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Coal utilization eco-paradigm towards an integrated energy system

Jiuping Xu[a,b,*], Jingqi Dai[b], Heping Xie[a,*], Chengwei Lv[b]

[a] Institute of New Energy and Low-Carbon Technology, Sichuan University, Chengdu 610064, PR China
[b] Uncertainty Decision-Making Laboratory, Sichuan University, Chengdu 610064, PR China

A R T I C L E I N F O

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A B S T R A C T

Over the past few centuries, coal has played a significant role in providing the world with the energy needed to encourage development. Since the 1990s, however, the environmental influence of the use of coal on the greenhouse effect and climate change has become a major concern to governments around the world. To explore the historic evolution of and the future trends in coal utilization, an optimized data analysis system (ODAS) based on research and environmental policies is proposed in this paper. Paradigm theory is adopted to explain the technological changes and the vital ecological coal utilization phases, and an imaginary no-coal-on-the-ground integrated energy system is introduced as a future coal utilization development. The advantages of ecological coal utilization are examined to develop possible policies and directions to assist the coal industry move towards green, clean production. Examining coal utilization using the ecological paradigm allows for an accurate view of coal future, with integrated energy systems expected to be a significant new trend.

1. Introduction

Coal is mostly used for power generation around the world with over 40% of worldwide electricity being produced from coal in 2015 (Mohajan, 2015; IEA, 2016). The most significant uses of coal are in electricity generation, steel production, cement manufacturing and as a liquid fuel (WCA, 2017). Attributes such as abundance, affordability and the ease with which it can be transported, stored and used have been the main reasons coal use has been popular since before the 19th century industrial revolution (IEA, 2016). The use of coal for power generation has continued to grow since that time and it has been predicted that our reliance will continue well into the future (Clark and Jacks, 2007). Power stations generate electricity by combusting thermal coal, a process which causes carbon dioxide and other greenhouse gas emissions, with about 60% of CO_2 emissions from known fossil fuel reserves being directly attributed to coal (Global, 2015).

In developing countries such as India and China, over 60% of the domestic power that provides energy for billions of people and promotes local, regional and national economic growth is still being provided by coal power (OECD/IEA, 2015). An IEA analysis of official 2013 data found that coal provided 29% of the total global primary energy supply and that emissions in emerging economies grew by 4%, largely because of increased coal consumption (IEA, 2015). With environmental problems worsening, there is a need to drastically reduce CO_2 emissions; therefore, cleaner energy technologies are being developed and applied (Pnoiu et al., 2008; Dov et al., 2009; Lazaroiu et al., 2012; Minutillo and Perna, 2014; Lazaroiu et al.,). The IEA believes that greater efforts by governments and industry are needed to reduce coal-generated emissions and develop more efficient coal-based technologies to ensure that coal can provide cleaner energy in the decades to come (IEA, 2016). While more efficient plants are being built, the transition from subcritical to supercritical (and ultra-supercritical) technology has been very slow. The greatest challenge with these large scale distributed clean energy schemes is the integration into the energy system as integrated energy systems based on the ecological use of coal are seen as the future coal utilization trends.

With continuous coal industry development and scientific and technological progress, coal utilization technology has also been evolving. Over the past decade, there have been significant developments that have had a great impact on energy systems, with some countries such as Denmark now producing most of their power from renewable sources. However, in general, the transition to cleaner energy has been slow, primarily because of a lack of action by governments. Therefore, if climate change and emissions problems are to be dealt with, governments need to promulgate powerful regulations and policies that force society and industry to harness clean energy (Jacobsson and Lauber, 2006). The coal industry is, therefore, not only affected by market changes and technological developments, but also by government environmental policies and regulations. The Declaration of the United Nations Conference on Human Environment (1972) was the earliest joint declaration focused on protecting the earths environment, after which the Nairobi declara-

* Corresponding authors at: Institute of New Energy and Low-Carbon Technology, Sichuan University, Chengdu 610064, PR China.
E-mail addresses: xujiuping@scu.edu.cn (J. Xu), xiehp@scu.edu.cn (H. Xie).

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tion (1982), the United Nations Framework Convention on Climate Change (UNFCCC, 1992), Agenda 21 (1992), the Rio Declaration (1992), the Kyoto Protocol (1997), the Cancun Agreement (2010) and the Paris Agreement (2015) were successively agreed on by a majority of the worlds countries. In response to the latest joint agreements, many coal producing and coal powered countries have developed focused environmental policies; for example, the USA enacted the Energy Policy Act and Pollution Prevention Act (1990), Japan passed the Air Pollution Control Act (2006), and China passed the Peoples Republic of Chinas Energy Saving Law in 2016. Taking a broad view, environmental policies introduced by enlightened governments have been gradually changing world energy use patterns, leading to the need for coal utilization technological developments to ensure efficient, clean production.

