The Promotion and Development of Solar Photovoltaic Industry: Discussion of Its Key Factors

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ABSTRACT

Due to the severe greenhouse effect and the decreasing reserve of fossil fuels, governments in the world have put more emphasis on the strategic use of renewable energy. Taiwan also considers the solar photovoltaic industry to be one of its important industry targets concerning effective and efficient renewable energy exploitation. However, the development of solar photovoltaic industry, in comparison to other high-technology innovation developments in this island country, is still way behind. This research adopts Porter's diamond model as a theoretical basis and uses the decision-making trial and evaluation laboratory (DEMATEL) to explore how to establish the competitiveness of Taiwan's solar photovoltaic industry based on the interactions among factors of industrial development. Our empirical results show that demand conditions, government support, and related supporting industries are three factors that mainly affect the country competitiveness of its solar photovoltaic industry. Factor conditions and firm strategy, structure, and rivalry are then the affected factors of the establishing of Taiwan's competence in solar photovoltaic industry. Moreover, according to pragmatic results, this research provides policy suggestions for the related authorities to refer.

Keywords: Development of Solar Photovoltaic Industry, DEMATEL, Energy Policy, National Competitiveness, Porter's Diamond Model

INTRODUCTION

In direct proportion to the fast growth of industrial progress, technology development, and population, massive use of scarce resources causes the reserves of fossil fuels to shrink. British Petroleum (2009) stated, the global petroleum reserve can be mined for another 42 years, natural gas another 60.4 years, and coal for 122 years in its 2008 research.

Moreover, the greenhouse effect has become more and more serious due to massive use of fossil fuels. The United Nations therefore established the United Nations Framework Convention on Climate Change (UNFCC) to control the emission of greenhouse gases (GHGs). Facing the challenge of decreasing fossil fuels and climate change, countries all over the world strive to develop renewable energies.

Taiwan is a small island with a high population density; it lacks natural resources and therefore its energy supply is largely imported from other countries. For example, in 2008, 99.34 percent of its energy supply was imported (Bureau of Energy, Ministry of Economic Affairs, 2009a). However, in recent years, the demand for energy has been growing fast, especially for petroleum, which leads to a rise in energy prices. The price of petroleum has increased the most. The development of renewable energy will provide relief from the dependence on imported energy (Bureau of Energy, Ministry of Economic Affairs, 2007).

To launch the development of renewable energy, Taiwan established the Renewable Energy Development Bill. The categories launched for the development of renewable energy include solar energy, wind power, nonpumped-storage hydropower, geothermal energy, biomass energy, and ocean energy. However, there are many drawbacks to these renewable energies. For example, hydropower may induce the lack of water resources and the destruction of the environment; ocean energy is still technically immature and is located in the subtropical zone; and the wind power of the northeast winds are strongest in the winter, leading to the instability of wind power in the summer when the electricity demands peak—thus, the best season for wind power and the peak of electricity demands have inverse trends. Additionally, geothermal energy has geothermal restrictions, are costly, and can only be developed in geothermal spring zones, and biomass energy is still in its early stages of development in Taiwan. However, solar energy is geographically unrestricted in comparison with the above energies and is technically mature; hence, it has become the most aggressively developed renewable energy worldwide.

The Sustainable Energy Policy Principles assert that the development of renewable energy should not only achieve energy security and environmental protection but also allow for economic development (Ministry of

Economic Affairs, 2008). The development of the solar photovoltaic industry can create significant job opportunities. On average, each million-watt production of solar electricity brings 17 more jobs, not to mention the extra opportunities due to the follow-up solar photovoltaic system equipment, sales, and services area (Wealth Publisher, 2006). Therefore, at the National Energy Conference in 2009, the solar photovoltaic industry was regarded as one of the most important industries to be developed (National Science Council, 2009). This research thus focuses on the development of Taiwan's solar photovoltaic industry.

To analyze the competitiveness and its development factors as a specific industry, Michael Porter's Diamond Model is often adopted as the theoretical basis (Clancy et al., 2001; O'Malley & O'Gorman, 2001; Koo, 2005; Wonglimpiyarat, 2006). However, most research focuses on the importance of industrial development factors for the establishment of industrial competitiveness rather than on how the factors interact and affect the establishment of industrial competitiveness (Sun & Lin, 2009). The purpose of this research is to adopt Porter's Diamond Model as the basis to explore how to establish competitiveness in Taiwan's solar photovoltaic industry through the interaction of industrial development factors. In addition, decision-making trial and evaluation laboratory (DEMATEL) organizes expert opinions and uses figures to illustrate the interactive relationships among development factors (Wu & Lee, 2007). The interactions among development factors constructed by DEMATEL help to interpret the path to establishing the competitiveness of Taiwan's solar photovoltaic industry.

This article consists of six main sections. The first section provides an introduction to the research, followed by the second section, which introduces the status of Taiwan's solar photovoltaic industry development. The third section will provide related literature reviews on the same topic. The fourth section discusses the methodology and the empirical results delivered by this research. Last but not least are the conclusion and suggestions based on the empirical results from the previous chapter.

