling based on highly-cited articles (Ho, 2014; Pislyakov, 2011; Small, 2006). To explore more details of the research fronts, research time are divide into different time frames, and sliding window are proposed to track the evolution process of research fronts. Besides, most studies take 5-year as a citation window (Small, 2006; Upham and Small, 2010).

3. Methodology

3.1. Research framework

To better understand the low-carbon technologies frontiers in the field of natural science in recent decade, this study retrieves the bibliographic data related low-carbon technologies articles from the *Science Citation Index Expanded (SCI-E) database* of *Web of Science database (WOS)*. Due to more standardized and consistent records than other database, *WOS* database has been widely used in related researches (other database can also be used to reveal new findings, but in this paper, we focus on the discoveries from SCI-E database). Bibliographic coupling method is employed to construct sliding window analysis, based on highly-cited articles. And then cluster analysis is utilized to reveal low-carbon technologies research fronts and its evolution trends (2007–2016). Based on the findings from data driven investigation, the paper proposes the policy implications for development of low-carbon technologies. The research framework is shown in Fig. 1.