There has been significant research on coal industry developments and coal utilization technology. In 2000, Noriaki Ebara gave a general outline of the basic technologies for each coal type and predicted that these technologies would be implemented in Japan within the next decade and a half (Ebara, 2000). At that time, oxy-fuel coal combustion utilization technology was being widely discussed as a viable environmentally friendly approach (Buhre et al., 2005; Hong et al., 2009). In more recent years, coal blending with other renewable energy sources and especially biomass has become a popular way to improve coal use efficiency (Lăzăroiu, 2009; Gheorghe et al., 2009; Pisa and Lazaroiu, 2012; Pisa et al., 2014). In a review of international research, Phdungsilp found that cities were and will continue to be the key drivers of energy use and the associated carbon emissions and presented a city based integrated energy and carbon emissions approach (Phdungsilp, 2010). More recently, underground coal gasification (UCG) and subsurface energy systems have been proposed to eliminate ash disposal problems and provide a more economical coal exploitation method (Prabu and Jayanti, 2012; Kolditz et al., 2015). Many research papers have focused on a specific coal energy technology or a particular area of use; however, very few have examined the complete coal energy use development process. Overall, there has been little universality or cohesiveness in coal utilization technological developments. The objective of this paper, therefore, is to reveal the current and future coal utilization development tendencies and related policies through an analysis of the connections between coal utilization technological research publication years and associated keywords.

To ensure efficient, healthy coal industry development, it is important to understand the industry evolution, existing status, and future trends. Kuhn (1970) first defined paradigm theory, thereby laying the foundation for paradigm research. Later, to solve economic problems using solutions based on natural science principles, Dosi proposed the technological paradigm and technological trajectories, which have now become classic concepts for the analysis of innovation and technological change literature (Dosi, 1993). The ecological paradigm was first introduced in the 1970s by Brofenbrenner as a reaction to the restricted scope of most developmental psychological child behavior, family policy and educational practice research (Bronfenbrenner, 1974, 1976, 1977). Schwartz felt that the dilemma associated with the relationship between people, nature, and the social environment, which is at the heart of current environmental problems, led to a value choice (Schwartz, 1994). Some people have addressed this dilemma by protecting the environment and living in harmony with the world, an approach which environmental sociologists have highlighted as a new ecological paradigm as it emphasizes environmental factors, constrains human behavior, and promotes ecological values (Stern and Dietz, 1994). Therefore, as the ecological paradigm is seen as a suitable approach to resolving the worlds current environmental problems, an ecological paradigm approach for coal utilization is proposed in this paper.

In this paper, based mainly on literature mining methods, an optimized data analysis system (ODAS) is built to summarize the development of coal energy and elucidate the trends. By combining the paradigm concept with the coal utilization technological diffusion process, a coal utilization paradigm (CUP) is proposed, which can predict the future of coal utilization. The CUP can be summarized in three stages; the first two stages are defined as technological paradigms, while the third stage is an ecological paradigm. When the coal utilization paradigm is established, it could aid in reducing carbon emissions through the use of combined energy sources as well as giving guidance to the development of integrated energy systems.

2. Coal utilization evolution

Because of the explosive growth in coal utilization research, it is difficult to screen for the most useful research foci and development directions. Literature mining, therefore, is indispensable in determining the most pertinent scientific research, especially in areas of particular interest such as energy systems (Scherf et al., 2005). With literature analysis tools, it is possible to focus on technological development paradigm research to understand the coal utilization development processes and future trends. An optimized data analysis system (ODAS) was designed to find the coal utilization relationships between the published years and the article keywords. In the ODAS, five main sections and an additional section were used to analyze the research, as shown in Fig. 1.

To discover the keyword trends, Data Collection involved using the Web of Science database (WoS), which is considered the most trusted citation index as it covers all leading scholarly research and provides researchers, governments, and faculties with prompt, effective access to the worlds leading citation databases. For example, Ridley et al. used the WoS to conduct a network analysis on the environmental and economic uncertainty of biofuels (Ridley et al., 2012). Dataset Handling Section was done using the free, open source software NoteExpress and Microsoft Excel, from which scholars from various fields have achieved vital research results (Bin and San-Dang, 2010; Li et al., 2013). The Cluster Analysis Section involved the use of NodeXL to calculate degree centrality, betweenness centrality, closeness centrality, and the clustering coefficients. The Visualization Results Section and Data Update Section were designed to aid in the research analyses. Further, the Policy Analysis Section was the main advantage of the ODAS as it provided greater depth than other systems.

As the WoS has rich knowledge, it is difficult to select the most useful articles if an appropriate filtering criterion is not specified. To avoid overlooking or duplicating important documents, the methodology for this research had the following rules.

Rule 1: Search for key words using '$X_i + Y_j$', where X_i were keywords such as coal utilization, coal use, coal consumption and coal utilization technology, and Y_i were keywords that covered energy systems, systems, and integrated energy systems. This approach ensured that the search process was accurate and efficient.

Rule 2: To ensure high article relevance, unnecessary research filtered out from the titles and abstracts review.

After following the above steps, the initial records were refined to 2089 articles. After carefully removing duplicate and irrelevant articles using NoteExpress, 497 coal utilization related articles were finally selected. When the articles were first imported into NoteExpress and the duplicates removed, 2365 keyword items from 1992 to 2016 were extracted. After filtering the primary analysis results, the new keyword foci were laid out in years on the horizontal axis, as shown in Fig. 2, from which a general annual incremental trend can be seen from 1992 to 2016. From the ODAS review, it was concluded that coal utilization and associated policies met the laws of the paradigm and could be summarized in three stages, each of which was characterized by different technologies, and together followed the trajectory of an S-shaped curve (Ayres, 1988). Fig. 3 shows the trajectory combined with the policy influences.

Based on the research objectives of this paper, a novel concept for the coal utilization paradigm (CUP) is proposed to illustrate the