DEVELOPMENT STATUS OF TAIWAN'S SOLAR PHOTOVOLTAIC INDUSTRY

Solar energy is one of the statutory renewable energies in the Renewable Energy Development Bill approved in 2009. As mentioned above, this research focuses on the discussion of key development factors in Taiwan's solar photovoltaic industry; thus, the following sections will provide some background introduction on the status of Taiwan's solar photovoltaic industry, its position in the global market, and the recent development of the solar photovoltaic industry in Taiwan.

Recent Development of Solar Photovoltaic Industry in Taiwan

Taiwan is a small island country with high population density; it lacks natural resources, and therefore most of its energy supply is imported from other countries. To improve the independence of energy supply, lower the emission of greenhouse gases, and promote the development of newly established energy industries, the launch of renewable energy policies is one of the most important aspects of Taiwan's energy policies. According to the Sustainable Energy Policy Principles introduced by the Ministry of Economic Affairs in 2008, the proportion of renewable energies using electrical power should be at least 8 percent by 2025 (Ministry of Economic Affairs, 2008). In the meeting on national energy in 2009, it was also pointed out that the development of renewable energy should be considered in terms of energy security, economic development, and environmental protection and that the solar photovoltaic industry is a renewable energy industry that would be able to achieve the three policy goals mentioned above (National Science Council, 2009).

Currently, the cost of solar photovoltaic system are still high as NTD 15–20/kWh (Bureau of Energy, Ministry of Economic Affairs, 2007). Therefore, government subsidy is a very important incentive to encourage the adoption of the solar photovoltaic system for electrical power. Taiwan, like other advanced countries such as Japan and Germany, offers subsidies and incentives for the solar photovoltaic system. Until the end of 2008, 385 cases of system launches were accomplished, with an accumulated system installment volume of 4,080 kWp (Bureau of Energy, Ministry of Economic Affairs, 2009b). To provide incentive for the launch of the solar photovoltaic system, the Bureau of Energy, Ministry of Economic Affairs subsidizes NTD 350,000 per kWp for installing stand-alone systems, and NTD 400,000 per kWp for emergency and precaution systems (Bureau of Energy, Ministry of Economic Affairs, 2006a). In addition, the Solar City promoted in 2006 subsidizes 120 million to the local government to build a solar photovoltaic public space and solar photovoltaic symbolic building (Bureau of Energy, Ministry of Economic Affairs, 2006). For public organizations such as government institution, public business, and public school, Solar Top is promoted to build solar photovoltaic system in public buildings (Bureau of Energy, Ministry of Economic Affairs, 2006b). In 2008, the Solar Community program was launched to allow the solar photovoltaic system to be implemented in community buildings in addition to public buildings (Bureau of Energy, Ministry of Economic Affairs, 2008). Taiwan Power Company is now spending NTD2 per kilowatt to buy electrical power produced by renewable energy. (Taiwan Power Company, 2003). The Renewable Energy Development Bill approved in 2009 obligates national grid companies to purchase the electrical power produced by renewable energy systems, including solar photovoltaic systems.

In addition to the incentive policy on the demand side, in order to control the supply side of key technologies of solar photovoltaic and improve the domestic development of solar photovoltaic industry, the Ministry of Economic Affairs held a discussion meeting "accelerating promoting the development of solar photovoltaic industry," to promote specific plans including: (1) build up the energy environment to drive industry development; (2) solve problems of polysilicon shortage; (3) strengthen the competitive capability of silicon solar photovoltaic systems; (4) accelerate thin-film solar photovoltaic system integration development; (5) establish a module in Asian Pacific that examines certificate services; (6) develop solar photovoltaic production equipment; (7) research and develop solar photovoltaic system grid connection technology (Bureau of Energy, Ministry of Economic Affairs, 2007). In "Economic Development Visions in 2015," polysilicon material and solar photovoltaic production equipment are considered key factors in the major development strategy of the solar photovoltaic industry (Ministry of Economic Affairs, 2007).

Current Status of the Solar Photovoltaic Industry in Taiwan

The solar photovoltaic industry began to flourish after 2000. The entire supply chain of the industry, including related industries such as the production of silicon wafers, solar cells, solar cell modules, and photovoltaic systems, are invested by manufactures, except for the silicon material industry in upstream. Among these related industries, the solar cell industry is the fastest-growing industry, due to internationalization, the transfer of information (communication), and the industry of electronic technology. Moreover, improvements in the semiconductor industry lead to the development of the solar photovoltaic industry. The supply chain of Taiwan's solar photovoltaic industry is almost complete, from silicon wafers, solar batteries, and modules to system installments in downstream are participated by numbers of manufacturers, except for the supply of silicon in the upstream. The number of middle-stream manufacturers grows fast in comparison to the related conservative up-stream industries.

