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Patent citation network analysis for the domain of organic photovoltaic cells: Country, institution, and technology field

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ABSTRACT

The goal of this work is to understand the structure and characteristics of technological knowledge flows between countries, institutions, and technology fields in the field of organic photovoltaic cells. This study was conducted in three stages: data collection, network creation, and network analysis. For network analysis, network visualization, network topological analysis, and node centrality analysis were performed in sequence. The network topological analysis revealed that all three citation networks, i.e., countries, institutions, and technology fields, are scale-free networks that follow the power law and display, to a greater or lesser extent, a more efficient knowledge transfer capability than a random network of the same size. The node centrality analysis showed that the United States, Japan, and Germany are the most important citation centers in the country citation network, while Boeing, Konarka Technologies, Eastman Kodak, and Sharp are the most important in the institution citation network, and the U.S. patent classification (USPC) classes of 136, 257, and 428 are the most important in the technology field citation network, each playing critical roles in each the network as core nodes. In this study, we applied various concepts of centrality to the analysis of individual nodes and found that the results from the network topological analysis and the node centrality analysis are not significantly different. The proposed analysis framework in this paper is applicable to different science and technology domains.

Contents

Abbreviations: EPFL, École Polytechnique Fédérale de Lausanne; GHG, Greenhouse gas; USPC, U.S. patent classification; USPTO, U.S. Patent and Trademark Office; SET-Plan, the Strategic Energy Technology Plan; TOE, Ton of Oil Equivalent.

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1. Introduction

Since the 19th century, mankind has depended mostly on fossil fuels for energy needs. However, as the awareness of environmental problems, such as the depletion of fossil fuels and global warming caused by rising levels of GHGs, has increased, the development and security of environmentally-friendly and sustainable energy sources has emerged as a major concern for the global community. In 2006, the U.S. announced its "Advanced Energy Initiative" and outlined a challenging goal to reduce oil imports from the Middle East by 75% by the year 2025 by developing new and renewable energy resources [1]. The EU adopted the "SET-Plan" and set the target of reducing EU emissions of GHGs by at least 20% by 2020, relative to the emissions levels in 1990 [2]. The Korean Government established "The 2nd National Plan for Energy Technology Development" to improve its global competitiveness in energy technology and the industrial sector. This plan aims to develop new and renewable energy technologies and to improve power efficiency by doubling the country's energy-related research and development (R&D) investments by 2020. Additionally, Japan, China and Canada also have set national agendas for the development of new and renewable energy technologies to reduce their dependency on fossil fuels and to foster a strategic green growth industry.

New and renewable energy technologies cover various fields, such as solar thermal, photovoltaics, wind, geothermal heat, and fuel cells. Among these, solar energy, which includes solar thermal and photovoltaics, is sometimes considered the perfect alternative to fossil fuels because it is an inexhaustible source of energy and does not produce GHGs or other pollutants [3]. Accordingly, many countries are promoting the national importance of R&D in solar energy as a key aspect of the new and renewable energy sector.

As mentioned earlier, solar energy is divided largely into two categories, photovoltaics and solar thermal. The former is a method of generating electrical power by the conversion of solar radiation into electricity through the use of photovoltaic cells made of semiconductors. The latter absorbs solar radiation, converts it into heat, and then utilizes the stored heat for cooling, heating, or power generation. Although photovoltaic energy production varies by country, it is generally a significantly larger component of the solar energy industry in comparison to solar thermal energy.[1]

The core technology of photovoltaics is the photovoltaic cell, which is a device that converts light energy into electrical energy. Among the various photovoltaic cells, organic photovoltaic cells have drawn significant attention as an eco-friendly energy source for the future, incorporating active R&D and knowledge transfer activities. The purpose of this paper is to understand the structure and characteristics of the technological knowledge flows between countries, institutions and technology fields by using a patent citation network in the field of organic photovoltaic cells.

2. Literature Review

The citation information contained in both scientific publications and patents has been the most important and basic indicator by which to measure the impact of such publications and patents [7]. Patent citations, in particular, are widely believed to represent knowledge transfer or knowledge spillover [8] and have been much used to measure disembodied knowledge flows between industries or technology fields [9].

However, there are a few drawbacks to the use of patent data as an indicator of technological knowledge flow. The first drawback involves whether patents can be used to represent technological knowledge. This arises from the fact that not all inventions are patented and patentable [10,11]. In reality, only some inventions are patented [12], and not all patents become innovations [10]. The second drawback is that the propensity to patent varies across technology sectors [10,13]. Patent protection is less significant in some industries [14]. Other means of protection, such as trade secrets or trademarks, might be preferred by individual firms to protect their technological know-how [15]. This propensity can cause bias in the analysis of technological knowledge flow when using patent data. Third, the inventive quality of patents varies greatly. That is, not all patents have equal value [16]. Few patents actually possess high technological and economic value. These three aspects may decrease the significance and value of patent data.

Despite these limitations to patent data, many attempts have been made to date to analyze knowledge flows using patent data. It is because the value of a patent is generally proportional to the citation count number [17,18]; additionally, patent citations can provide information on the diffusion of technologies in a certain technology domain [19]. From the viewpoint of technological knowledge flows, patents, as a medium for the disclosure of technology, clearly show the developmental trace of the technology because they contain the "prior art" [19]. Additionally, patent citations provide good evidence of the links between technological antecedents and descendants [20]. Therefore, patent citations have become one of the main indicators used to explain technological relationships.

In this sense, patents and patent citations are typically considered to be very useful in the study of technological knowledge flows, as has already been demonstrated in previous studies. Huang et al. [21] analyzed patent citation networks in the field of nanoscale science and engineering, presenting the longitudinal changes in R&D in this technology field. Hu and Jaffe [22] used patent citation information to examine the patterns of knowledge diffusion between countries. Kajikawa and Takeda [23] studied the literature citation network of organic light-emitting diodes (OLED) to investigate the structure of research and to detect emerging research domains. No et al. [20] attempted to deepen the understanding of technological trajectories and trends by utilizing patent citations in nanobiotechnology fields. Yoon et al. [24] constructed a patent network based on semantic patent analysis, identifying the

[1] The annual growth rates in the supply of the new and renewable energy sector in OECD countries from 1995 to 2007 shows that photovoltaic energy exhibited the highest growth rate (43.2%), while solar thermal energy remained at 6.8% [4]. In Korea, compared with 30,700 TOE of solar thermal energy supply in 2009, the supply of photovoltaic energy reached 121,700 TOE, which is almost four times higher [5]. In the U.S., photovoltaic energy occupies the largest proportion in the solar energy industry [1], and the Solar Energy Program initiated by the U.S. federal government places the highest priority on the photovoltaic energy market [6].