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Global transition to low-carbon electricity: A bibliometric analysis

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HIGHLIGHTS

- Since 1990, 13,767 publications have addressed decarbonization of electricity systems.
- Bibliometrics and novel graphics are used to characterize this field of research.
- Successful research involves a range of inter-institutional collaborations.
- We describe three phases of the global transition to low-carbon electricity.
- We also document the evolution of economic and policy analysis.

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ABSTRACT

Decarbonizing the global electricity system is expected to contribute significantly to mitigating climate change. A significant body of research has focused on the development of low-carbon power systems; hence, this bibliometric review is timely. We assess the global scientific research on low-carbon electricity both quantitatively and qualitatively, based on the Science Citation Index Expanded (SCI-Expanded) and Social Sciences Citation Index (SSCI) spanning a quarter century and 13,767 publications. Our analysis illustrates the role of inter-institutional collaboration in successful scientific research on low-carbon power systems. The United States has contributed most to the low-carbon electricity literature with 3074 publications, the highest h-index (58), 8 of the 10 most cited articles, and 4 of the 10 most productive institutions. The Chinese Academy of Science is the most productive institution with 270 publications and notably high levels of international collaboration. Based on an analysis and visualization of author keywords and content analysis, we also characterize three phases of the global transition to low-carbon electricity. The 1990s involved reliance on traditional base-load fuels (coal and nuclear), which spurred the search for cleaner alternatives. These alternatives materialized as the rise of clean coal and wind in the first decade of the 21st century, followed by the growth of solar and natural gas beginning in 2010. Besides this evolution of technologies, we document the transition to more nuanced forms of economic and policy analysis in recent years.

1. Introduction

According to the Intergovernmental Panel on Climate Chante (IPCC), it is extremely likely that at least half of observed global warming since 1950 is due to the observed increase in anthropogenic greenhouse gas (GHG) concentrations [1]. Global climate change appears to be one of the most difficult challenges that human beings have ever faced [2–6]. In particular, electricity generation, by far the single largest source of GHG emissions, accounts for about 40% of the global carbon dioxide emissions [7]. Over the past two decades, the electricity system has undergone significant transformations under the pressures of reducing carbon emissions, meeting increasing electricity demand, providing affordable and reliable electric services, and sustaining economic growth [8–11]. By the adoption of new technologies and the implementation of a variety of measures and policies, methods of producing, transmitting, distributing, and consuming electricity are significantly changing [12,13]. For example, coal consumption experienced the largest percentage decline in power generation, while renewable energy continued to grow steadily, supplying nearly 24% of world electricity in 2015 [14].

As many countries have submitted their pledges to the Nationally Determined Contributions (NDC) to the United Nations Framework

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Convention on Climate Change (UNFCCC),[1] they also committed to CO_2 emission reductions in the electricity sector by setting ambitious mitigation targets. For example, in 2015, according to the U.S. placed its first federal regulations on carbon pollution from electric utilities, targeting a 32% CO_2 reduction by 2030 below 2005 levels.[2] Australia established a goal of 23.5% renewable electricity generation by 2020,[3] while the European Union aimed for 50% renewable electricity by 2030.[4] Recently, China announced to increase the percentage of non-fossil fuel generating capacity to 35% by 2020 in its 13th Five-Year Plan for the power sector.[5] Simultaneously, research on pathways to decarbonizing power sector is booming over the past twenty years. As the status quo of electricity systems across countries varied significantly, scientists and researchers are working independently and collaboratively on new technologies as well as regulatory and policy measures, with the joint efforts of governments, research institutes, and non-profit organizations, aiming to find means to achieve low-carbon, affordable, and reliable electricity systems [15–21].

With a continuously increasing volume of academic outputs, this paper applies bibliometric analysis to assembly and analyze the existing literature on decarbonizing electricity system on a global scale. We not only aim to characterize the basic performance of previous studies, such as the temporal development of scholarly outputs, scientific collaborations, geographical and institutional distributions of publications, but also seek to forecast research trends by using frequency analysis and co-word analysis.

