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Evolution of international trade for photovoltaic cells: A spatial structure study

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ABSTRACT

Photovoltaic (PV) cell plays crucial role to utilize the solar energy. The regional differences in the PV industry have created unbalanced flows of PV cells. This paper examined patterns of the PV cells international trade from spatial and temporal perspectives. Data sources are regional monetary import-export tables and the world renewable energy statistics in 1996–2015. Based on the Haggett's cognitive model of spatial structure, the patterns and evolution characteristics are identified with an aid of ArcGIS. This study revealed most PV cells exporters are distributed in East Asia and Southeast Asia intensively whereas relatively balanced exports are presented in Europe and North American in recent years. Most PV cells are flowing from east to west while the pattern of PV cells international trade has transformed from single-pole to multi-pole. Meanwhile, the international trade intensity of PV cells grew steadily at the global scale, and evolution features of PV cells trades varied from region to region. Economics conditions, incentive policy and producers' demand are three critical factors. These findings provide a useful reference for identifying the intensity, orientation, main connections and development trend of traders. Moreover, the PV industrial practitioners can benefit from this research to develop corresponding international business strategies.

1. Introduction

The rapid urbanization has created significant energy demands where the world total energy supply amounted to 13,699 Mtoe in 2014. Traditional fossil fuel still dominates the energy mix of many countries, accounting for 81.1% of the total energy supply in 2014 [1]. The environmental issues associated with traditional fossil fuel have gained a growing level of public concern, e.g. air and water pollution [2,3]. This is compounded by the rapid depletion of natural resources. As a result, renewable energies such as solar energy have gained substantial development in the last decades.

Since 2013, solar energy is amongst the fastest growing renewable energies [4]. The global cumulative installed capacity of solar power reached 230 GW in 2015 with an annual growth rate of approximately 30%. It is predicted to reach 195 GW by 2040, accounting for 21% of the total power generation capacity [5]. Meanwhile, the global production of PV industry chain reached 94 billion US$ in 2014, 12 times higher than that in 2007 [6].

Reflecting the allocation of resources and the optimization of energy structure, the trade flow is one of the starting points of examining the energy efficiency at the regional scale. The regional differences in terms of Photovoltaic (PV) industry development have created unbalanced flows of PV cells (including panels and modules) within and between regions. The connections among participants in the international trade market presented dynamic changes. The analysis of PV trade flow would assist understanding the role of countries and regional connections.

Various studies have been carried out on the development of PV industry in the last two decades. During the early stages, the studies generally focused on industry investment and market [7,8], technological development [9,10], status quo and prospects [11,12]. With the rapid development of PV industry, attention was gradually turned to the industry strategies in technological innovation [13,14], regional development [15,16] and regional incentive policies [17–20]. Similarly, studies have been conducted on the PV international trade and international competition via the analysis of annual summary, thematic reports, market financing, and so on.

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As an illustration, Bernardina Algieri presented a national competitiveness analysis of PV trade flow through Balassa index and Grubel-Lloyd index, which indicated a long-run equilibrium relationship between PV exports, foreign income, and relative prices in US [21]. Based on PV statistics of 16 nations, Kyunam Kim revealed the interaction among technical innovation, market driven and international trade [22]. Hyun Jin Julie Yu identified the systematic logical framework of the PV industry via a multi perspective approach in Germany, Japan, and China, which was consequently used to explain the PV policy strategy and outcomes in each country [23]. However, vast majority of these studies [24–26] focused on the overall situation for a long period or specific issues between individual countries. For example, Galen Barbose et al. drawn from more than 200,000 PV projects in the United States to identify price patterns of PV systems installed from 1998 to 2012, and found the average installed price of PV systems in the United States declined 6–7% annually [25]. These studies help to understand the trade issues in the development of the photovoltaic industry from multiple perspectives. However, very few studies attempted to explore patterns of the international PV trade in each individual country and region during a long period of time.