The structure of Taiwan's solar photovoltaic industry is shown in Figure 1. The inexistence of investment in upstream industry like silicon material is due to the high primary capital investment in beginning period, the unavailability of metallurgical-grade silicon, and environment assessment. However, the fast growth of the solar cell market has become an incentive to manufacturers. Muto Silicon, Eversol, LCY, Chinese Petroleum Corporation (CPC), Sayoun (transferred investment by Taiwan Semiconductor), and AE (transferred investment by Modern Technology) are currently investing in the upstream industry. Institutes such as Industrial Technology Research Institute of Taiwan, Chung-Shan Institute of Science & Technology, and Metal Industries Research & Development Centre are working on related researches as well. The government has not only promoted related solar photovoltaic businesses through the Bureau of Energy, Ministry of Economic Affairs but also has established the solar photovoltaic material industry promotion plan to map out the development strategy of key materials through Industrial Development Bureau and thus encourage foreign silicon material companies to build factories or transfer technology to local companies. Formosa Plastics is seeking the opportunity to cooperate with REC from Norway to build a polysilicon factory. This investment is estimated at more than NTD 10 billion. Chinese Petroleum Corporation is getting in

	Silicon material	Silicon ingot Silicon wafer	Solar batteries	Solar battery modules	System installments and routes
Domestic manufacturers	None at the moment * CPC (planning) * Formosa Plastic (planning)	* Sino-American Silicon (SAS) * Green Energy Technology * Wafer Works * Modern Technology (Kunshan) * Topco	Modern Technology, e-ton Solar, Delsolar, Gintech, Phoenix Silicon, Neo Solar Power, Big Sun Energy Technology, Sinonar, Wisdom, Mosel Vitelic, Formosun…	Sinonar, Perfect Source Tech, , Sunner Solar, NewCore Tek, Ever Bright, Taiwan Sun Energy Photoelectric, LIGI TEK, Lucky Power Technology, China Electric MFG…	Modern Technology, China Electric MFG, Ever Bright, Lucky Power Technology, Top Power Technology, Uniergy Engineering, Lightwave Solar Power, Deniz Electric Glass, Hengs [illegible]

Figure 1. Structure of Taiwan Solar Photovoltaic Industry

touch with Tokuyama from Japan, Hemlock from the United States, and SOLMIC from Germany and plans to invest NTD 10 billion. If successful, in 2011 it will build a polysilicon factory that has an annual production of 3,000 tons. Moreover, the Chinese Petroleum Corporation plans to use the cold energy generation by importing liquid natural gases to produce polysilicon materials with cheap electricity. This will become a relative cost advantage for the Chinese Petroleum Corporation. In 2007, the demand for polysilicon in Taiwan was 5,000 tons, and the demand is estimated to grow to 13,000 tons by 2011, given that middle- and downstream companies are expanding their capacity. As for the supply side, AE and Sayoun, invested by Modern Technology, are the first two companies to start mass production among other companies. However, primary scales are still not good enough to improve the demand-and-supply imbalance for Taiwan solar cells. According to the estimation of the Ministry of Economic Affairs, there will be at least two companies providing 2,000 tons of polysilicon production by 2010, and providing 10,000 tons by 2015, which is equal to a production value of more than NTD 430 billion. The demand-and-supply imbalance of polysilicon material can only be reversed after 2011, when the demand-and-supply gap is expected to be smaller.

Thanks to the development of the semiconductor industry in Taiwan, the silicon wafer/stick, upstream companies such as factories of crystal growth and pulling process for the silicon briquette are relatively common. As the solar photovoltaic industry power becomes stronger, many related semiconductor silicon wafer/stick companies have begun to invest in the production of the solar cell silicon wafer/stick. Representative companies are Sino-American Silicon (SAS), Wafer Works, and so on. Among the new entrants, Green Energy Technology, reinvestment by Tatung is the most eye-catching company. Green Energy Technology has focused on the polysilicon wafer and has served as material OEM which acquires material and reuses or incorporates it into a new product since its establishment. Among the top three silicon wafer factories, it is the one most active in expanding its capacity.

Currently there are sufficient companies in the middle and downstream supply chain of this industry because the entrance barrier is relatively low. This phenomenon has doubled the production scale of the solar photovoltaic industry, and the growing trend will continue for the coming years. In 2007, solar cells in Taiwan achieved a production rate of 435 MWp, 418 MWp for crystalline silicon solar cells and 17 MWp for amorphous silicon solar cells, which implied a growth of 81.25 percent since 2006. By 2010, the production rate of solar cells in Taiwan is estimated to be 1,936 MWp, a quantity surpassed only in Europe, North America, Japan, and China. The domestic company Modern Technology had a production rate of 280 MW in 2008 and was one of the top seven solar cell manufacturers worldwide.

NATIONAL COMPETITIVENESS DRIVING FACTORS

Kao, Wu, Hsieh, Wang, Lin, and Chen (2008) applied four dimensions to measure competitive advantages of nations, such as economy, technology, human resource, and management. Önse, Ülengin, Ulusoy, Aktaş, Kabak, and Topcu (2008) adopted the basic requirements factor, efficiency enhancers factor, and innovation and sophistication factor to estimate the national competitiveness. Wang, Chien, and Kao (2007) examined the influence of technology development on national competitiveness. They thought that technology development plays a key role in national competitiveness. Cho, Moon, and Kim (2008) used eight variables to evaluate the national competitiveness, including conditions, business context, related and supporting industries, demand conditions, human factors, politicians and bureaucrats, entrepreneurs, and professionals.