2. Methodology

In this paper, we used a group of keywords representing three aspects of the topic of decarbonizing electricity system: “climate change”, “electricity/electric power”, and “low carbon”. Particularly, specific technologies, such as nuclear, renewable energy, capture and storage, energy efficiency and so on, were used as a searching strategy to access the full of scope of the data.[6] The data were collected from the database of the Science Citation Index Expanded (SCI-EXPANDED), Social Sciences Citation Index (SSCI), which was accessed on December 26, 2016. Given that the year 1990 serves as the basis of the United Nations Framework Convention on Climate Change (UNFCCC) as the First Assessment Report of the IPCC was completed then, and additionally, prior to 1990, only 8 articles were published intermittently with much information missing. Publications occurring within the timespan from 1990 to 2016 were included with all categories, totaling 14,339 records.[7]

2.1. Bibliometric analysis

Bibliometrics, or the statistical analysis of bibliographers, appears to have been first introduced in 1969 as an “illumination of the processes of science and technology by means of counting documents” [22]. Nowadays, bibliometrics is widely used to evaluate the characteristics of articles, books, and other media of academic outputs, to assess the influence of researchers and institutes, to identify patterns of research collaboration, and to identify and predict trends in given research fields. The mathematical and statistical methods used in bibliometrics are based on three typical models: Bradford literature dispersion law, Lotka’s law, and Zipf’s law [23–26]. Given the rapid growth of academic outputs, bibliometrics is taken as one of the most important and efficient methods to research libraries of published information – both qualitative data (e.g., hotspots and future research trends) and quantitative information (e.g., temporal and geographic distribution of outputs, leading researchers, and mainstream journals).

2.2. Impact factor and h-index

When measuring the influence of journals, a variety of quantitative tools are provided by the Journal of Citation Report (JCR) to rank, categorize, evaluate and compare journals. The impact factor (IF) is one of them, considered as one of the most influential tools in modern bibliometric studies [27]. By measuring the average number of citations to the articles published in journals within a particular year or period, the impact factor is useful in clarifying the significance of total citation frequencies, thereby accounting for the relative importance of a journal in a given field. Generally, journals with higher impact factors are expected to be more important than those with lower ones [28]. In this study, impact factors of identified journals are recorded from the Journal Citation Reports 2015.

When estimating the influence of individual researchers, the h-index is commonly used. The h-index was initially developed by Jorge Hirsch in 2005 as a process for quantifying the outputs of an individual researcher [29]. This author-level metric attempts to measure both the productivity and citation impact of the publications of a scientist, a scholarly journal, or an institute. It thereby not only simplifies the measures of quantity and impacts in a single value, but it also allows for direct comparisons across and within disciplines [30,31].

2.3. Content analysis

Content analysis is a quantitative method for summarizing any form of content, often in the form of written words or by counting various other aspects of the content, with the expected results of numbers and percentages [17]. This enables a more objective evaluation than comparing content, aiming to analyze research progress, characterize trends, and anticipate changes in a certain research area [32].

Co-word analysis is a technique of content analysis, which is effective in analyzing the co-occurrences of keywords, thereby mapping the strength of association between words in textual data, and identifying relationships and interactions between the topics and emerging research trends [25]. By presenting quantitative information in multi-dimensional graphs, co-word analysis has an advantage over other content analysis methods [30,31].

3. Results

3.1. Basic characteristics of publications

Of all obtained publication records, nearly 85% fall in the category of “Article”, followed by “Proceeding paper” with 9.05%. Other media of materials like editorial material and book chapters are filtered out, with a total of 13,767 records finally selected for this study. They were published in 18 languages, but English (97.15%) is dominant, with Chinese (0.93%) and German (0.76%) next in rank order. A total of 116 research subjects are covered, among which the subject of natural science and engineering dominate (see Table 1). For example, “energy and fuel” accounts for the biggest share, followed by “environmental science”, and “chemical engineering”. “Economics” is the only social science subject that is among top 10 subjects, at it represents less than 5%. Publications in other social science subjects such as business, management, public policy, and public administration, fall far short of reaching the top ten list.

[1] http://unfccc.int/paris_agreement/items/9485.php.

[2] https://www.epa.gov/cleanpowerplan/clean-power-plan-existing-power-plants.

[3] https://www.environment.gov.au/climate-change/renewable-energy-target-scheme.

[4] http://ec.europa.eu/energy/en/topics/energy-strategy/2050-energy-strategy.

[5] http://www.sdpc.gov.cn/zcfb/zcfbghwb/201612/P020161222570036010274.pdf.

[6] The search query is specified as follows: TS = ((electricity or “electric power” or “power system” or “power sector” or “power plant*”) and (carbon or CO2 or greenhouse or ghg or “climate change”) and (green or clean or low-carbon or decarboniz* or mitigat* or nuclear or renewable or hydroelectricity or hydropower or solar or PV or hydrogen or wind or biomass or bioenergy or biofuel or waste or geothermal or “capture and storage” or CCS or energy efficiency or “combined heat and power” or CHP or energy storage)).

[7] For the purpose of this research, we later applied certain filters to the 14,399 records, thus, only 13,767 records were selected in accordance with the search criteria. Details are seen in Section 3.1.

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