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Innovative technological paradigm-based approach towards biofuel feedstock

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ABSTRACT

Biofuels produced from renewable energy biomass are playing a more significant role because of the environmental problems resulting from the use of fossil fuels. However, a major problem with biofuel production is that despite the range of feedstock that can be used, raw material availability varies considerably. By combining a series of theories and methods, the research objective of this study is to determine the current developments and the future trends in biofuel feedstock. By combining technological paradigm theory with literature mining, it was found that biofuel feedstock production development followed a three-stage trajectory, which was in accordance with the traditional technological paradigm – the S-curve. This new curve can be divided into BFDP (biofuel feedstock development paradigm) competition, BFDP diffusion, and BFDP shift. The biofuel production diffusion velocity model showed that there has been constant growth from 2000, with the growth rate reaching a peak in 2008, after which time it began to drop. Biofuel production worldwide is expected to remain unchanged until 2030 when a paradigm shift is expected. This study also illustrates the results of our innovative procedure – a combination of the data analysis system and the technological paradigm theory – for the present biofuel feedstock soft path that will lead to this paradigm shift, with integrated biofuel production feedstock systems expected to be a significant new trend.

1. Introduction

Because of diminishing supplies and greenhouse gas (GHG) emissions concerns related to climate change, continuing to use fossil fuels has been seen to be unsustainable. Biofuels derived from biomass are one of the most feasible alternatives to petroleum and many countries have initiated extensive biofuel research and development programs to develop sustainable and renewable energy transportation fuels [1,2]. Produced from plants or organic waste, biofuels could assist in reducing both the world's dependence on oil and CO_2 emissions. Additionally, biofuels have the potential to deliver at least one-quarter of the world's projected energy needs of 623 exajoules by 2035 [3], which would significantly limit the effects of climate change, create jobs in rural areas and improve energy security. Some countries, notably the United States, Austria, Brazil, and China, have made substantial developments by dramatically accelerating their biofuel technological development.

Despite the above advantages, there is still some debate about the social, economic, environmental, and technical issues related to biofuel production and utilization. Of these, the "food vs. fuel" issue has been the most discussed in biofuel feedstock production research [4,5]. Although corn-based and sugar-based biofuels are promising substitutes for gasoline in the transportation sector, there are insufficient quantities available to replace the fossil fuels consumed annually worldwide. Lignocellulosic biomass has been found to be a substantial renewable substrate for biofuel production which does not compete with food or animal feed production. However this also has limitations in terms of technology even though it can be supplied on a large-scale using different low-cost raw materials such as municipal and industrial waste, wood, and agricultural residue [6]. Besides the above mentioned biofuel feedstocks, cellulosic plants, corn stover and algae are regarded as the most promising feedstocks for the next biofuel generation.

The research objectives aim to discover the current and future biofuel feedstock developments through a combination of theories and methods on biofuel production feedstock conditions, for which no systematic analytical framework has yet been developed. Further, much of the previous research in the related fields has lacked integrity and universality, so there is a need to explore biofuel production feedstock development so as to allow for an extension to other new renewable energy feedstocks.

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To focus on feedstock use for biofuel production, a data analysis system (DAS) was created based on bibliometrics and certain mining methods to allow for a comprehensive literature analysis to determine whether the focus trends, as expressed by the keywords, were in accordance with the paradigm theory first defined by Kuhn [7]. Dosi later proposed the technological paradigm to solve economic problems using solutions based on natural science principles, which became a classic concept in innovation and technological change literature [8]. Similar to the gradual evolutionary process of life, the technological paradigm also evolves under the driving forces of market demand and industrial competition [9]. Through paradigm theory and a literature analysis, three phases were identified and a biofuel feedstock development paradigm (BFDP) was proposed to describe the evolution and provide a method for an investigation of past trends a prediction of future possibilities [10–12].

A biofuel production diffusion velocity model based on a logistics model is proposed here to demonstrate the biofuel production conditions and predict the feedstock development. Thomas Kuhn's paradigm shift theory argues that paradigm shifts occur because the existing paradigm no longer fits the traditional framework. According to the DAS and literature support, our contribution was to find that a soft path [13] was required to generate this paradigm shift. The soft energy path was first proposed by Lovins, which was then used for water management. However, this concept has not been used for other energy sources. Therefore, the soft path used in this paper seeks to improve the management of biofuel sources rather than merely find new technologies or sources, so offers a marked improvement on today's approaches and provides an entirely new perspective.