We believe that most of the above chiefly stem from a major breakthrough for the concept of national competitiveness derived from Porter's *Competitive Advantage of Nations* (1998), which advocated specialization according to historical strength by emphasizing the power of national competitiveness. Porter highlighted that multiple factors beyond those internal to the firm may improve its performance. As shown in Figure 2 in his "diamond model," four sets of interrelated forces are brought forward to explain national competitiveness: factor conditions; local demand conditions; related and supported industries; and firm structure, strategy, and rivalry. The below describes key dimensions of national competitiveness, mainly derived from Porter's diamond model.

Factor Conditions

Porter agreed that a state's or nation's endowment of factors for encouraging production has a role in determining competitive advantage. However, Porter broadened the definition of factors for production into five major categories: human resources, physical resources, knowledge

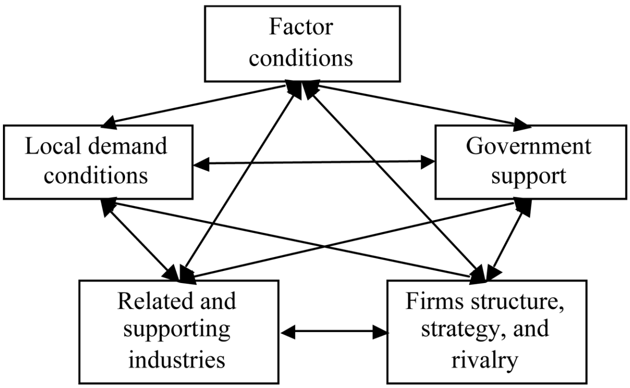

Figure 2. Diamond Model

resources, capital resources, and infrastructure (Rojas, 2007).

Abundant natural resources, which are factors of production, could provide the original momentum for establishing an industry. Their presence might also entice a predecessor industry to relocate, thereby creating the initial framework for a subsequent industry (Porter, 1998).

The fact that competitive pressure compels firms to be innovative to overcome their microeconomic environment's disadvantages represents a major theme in Porter's work. The remaining fundamental determinants in the model play an important and powerful role in inciting firms to innovate to remain competitive players in their industries. Specialized factors of production are skilled labor, capital, and information infrastructure. Specialized factors involve heavy, sustained investment, and they are more difficult to duplicate. These factors include entrepreneurship and venture capital.

Demand Conditions

Consumer demand plays possibly the most important role in forming and building up national competitiveness. A large number of industrial customers in the nearby area create sufficient demand to enable suppliers to acquire and operate expensive specialized machinery.

Porter (1998) has argued that a sophisticated domestic market is an important element in developing competitiveness. Firms that face a sophisticated domestic market are likely to sell superior products because the market demands high quality, and a close proximity to such consumers enables the firm to better understand the needs and desires of the customers (Lai & Shyu, 2005). As a result, demand conditions can stimulate an industry through local demand for a product and can prove viable in regional, national, and international markets as well (Woodward, 2004).

Related and Supporting Industries

Spatial proximity of upstream or downstream industries facilitates the exchange of information and promotes a continuous exchange of ideas and innovations. The availability, density, and interconnectedness of vertically and horizontally related industries are important drivers for national competitiveness (Lai & Shyu, 2005). This includes suppliers and related industries.

The term "related industries" refers to firms that provide complementary products or services to one another. While competing on the basis of their value chain management within their product- or service-specific industry, they might share or coordinate certain activities, such as distribution, technology development, manufacturing, or marketing (Porter, 1998). Competitive related industries can provide opportunities for technological exchanges and, possibly, can accelerate the development of competitive local supplier industries serving both. However, close working relationships among related industries do not happen automatically. Related industries must explicitly seek to forge alliances that will add to their competitive advantage (Rojas, 2007).

Firm Strategy, Structure, and Rivalry

Porter (1998) argues that intense competition spurs innovation. The world is dominated by dynamic conditions. Direct competition impels firms to work for increases in productivity and innovation. Firm strategy, structure, and rivalry refer to the various approaches to a firm's inception, organization, and management that establish the context for local rivalry and competitive advantage.

Differences in management systems and organizational structure offer opportunities for establishing competitive advantage. Relationships between labor and management represent a particularly important element for the firm, given their powerful impact on the process of innovation and improvements (Porter, 1998). Porter established that rivalry with domestic firms proves to be the factor most beneficial in terms of innovation and improvements. Local rivals compel one another to seek effective cost-cutting measures, product/service innovations, and organizational improvements. Local competitive pressure also leads to com-

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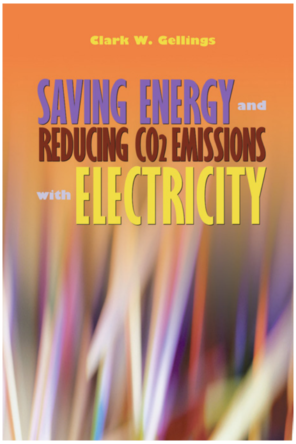

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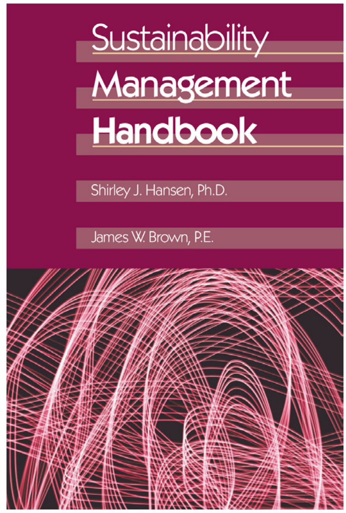

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mercially successful firms, which in turn, lure new firms to the industry.