It is worth noting very limited number of studies has adopted the spatial analysis method to investigate renewable energies, which has been widely used in research fields of traditional energy and natural resources. Qing Guan used a link prediction approach to estimate potential trade links in the international crude oil trade [27]; Bethany A. Frew analyzed the temporal and spatial tradeoffs in power system modeling [28]; Lisha Hao et al. examined the hierarchy of spatial structure and evolution of the distribution of the world's oil resources via ArcGIS [29]. Hai-Ying Zhang et al. investigated the spatial characteristics of current global oil trade patterns by proposing a new indicator (Moran-F) [30]. Meanwhile, the factors that influence the formation of oil trade patterns are identified by constructing four different kinds of spatial econometric models. Similar empirical studies have been conducted on pollution linkage analysis [31], urban ecological resources [32] and so on. Fengnan Chen et al. employed the spatial analysis and statistical methods to examine the spatial pattern of the Chinese solar energy industry based on the 2009 PV data and ArcGIS [33]. Boudewijn Elsinga and Wilfried van Sark investigated the spatial dependence of variations in power output of small residential solar photovoltaic (PV) systems in a densely populated urban area in and around Utrecht, the Netherlands [34]. These studies combined international trade network and energy geography which helps to effectively describe the energy distribution in the international trade. There have been abundant studies on traditional energies such as oil and coal. However, the development patterns and evolution characteristics of PV cells international trade are largely overlooked in existing studies.

This study aims to capture the characteristics of PV cells international trade among countries globally from spatial perspective, and to identify the evolution process during the last two decades. The dynamic revolution process of PV cells international trade is captured with an aid of ArcGIS. As a result, the development trend and connections of continents in PV cell international trade will be identified.

2. Research methodology

A range of research methods were employed in this paper to investigate the evolution patterns of PV cells international trade. Research methodology for establishing spatial structure of PV cells international trade flow are illustrated in detail from the following aspects, e.g. data selection, staged development, and cognitive model.

2.1. Data selection

The export-import value is an essential indicator for international trade related studies. The export-import value can be identified via 3 codes, i.e. 8-digit Combined Nomenclature Classification (CN), 10-digit Harmonized Tariff Schedule (HTS) code and 6-digit Harmonized System Code (HS). 8-digit CN and the 10-digit HTS code is mainly used in Europe and US respectively. By contrast, the 6-digit HS is widely adopted in the international trade, which reflects accurate trade information [21]. Therefore, the 6-digit HS is more appropriate for the international trade analysis.

As for the photovoltaic trade, the monetary trade data of HS 280461 (Silicon containing by weight not less than 99.99% of silicon), HS 854140 (Photosensitive semi-conduct device, photovoltaic cells & light emit diodes) and HS 854370 (Electrical machines and apparatus, having individual functions) were selected from International Trade Center (ITC) to represent the trade data of three industrial links separately. Located in the midstream of PV industry chain, PV cells (panels and modules) occupy the largest share (64.43% in 2015) of the PV market. Compared to the upstream share (29.93% in 2015) and downstream share (5.64% in 2015), the trade value of PV cells is more representative to the regional status of PV industry as well as the utilization of solar energy. Therefore PV cells were selected as the focus of this study.

2.2. Staged development

The development of PV industry is dynamic due to the internal and external factors such as technology, policy, price, market, and international environment. Since 1996, the PV installed capacity has gain steady growth for the last two decades. The growth rate of installed capacity could serve as an important index to reflect the phase characteristics of PV industry. The statistics of world accumulative installed PV power from 1996 to 2015 [4] and the annual growth rate are shown in Fig. 1. Based on the annual growth rate of 1996–2015, four stages were identified for the development of PV industry, i.e. the infancy stage, the slow growing stage, the rapid growing stage, and the stabilizing stage.

- The infancy stage (before 2001). In this stage, the average annual growth rate maintained nearly 40%, and the scale of industry remained small (less than 2 GW). By the end of 2001, the cumulative installed PV power was only 1569 MW.
- The slow growing stage (2002–2004). The average annual growth rate kept between 25 and 30%, lower than the infancy stage. While the cumulative installed PV power added 1686 MW in this period.
- The rapid growing stage (2005–2011). Since 2005, the formulation of incentive policy [33], such as Feed-in Tariff Law in developed countries has stimulated a global growth of PV power capacity. As a result, the world accumulative installed PV power experienced an explosive growth. The growth rate maintained at a high level among 40%–75%. The cumulative installed PV power exceeded 10,000 MW in 2008 and reached 71,810 MW in 2011. Similarly, the growth rate was as high as 75% in 2010 and 2011 because of the massive profits derived from the hysteretic falling of PV products' prices. This has led to a fast recovery of PV industry from the global financial crisis.
- The stabilizing stage (2012–2015). The cumulative installed PV power has reached 100 GW in 2012. With the gradually maturing legal systems, policies and subsides, the PV industry maintained a steady growth. The annual growth rate was around 30%–40% during this period.