Journal of Cleaner Production xxx (2016) 1–13

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Global solar photovoltaic industry: an overview and national competitiveness of Taiwan

Fu Jia [a,b], Hui Sun [c,*], Lenny Koh [c]

[a] School of Economics and Management, Minjiang University, Fuzhou, PR China
[b] University of Exeter Business School, EX4 4PU, UK
[c] University of Sheffield School of Management, S10 1FL, UK

ARTICLE INFO

Article history:
Received 14 November 2014
Received in revised form
18 March 2016
Accepted 22 March 2016
Available online xxx

Keywords:
Solar photovoltaic
Supply chain
Institutional environment
Deployment policy
Taiwan

ABSTRACT

Global Solar Photovoltaic (PV) industry is fast evolving and is heavily affected by the government policies. In this study, it has been attempted to present a detailed comparison of the solar PV industry of five countries (i.e., Taiwan,[1] China, Japan, Germany and USA) in terms of policy, industry and supply chain analyses. Based on a rich description and mapping of PV supply chain, it's found that China is the biggest producer and consumer of PV products and Taiwan is only strong in solar cell production. The double-anti duties make Taiwan overly reliant on China and Taiwan gradually loses its competitive advantage even in cell production. The success of China is explained adopting Porter's national competitiveness perspective based on the supply chain analysis. Finally, some recommendations are provided to improve national competitiveness for Taiwanese solar photovoltaic industry. This paper contributes to the clean production literature by providing a comprehensive mapping of PV industry supply chain, comparing the industry of five countries and making tailored policy recommendations to Taiwan.

1. Introduction

The shortage of natural resources has compelled many countries to search for renewable resources as well as develop green technologies and governments around the world have established a series of supportive policies to flourish new energy industry (Su, 2013). Solar Photovoltaic (PV) industry is one of the potential industries that offer clean and renewable energies. Compared to coal's Carbon dioxide (CO_2) emission of 975 g per kilowatt-hour (kWh), the use of PV emits only about 50 g of CO_2 per kWh (Burkart, 2010). It offers ongoing free energy and the life expectancy of solar products could be up to 30 years (ibid).

However, the cost of electricity generated from PV system is still higher than conventional sources (e.g., nuclear power, coal and gas) (Echegaray, 2014). In order to stimulate market demands, governments all over the world provide various financial incentives to encourage its adoption since the price is the dominant constrain factor (Olson, 2014). In 2000, Germany was the pioneer in enacting Renewable Energy Sources Act (EEG) that guarantees a fixed Feed-In-Tariff (FIT) for at least 20 years in which the government pays users to reduce price gaps between solar-generated and conventionally generated electricity and the banks offered a low interest rate for solar installation investors (Taiwan Photovoltaic Industry Association, 2013; Diekmann et al., 2012). These regulatory policies successfully expanded the German solar market and had enabled Germany to be the leading European installed capacity market over the past 14 years (Dunford et al., 2012).

The emergence of PV industry has been studied from multiple perspectives including geography of demand and supply (Dunford et al., 2012); innovation space (Smith et al., 2014); stakeholder analysis (Echegaray, 2014); status quo analysis/challenges (Sun et al., 2014) and socio-technical analysis (Zhang et al., 2014). Olson (2014) carries out a Green Innovation Supply chain (GIVC) analysis of PV considering manufacturing, distribution/utility companies, end users, government and environment.

Global PV industry is fast evolving and is heavily affected by the government policies (Dunford et al., 2012); however there are a few gaps identified from the literature: *first*, a detailed supply chain mapping analysis at an industrial supply chain level (from raw

* Corresponding author.
E-mail address: hsun19@sheffield.ac.uk (H. Sun).

[1] Taiwan is part of China in political term but is independent economic region itself due to historical reasons. The statement of Taiwan as a country in this paper is for the convenience of academic discussion rather than show political orientation of the authors.

http://dx.doi.org/10.1016/j.jclepro.2016.03.068
0959-6526/© 2016 Published by Elsevier Ltd.

materials to finished products) is lacking. *Second*, to the best of our knowledge, a comparison between the major production and/or consumption countries, which provides an overview of the global PV industry and national policies for PV industry, doesn't exist. *Third*, there is little research focussing on supply chain analysis of Taiwan's PV industry and making tailored recommendations. The purposes of the paper are therefore to: *first*, identify and compare the current state of solar industry in mainland China, Taiwan, Germany, Japan and USA, who collectively represent 85% of global production and 71% global installation/consumption, with a particular focus on supply chain mapping and national policies regarding PV industry. *Secondly*, explore the effects of anti-dumping and anti-subsidy duties on the inter-regional trade of solar products between China and Taiwan and competitiveness of Taiwan PV industry based on the supply chain analysis at an industry level. *Third*, building on national competitiveness perspective and supply chain analysis, detailed recommendations are provided to Taiwan's PV industry to improve its national competitiveness.

The rest of paper is structured as followed. In Section 2, the six-tier of PV supply chain is discussed. In Section 3, findings are provided with regards to the PV industry of top five solar production countries. In Section 4, a detailed comparison was made for the PV industry between five countries. Section 5 examines the effects of double anti duties levied by US and potentially EU on the inter-regional trade of solar cells. Detailed recommendations are provided for the future development of Taiwanese PV industry in Section 6. Section 7 highlights the contributions of the paper and points out interesting paths to explore in future research.