Government Support

The role of government in Porter's diamond model is to act as a catalyst and challenger; it is to encourage—or even push—companies to raise their aspirations and to move to higher levels of competitive performance. Government must encourage companies to raise their performance, to stimulate early demand for advanced products, to focus on specialized factor creation, and to stimulate local rivalry by limiting direct cooperation and enforcing antitrust regulations.

Additionally, government must provide the required infrastructural needs of the developing national competitiveness. The role of the government in a regional economy is necessarily a variable over the life cycle of the national competitiveness, and as a result it needs to have the capability to identify and monitor the set of natural industries that exist within the region and their stages of development (Porter, 1998).

THE DEMATEL METHOD

In a totally interdependent system, all criteria of the system are mutually related, directly or indirectly; thus, any interference with one of the criteria affects all of the others, so it is difficult to find priorities for decision making (Tzeng et al., 2007). The DEMATEL, having originated from the Geneva Research Centre of the Battelle Memorial Institute (Gabus & Fontela, 1973; Fontela & Gabus, 1976), aims to convert the relationship between the causes and effects of criteria into an intelligible structural model of the system (Tzeng et al., 2007; Huang et al., 2007; Liou et al., 2008; Lee et al., 2009; Lin & Tzeng, 2009; Ou Yang et al., 2009). The DEMATEL method has been widely applied in many different research fields, such as the design of human interface for the supervisory control system (Hori & Shimizu, 1999), e-learning system (Tzeng et al., 2007), innovation policy (Huang et al., 2007), human resource management (Wu & Lee, 2007), airline safety management (Liou et al., 2008), knowledge management (Wu, 2008), customer satisfaction management (Hu et al., 2009), service quality (Tseng, 2009a; Tseng, 2009b), sustainable development strategy (Tsai & Chou, 2009), industrial cluster policy (Lin & Tzeng, 2009), municipal solid waste management (Tseng, 2009c), etc. The DEMATEL model construction process is described below:

Step 1: Generating the direct-relation matrix

Measuring the relationship between criteria requires that the comparison scale be constructed according to the following four levels: No influence (0), Low influence (1), Medium influence (2), High influence (3), and Very high influence (4). The integer score that the *k*th expert gives to indicate the degree of influence that factor *i* has on factor *j* is x_{ij}^{k}. The n × n matrix ***A*** is found by averaging all experts' scores.

$$a_{ij} = \frac{1}{H}\sum_{k=1}^{H} x_{ij}^{k} \quad (1)$$

Step 2: Normalizing the direct-relation matrix

On the basis of the direct-relation matrix *A*, the normalized direct-relation matrix *X* can be obtained by the following formulas:

$$y = \frac{1}{\max\limits_{1 \le i \le n} \sum_{j=1}^{n} a_{ij}} \quad (2)$$

$$\boldsymbol{X} = y \bullet \boldsymbol{A} \quad (3)$$

Step 3: Obtaining the total-relation matrix

Once the normalized direct-relation ***X*** is obtained, the total-relation matrix ***T*** can be calculated by applying the following formula, (4), in which ***I*** is denoted as the identity matrix.

$$\boldsymbol{T} = \boldsymbol{X}\,(\boldsymbol{I} - \boldsymbol{X})^{-1} \quad (4)$$

Step 4: Calculate the prominence and relation of each factor

The sum of rows and the sum of columns are respectively denoted as ***D*** and ***R*** within the total-relation matrix ***T*** through the formula 5 to 7:

$$\boldsymbol{T} = [t_{ij}]_{nxn} \qquad i,j = 1,2,\ldots,n \quad (5)$$

$$\boldsymbol{D} = \sum_{j=1}^{n} t_{ij} \quad (6)$$

$$\boldsymbol{R} = \sum_{i=1}^{n} t_{ij} \quad (7)$$

where ***D*** indicates the level of influence to others and ***R*** denotes the level of relationship with others (Seyed-Hosseini et al., 2006; Tsai & Chou, 2009). The values of $D + R$, named "prominence," show the importance of factors. Similarly, the values of $D + R$, named "relation," divide factors into dispatchers and receivers (Wu, 2008). Factors having positive values of $D + R$ have greater influence on one another and are assumed to have higher priority and are named dispatcher; others with negative values of $D - R$ receiving more influence from another are assumed to have lower priority and are called receiver. The value of $D + R$ indicates the degree of relation between each factor with others, and factors with a higher value of $D + R$ have a stronger relationship with one another. Those having a lower value of $D + R$ have a weaker relationship with one other (Seyed-Hosseini et al., 2006; Tsai & Chou, 2009).

