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Integrating bibliometrics and roadmapping methods: A case of dye-sensitized solar cell technology-based industry in China

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ABSTRACT

Emerging industries are attracting increasing attention as they engage in innovation activities that transgress the boundaries of science and technology. Policy makers and industrial communities use roadmapping methods to predict future industrial growth, but the existing bibliometric/workshop methods have limitations when analyzing the full-lifecycle industrial emergence, including the transitions between science, technology, application, and the mass market. This paper, therefore, proposes a framework that integrates bibliometrics and a technology roadmapping (TRM) workshop approach to strategize and plan the future development of the new, technology-based industry. The dye-sensitized solar cell technology-based industry in China is selected as a case study. In this case, the bibliometrics method is applied to analyze the existing position of science and technology, and TRM workshops are used to strategize the future development from technology to application and marketing. Key events and impact on the development of the new, technology-based industry have been identified. This paper will contribute to the roadmapping and foresight methodology, and will be of interest to solar photovoltaic industry researchers.

1. Introduction

In recent years, emerging industries and technologies have been attracting increasing attention worldwide, due to a series of events, such as the financial crisis, climate change, and other global issues. Many developed nations encourage the development of emerging industries to uphold their leadership position when faced with intensive global competition and also to cope with late-comers and challenges in the form of innovations. Meanwhile, several developing economies are striving to promote the emerging industries, in order to boost their economies and catch up in the global innovation race [1].

Emerging industries are being pushed by developments in the field of science and technology[1] [2]. The emergence of this new science and technology may have a profound influence on the global industrial and economic structure, leading to a new wave of industrial revolution [3]. In these circumstances, it becomes a strategic concern for all nations to identify and grasp the opportunity to develop their emerging industries, which will ultimately contribute to their international competitiveness and sustainable development when facing the wave of revolutionary industrial changes. This strategic issue raises two sub-questions: firstly, how can opportunities to develop specific technologies be identified, given the existing position and resource endowments? And, secondly, how can the emergence and growth of the technologies that will form new industries be strategized and planned? In response to these questions, this paper attempts to develop a framework for strategizing and planning the future development of these new industries in emerging countries like China, based on an understanding of the existing science and technology trajectory and the identification of the future macro-level trends in the policy, market, and industry dynamics.

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[1] Scholars, such as Alan Porter, define this new science and technology as newly-emerging science and technologies (NESTs).

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The technology roadmapping (TRM) approach is widely applied at both the firm and industrial levels, supporting the development of technological innovation, strategy, and policy. It provides a structured approach to map the evolution and development of complex systems [4], and is recognized as an effective, comprehensive tool for planning the future development of emerging technologies [5]. However, the traditional TRM methods suffer from several limitations; for example, the workshop processes rely on the intuitive knowledge of participating experts, which might be subjective and biased in some cases. By contrast, some newly-adopted quantitative analyses are using objective data, such as publications, patents, literature and commercial data, which can help to analyze the past and existing trajectory of technological innovation, which are viewed as more valid and less biased as they are supported by objective data. One of the objective analysis methods is bibliometrics. Bibliometrics helps to explore, organize and analyze large amounts of historical data, thus helping researchers to identify the "hidden patterns" and thereby assisting the decision-making process [6]. It has been widely applied to detect emerging research domains and forecast emerging technologies [7,8].

The authors believe that this bibliometric method can supplement the traditional TRM methods, like workshops. Therefore, this paper proposes a framework that integrates bibliometrics with the TRM workshop approach to strategize and plan the future development of new technology-based industries. It takes the dye-sensitized solar cell technology-based industry as a case study, against the background of the rapid development of China's photovoltaic market. Bibliometrics is applied to analyze the existing position and path of science and technology in the dye-sensitized solar energy domain, and TRM workshops are used to strategize and plan the future development of this technology-oriented industry.

The rest of this paper is organized as follows. Section 2 presents the literature review. Section 3 provides the methodology. Section 4 analyzes the case study. Finally, Section 5 concludes and discusses the paper.

2. Literature review

2.1. TRM for emerging industry

Regarding the concept of emerging industry, scholars offer various definitions from different perspectives. Forbes and Kirsh pointed out that an emerging industry represents the intersection of a unit of analysis and a temporal interval. The unit of analysis is the industry [9]. The most common definition of an "industry" is that it is a group of firms producing products that are close substitutes for one another [10,11]. Porter defines emerging industries as "newly formed or re-formed industries that have been created by technological innovations, shifts in relative cost relationships, emergence of new consumer needs, or other economic and sociological changes that elevate a new product or service to the level of a potentially viable business opportunity" [10].

However, it is difficult to study emerging industries, because it is often hard to identify them until after they have matured [12]. In addition, many emerging industries fail, and it is even more difficult to find and study failed industries [9]. Over time, moreover, scholars tend simply to stop asking theoretical questions about phenomena that are hard to study empirically [13], and as a consequence fewer scholars seek to solve the associated empirical problems. Therefore, advancing the study of emerging industries will require scholars to develop new methodologies and theories, to make more extensive use of qualitative and historical data [9].

Technology roadmapping (TRM) is a flexible technique that is widely used within industry to support strategic and long-term planning [14]. It is recognized as an effective and comprehensive tool for mapping emerging industries when studying the complex behaviors of the industrial development process [4,15], and is widely applied at both the firm and sector levels to support innovation, strategy, and policy development and deployment [5]. It provides a structured approach for mapping the evolution and development of complex systems. The TRM approach has been employed to map historical industrial emergence and thus improve our understanding of its dynamics and characteristics. For example, Phaal et al. develop more than 25 "emergence maps" of historical industrial evolution to support the development and testing of the TRM framework as a tool for historical analysis [4], and pointed out that science, technology, application and market oriented demonstrators form key milestones that demarcate the phases and transitions of industrial emergence [8]. Zhou et al. present a preliminary policy-TRM tool in order to facilitate our understanding of policy–industry interactions through the growth process of emerging industries, and undertake a systematic analysis of the policy, markets, product, and technology development throughout the process [16]. The TRM approach has also been used to map the emergence of the automotive industry [17], China's wind energy equipment manufacturing industry [16], and China's solar cell industry [2].

TRM is also a useful tool for mapping emerging technologies in an environment of disruptive change. Gerdsri proposes the concept of 'Technology Development Envelope' and attempts to make the emerging technology roadmap more dynamic, flexible and operating, in order to find the optimal path for enterprises' technology strategy [18]. Holmes and Ferrill apply TRM to help Singaporean SMEs to identify and select emerging technologies [19]. Robinson and Propp construct a "multi-path mapping (MPM)" method that is used to map the alignment strategies in the field of emerging science and technology. It can also be applied to the strategic management of research and R&D at the level of science-to-industry networks [5].

TRM has also been applied in the renewable energy sector during the creation of energy/national strategies. Lee et al. present an energy technology roadmap for South Korea for the next 10 years in order to provide guidelines for an energy technology development policy [20]. Daim et al. propose a wind energy roadmap for Pacific Northwest and consider environmental concerns, the rising cost of and dependency on fossil fuel, business opportunities, government involvement, and the availability of natural wind resources in the Pacific Northwest as the most important drivers [21]. Daim and Oliver implement a TRM process in the energy services sector, and provide details of energy efficiency roadmaps [22]. The objectives involve creating a consensus among the various stakeholders, agreeing on a common vision, providing guidelines for policymakers and decision-makers, establishing goals and targets, assessing promising technology alternatives, identifying markets, gaps and barriers, formulating strategies

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