2. Global solar photovoltaic industry

In this section, the background of PV industry is briefly introduced and a detailed description of the six supply chain stages included in three streams for solar PV production is provided.

2.1. Industry background and size

More than fifty countries have launched similar FIT schemes so far, which boomed the solar industry all over the world. In 2013, 37.6 Gigawatts (GW) of PV panels has been installed globally and the cumulative installed capacity was totalled 140 GW (EPIA, 2014). Among the regions, EU remained the largest market in terms of cumulative installation capacity, with 81.5 GW in 2013 (EPIA, 2014). However, the financial crisis has forced government to reduce political support in 2012 and further negatively influenced European PV markets, while the FIT programme has led to increase in markets of emerging countries (e.g., China). In 2013, Asian countries became the fastest growing area in terms of PV installation especially for China who achieved the largest installation figure of 11.8 GW, followed by Japan with 6.9 GW (EPIA, 2014). USA is another fast growing country that scored 4.8 GW PV capacities in 2013. Outside Europe, several markets continue to grow and are expected to boost the next wave of high demand.

With strong global demand, new businesses flood into this industry (Smith et al., 2014). Fig. 1 shows that the top five solar supplying countries are China, Germany, Japan, Taiwan and USA in 2012 (Earth Policy Institute, 2013b). In fact, the early development of photovoltaic devices took place in Europe, Japan and USA, but now most of the production and some of the technologies have been transferred to Taiwan and China thank to the lower production cost in this area.

Benefiting from the assistance of Chinese government in the form of tax rebates, free land for factories and low-interest government loans, Chinese solar suppliers have expanded their

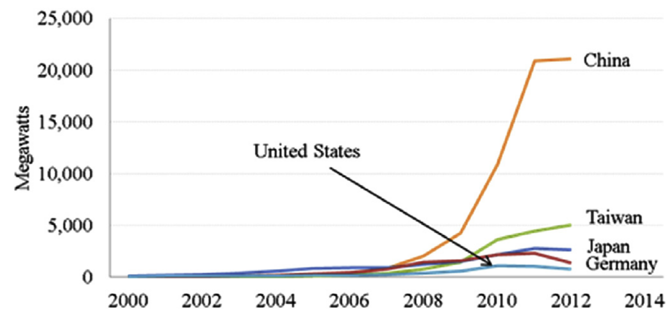

Fig. 1. Annual solar photovoltaics production by 5 countries (2000–2012). Source: Earth Policy Institute (2013a).

product lines rapidly especially on the solar cells and modules that is labour-intensive and requires less know-how. Hence, China was ranked number one PV manufacturing nation with roughly 58% of global market shares overall (Su, 2013). On the other hand, Taiwanese government has set green energy as priority industry and thus implementing the "Green Energy Development Plan" in 2009 to facilitate its development. Moreover, to stimulate domestic market demand of PV system, Taiwan also launched "Million Rooftop PVs Plan" and is expected to install 3.1 GW capacities by 2030 (Green Energy Industry Information Net, 2014a).

In 2000, the global PV market value was only USD 2.5 billion but has boomed over the past 15 years as a result of strong global demand. In 2010, the market value worldwide was seized at USD 71.2 billion and increased to USD 91.6 in 2011, the highest figure since 2000. Although the economic recession caused a 13% drop in market value to USD 79.7 billion in 2012, this industry brought a 15% recovery in 2013 with USD 91.3 billion (Pernick et al., 2014).

Regarding the global investment in solar energy technologies, there was a stable growth from 2004 to 2009 and a boom in 2010 that crossed a little over USD 100 billion. This figure jumped to USD 157.8 billion in 2011, but fell for the following two years, slumping to USD 142.9 billion in 2012, and fell to USD 113.7 billion in 2013. The decline in investment was mainly due to a sharp fall in PV system costs and the effect of policies uncertainty in many countries.

2.2. Solar PV supply chain mapping

Fig. 2 shows that the whole solar photovoltaic industry is categorized into three streams: 1) upstream: polysilicon materials and wafer production; 2) mid-stream: solar cells and PV modules production; and 3) downstream: PV system and installation and the top companies in terms of production volume.

2.2.1. Upstream

The upstream of PV industry basically encompasses the design and production of polysilicon (poly-Si) materials and wafers. The basic component of a solar cell is pure silicon (Si), which is not pure in its natural state. The first step is to place silicon dioxide (SiO_2) into an electrical arc furnace and then yield silicon with one percent impurity. The 99% pure silicon called Polysilicon material is purified even further by dragging the impurities toward one end with each pass. At a specific point, the impure end is removed and the rest becomes pure seed crystal of silicon. Next, a seed crystal of silicon is dipped into melted polycrystalline silicon. As the seed crystal is withdrawn and rotated, a cylindrical ingot is formed. An ingot can be a single crystal, called monosilicon (mono-Si), or multiple silicon crystals, called polysilicon. The monosilicon solar panels have the highest conversion efficiency of 15–20%, while polysilicon achieves

Please cite this article in press as: Jia, F., et al., Global solar photovoltaic industry: an overview and national competitiveness of Taiwan, Journal of Cleaner Production (2016), http://dx.doi.org/10.1016/j.jclepro.2016.03.068