EMPIRICAL ANALYSIS

The main purpose of this article is to explore how to establish the competitiveness of Taiwan's solar photovoltaic industry through analyzing the reactions among industrial development factors, adopting Porter's diamond model. See Figure 3 for research structure.

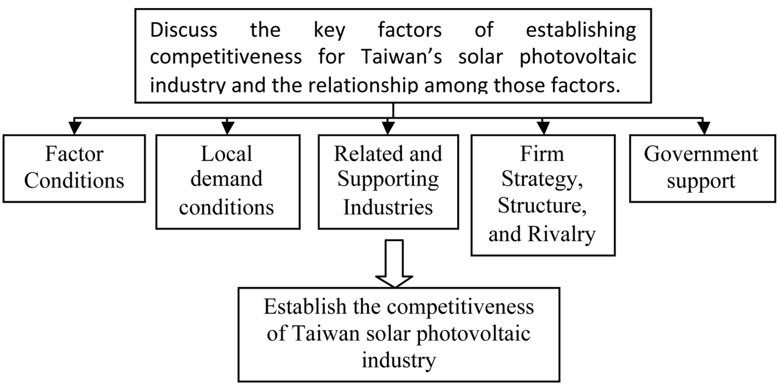

Figure 3. Research Structure

Discuss the Relationship between Factors Using DEMATEL

To understand the key factors of industrial development in solar photovoltaic industry, the relationship among those factors, and the casual relationship, this article surveys thirty-two experts who are familiar with the current status of Taiwan's solar photovoltaic industry and renewable energy policy. The results of the survey are conveyed in a direct-relation matrix using arithmetic averages. See Table 1 to review the direct-relation matrix.

Using equations 1 and 2, we transform the direct-relation matrix into a normalized direct-relation matrix (see table 2).

We can use equation 3 to transform the normalized direct-relation matrix into a total-relation matrix. Then we can use equations 4–6 to compute the D and R values for each factor to obtain the prominence

Table 1. Direct-relation Matrix

	Factor conditions	Local demand conditions	Related and supporting industries	Firm strategy, structure, and rivalry	Government support
Factor conditions	0	1.781	2.688	3.188	2.344
Local demand conditions	2.063	0	2.250	2.438	2.906
Related and supporting industries	2.781	2.281	0	3.125	2.781
Firm strategy, structure, and rivalry	2.813	2.094	3.156	0	2.969
Government support	2.563	2.844	2.719	3.063	0

Table 2. Normalized Direct-relation Matrix

	Factor conditions	Local demand conditions	Related and supporting industries	Firm strategy, structure, and rivalry	Government support
Factor conditions	0	0.159	0.240	0.285	0.209
Local demand conditions	0.184	0	0.201	0.218	0.260
Related and supporting industries	0.249	0.204	0	0.279	0.249
Firm strategy, structure, and rivalry	0.251	0.187	0.282	0	0.265
Government support	0.229	0.254	0.243	0.274	0

value of D + R and the relation value of D – R (see Table 3). We can see from Table 3 that the highest prominence factor is "firm strategy, structure, and rivalry" (D + R = 38.912); and the highest relation factor is "local demand conditions" (D – R = 0.980). As mentioned above, if a factor has a D – R value greater than zero, we can call it a dispatcher and receiver if the value is less than zero. Therefore we can see from the figures that the main dispatchers used in establishing the competitiveness of Taiwan's solar photovoltaic industry are "local demand conditions," "government support," and "related supporting industries," and the receivers are "factor conditions" and "firm strategy, structure, and rivalry." Promoting the three key dispatchers "local demand conditions," "government support," and "related supporting industries" can improve receivers such as "factor conditions" and "firm strategy, structure, and rivalry." By doing so, we can also achieve the goal of improving the competitiveness of Taiwan's solar photovoltaic industry.

Dispatchers

As seen in Figure 4, the main dispatchers of the competitiveness of Taiwan's solar photovoltaic industry are "local demand conditions" (***D*** – ***R*** = 0.980), "government support" (***D*** – ***R*** = 0.259), and "related supporting industries" (***D*** – ***R*** = 0.145). The receivers can be improved by improving these dispatchers and thus building up the competitiveness of Taiwan's solar photovoltaic industry. Among the three influence factors, "local demand conditions" has the highest influence (***D*** – ***R*** = 0.980) that would affect "government," "related supporting industries," "fac-

Table 3. ***D, R, D*** **+** ***R*** **and** ***D*** **–** ***R*** **values**

	D	***R***	***D + R***	***D – R***
Factor conditions	17.503	17.833	35.336	-0.331
Local demand conditions	16.954	15.974	32.927	0.980
Related and supporting industries	18.818	18.673	37.491	0.145
Firm strategy, structure, and rivalry	18.929	19.983	38.912	-1.054
Government support	19.073	18.814	37.887	0.259