The remainder of this paper is structured as follows. Materials and methods are presented in Section 2, which includes the DAS and literature mining based on bibliometrics, the combination of the technological paradigm theory and literature mining to determine current development of biofuel feedstock, and a biofuel production diffusion velocity model to simulate and predict future trends. Results and discussion are presented in Section 3 along with the data mining results analyses, the three BFDP stages, the model results, and a paradigm shift discussion. Through an analysis of the keyword foci in accordance with the theoretical paradigmatic framework, three biofuel feedstock stages are proposed. The model results reveal a need for a new path and a paradigm shift. Combining the data mining results with the soft path, conclusions are given in Section 4 and an integrated system proposed for the coming paradigm shift.

2. Materials and methods

This section introduces the literature mining and analytical process, then discusses the combination of the technological paradigm theory with relevant paradigm theories to explore current biofuel feedstock trajectories, after which a diffusion velocity model is proposed to predict the future development of biofuels through a biofuel production simulation.

2.1. DAS and literature mining

Kuhn [7] first popularized the terms "paradigm" and "paradigm shift". Dosi [8] then investigated technological trajectories on the basis of paradigm shift and found that continuous innovation could proceed within a technological paradigm, while discontinuous innovation could indicate the initiation of a new paradigm. Many studies have subsequently proposed and applied these methodologies across various fields to seek further understanding of the paradigm and its dynamic development in selected fields [14]. The methodology usually used has been a bibliometric analysis of literature publication metadata and information. Several previous studies have used bibliometric techniques to analyze the status and trends in technological development [15].

2.1.1. Keywords for forecasting

Kostoff combined text mining and statistics for a study of scientific papers and proposed a systematic literature-related discovery method [16]. Also, citation-based analyses together with keyword analyses have been investigated. Kajikawa utilized citation analysis on SCI papers together with a clustering of citation network actors and analyzed the keywords to understand structural changes in sustainable energy [17], biomass and bio-fuels [18].

Given the increasingly fierce controversy on the choice of biofuel feedstock, energy research needs to consider a broader coverage of scientific and technological research so as to be able to make effective investment decisions on promising and emerging sources [19]. Forecasting is a descriptive approach based on retrospective data from the past to the present [20]. In this sense, to enable precise forecasting and effective road maps, policy makers and R&D managers have to understand the global trends in research and emerging technologies.

Keywords are essential to clearly identify the range within a specified boundary to provide an objective foresight definition. As a type of co-word analysis, keyword-based analysis has played an important role in understanding knowledge development dynamics [14]. Baldwin et al. mapped ethics and dementia research using keywords [21]. Tian et al. used the Institute of Scientific Information (ISI) database to measure scientific output in the Geographic Information System (GIS) field using keywords [22].

Keywords can be filtered out to motivate researchers to define a new research field, or can be retrieved from published research to be used as network actors. Also, by combining social network analysis and bibliometric analysis for the systematic foresight field method using a keyword-based bibliometric analysis and social network analysis, a quantitative, visual knowledge map can be obtained. Therefore, to visualize the global biofuel feedstock research structure, a data analysis system (DAS) was used to develop a keyword-network analysis of scientific publications.

2.1.2. Data analysis system (DAS)

Literature mining from published scientific literature is useful to discover key areas and trends [23]. To determine the relevant research foci, intensive research using popular academic search engines is conducted, after which appropriate technology and software are used to evaluate the relevant research papers [24]. In this section, the development of the DAS and the research process are described, and the visualization results given.The organization of the data analysis system (DAS) is shown in Fig. 1. The four necessary modules are on the left of Fig. 1, the center shows the specific procedures used, and the software interface diagrams are on the right.

The data collection module interrogates the initial literature database to obtain the most relevant information. The ISI Web of Science was chosen as the primary database because of its powerful access to multiple research databases. Using Boolean Logic technology 374 and the search string "(TI = biofuel production) AND (TS = biofuel feedstock)" "biofuel production (feedstock)", related literature was first identified. When the search was completed, filtering to select the research field was conducted on some reselected articles to identify the specific target. Then, 355 related articles were downloaded directly to NoteExpress.

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