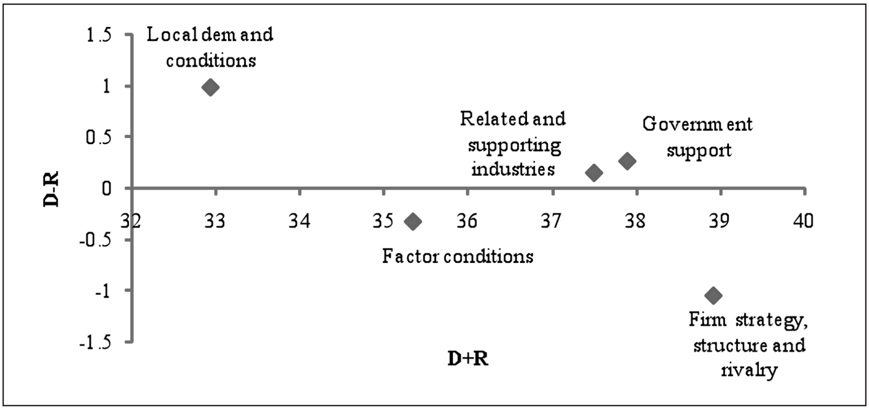

Figure 4. Causal Effect Chart

tor conditions," and "firm strategy, structure, and rivalry." Porter (1998) indicated that local demand is the most important factor in improving industrial competitiveness. If the solar photovoltaic industry creates more demand, more superior human resources will enter this industry and thus improve the production factors needed for Taiwan's domestic solar photovoltaic industry. In the meantime, more companies will be attracted to invest in this industry, resulting in a complete supply chain of Taiwan's solar photovoltaic industry. A good example of a link in this chain would be the investment of more semiconductor and electronics companies in solar cell production. Moreover, the increasing demand for solar photovoltaic facilitates government to establish an incentive policy or to assist companies to develop key technology.

"Government support" is another key factor affecting the competitiveness of Taiwan's solar photovoltaic industry, and it has the highest prominence ($D + R = 37.887$) among the three influence factors. To build up the core competitiveness of Taiwan's solar photovoltaic industry, the government policy's coordination and support is essential. The incentive mechanisms for the installment of solar photovoltaic equipment from government can directly increase local demand for the solar photovoltaic industry. Seventy-five percent of the solar photovoltaic market comes from the government subsidy incentive policies around the world. Due to the high installment cost, local demand does not increase significantly. Having not reached to the "grid parity" (the cost of electrical power generated from solar is equal to the traditional source of electricity), this industry needs government policy to stimulate demand.

In the "Investment Plan of Economic Development and Public Construction Expansions" in 2009, Taiwan included a solar photovoltaic system demonstration plan (Council for Economic Planning and Development, 2009). Meanwhile, based on the Renewable Energy Development Bill, prices of electrical power generated from renewable energy equipment can be more reasonable and thus increase the local demand of renewable energy including solar photovoltaic energy. In addition, the government can establish incentives for university and research institutions to develop key technology as well as independent process equipment. This will help to increase the demand for a solar photovoltaic industry in Taiwan and the willingness for related industries to invest in this industry. Recently the Industrial Development Bureau used a solar photovoltaic industry promotion plan as a window to attract investment from foreign companies, technology transfer, and investment in the development of key technology with the Technology Development Program of the Department of Industrial Technology (Bureau of Energy, Ministry of Economic Affairs, 2007). The Photovoltaics Technology Center of Industrial Technology Research Institute of Taiwan is responsible for the research of the key technology of solar photovoltaic.

"Related and supporting industries" is also one of the dispatchers of the establishment of competitiveness of Taiwan's solar photovoltaic industry. The more complete the solar photovoltaic industry, the more high-quality human resources and capital will enter this industry and thus improve the strength of "factor conditions." In the meantime, the more related industries support each other and share information, the faster the problems can be solved during the process, increasing product quality as well as the demand for solar cells. Having more complete upstream and downstream and peripheral supporting industries of the solar photovoltaic industry implies that Taiwan's solar photovoltaic industry is expected to build up its competitiveness in the global market in the future. This, in turn, attracts government subsidy and support. Furthermore, the more complete the related supporting industry cluster is, the more intense the competition will be, possibly improving the competitiveness of Taiwan's solar photovoltaic industry in the global market.

Receivers

As shown in Figure 4, "factor conditions" ($\boldsymbol{D} - \boldsymbol{R} = -0.331$) and "firm strategy, structure, and rivalry" ($\boldsymbol{D} - \boldsymbol{R} = -1.054$) are two receivers for establishing the competitiveness of Taiwan's solar photovoltaic industry. "Firm strategy, structure, and rivalry" with the highest prominence (***D*** + ***R*** = 38.912) of the two receivers is affected by "government support," "related and supporting industries," and "local demand conditions," which implies that it will receive the best improvement. Although Taiwan's solar photovoltaic industry has become stronger since 2000, the fast-growing part of the whole supply chain is limited in solar cells, and there is no company investing in the top upstream industry of the silicon material. Moreover, many solar photovoltaic companies in Taiwan are semiconductor or electronic companies that transfer their investment across industries and thus lack up- and downstream strategy alliance. Krugman (1981) argued that economics of scale is the basis of vertical integration as well as the condition of production diversification. Due to the fact that the cost of solar energy is still higher than that of fossil fuels, the absence of government incentive will be an obstacle for economics of scale. Therefore, to construct a complete structure of solar photovoltaic industry, the government's incentive on renewable energy is still the most important factor to simulate the demand of solar energy.

"Factor conditions" is another receiver that is affected by "government support," "related and supporting industries," and "local demand conditions.," As mentioned above, "factor conditions" include human resources, nature resources, knowledge, capital, infrastructure, and so on. The upstream silicon material supply is currently the most deficient investment in the solar photovoltaic industry. The Ministry of Economic Affairs invests in the development of pyrometallurgy purification technology in affiliation with the Technology Development Program of the Department of Industrial Technology to obtain the key technology of silicon material production as well as to encourage the Chinese Petroleum Corporation to consider investing in silicon material production. Moreover, the government is investing in the next generation technology development of thin-film, hoping to establish independent thin-film solar cell technology (Bureau of Energy, Ministry of Economic Affairs, 2007). The higher the demand for a solar photovoltaic system in the domestic market, the better the vision for the industry will be, which will result in more high-quality human resources joining the industry. The other drawback is the lack of capital in the Taiwanese market, which will be an obstacle for developing the industry cluster (Huang, 2008). Taiwan needs to open the domestic capital market for foreign capital to flow in to compensate for the insufficient capital in local market.

CONCLUSION AND SUGGESTIONS

The solar photovoltaic industry has become an irresistible trend in recent years due to the impact of deficient energy and environment protection. This country is comparatively slower than Germany, Japan, the United States, and other advanced countries in the development of a solar photovoltaic industry. Taiwan, the island of high technology and innovation development, still needs to create its own innovative energy policy. This article organizes and presents facts about the current status of Taiwan's solar photovoltaic industry and government policies for renewable energy through a literature review and analysis of secondary data, using the DEMATEL method to explore the key development factors for establishing the competitiveness of Taiwan's solar photovoltaic industry and the causal effects among those factors. Empirical results indicate that "local demand conditions," "government support," and "related and supporting industries" are factors that affect the establishment of a competitive solar photovoltaic industry in Taiwan, whereas "factor conditions," and "firm strategy, structure, and rivalry" are the receivers. Improving the three dispatchers strengthens the two receivers and further builds up the competitiveness of the solar photovoltaic industry. Among the three dispatchers, "government support" has the highest prominence ($\boldsymbol{D} + \boldsymbol{R} = 37.887$), which implies that the government's policy support is the most urgent factor to be implemented. As examples of fast-growing and advanced countries in the solar photovoltaic industry, Germany has the most complete electrical power repurchase measures; Japan has two main policies: to promote industrial technology and to market; the United States uses financial incentive policies such as taxes, subsidy, debts, discounts, and so on. These are good models for Taiwan's government. As to the development of related and supporting industries, the government can dominate the key technology development of the solar photovoltaic system—such as silicon material (refining technology), next-generation thin-film technology, and process equipment development to assist in establishing related and supporting industries. To sum up the empirical analysis mentioned above, concrete policy suggestions for the three influence factors "government support," "local demand conditions," and "related and supporting industries" are as follows:

A. Promote a reasonable purchasing price for solar photovoltaic power. Taiwan passed the Renewable Energy Development Bill in 2009 to accelerate the promotion of reasonable prices for electrical power generated by renewable energies, including solar photovoltaic, to simulate the demand for solar power and to provide an incentive for the solar photovoltaic industry.

B. Leverage the huge market of China. The local demand in Taiwan is limited, so domestic solar photovoltaic companies can compensate the insufficient local demand by leveraging the market in China.

C. Construct complete up- and downstream supply chains and peripheral related industries. The government can use tax reduction, installment subsidies, and other policy incentives to stimulate local demand for renewable energy equipment and at the same time simulate the capacity of related equipment assembly and repair as well as develop a solar photovoltaic system that corresponds to the characteristics of Taiwan buildings.

D. Establish a national energy plan. The government should establish a new energy national plan to precisely define short- and long-term development goals and to increase budgets as well as organize the items that universities and related research institutions work on. Moreover, the government should encourage firms to make good use of government incentive systems to improve the transform efficiency of solar photovoltaic technology and to develop new substitute materials to obtain leading technology.

E. Improve R&D production and develop solar photovoltaic process equipment. In the future, firms and related research institutions in Taiwan can develop core equipment such as directional crystal growth furnaces, square machines, wire saw machines, phosphorus diffusion furnaces, PEVCD, efficiency measurement systems, and so on to reduce costs.

Finally, this article focuses its exploration on the solar photovoltaic industry rather than including other promising renewable energy industries. Due to the uniqueness of each industry, demonstrated in the internal resources it possesses and external environment it faces, future studies for other industries should be implemented. For example, a question for further research is: what are the key competitiveness factors of renewable energy industries (i.e., wind power, fuel cells)?

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