Innovation Capability and Network Position of Technology Innovation in the Wind Energy

Chun-Yao Tseng
Tunghai University, Taichung, Taiwan
Email: cytseng@thu.edu.tw

***Abstract*—Wind power has become a pillar of the energy systems in 100 countries and is recognized as a reliable and affordable source of electricity. Understanding technological innovation of wind energy is very important for a firm to build competitive advantage in the wind energy sector. This study aims to investigate three issues related to innovation capability and network position of technological innovation in the wind energy based on a firm level analysis. This study measures technological innovation from patent dataset comprised of all patents granted by the U.S. Patents and Trademark Office (USPTO) to assignees in wind energy from 1976 to 2012. Three empirical findings were shown as follows: Firstly, there was a marked growth tendency of patents in wind energy after 2006, peaking in 2012. General Electric firm owns the greatest innovation capability in wind energy. Secondly, there are high interrelationships among different firms in the innovation network of wind energy. Finally, there are obviously differences among network position from results of four centrality indicators. United Technologies firm owns the most important network position in innovation network of wind energy from two centrality indicators, and Vestas Wind Systems firm occupies the most important network position from the other two centrality indicators. General Electric firm doesn't own the important network position from four centrality indicators.**

***Index Terms*—wind energy, technological innovation, innovation capability, innovation network, network position, patent and citation analysis**

I. Introduction

Wind power has become a pillar of the energy systems in 100 countries and is recognized as a reliable and affordable source of electricity. The contribution of wind power to the energy supply has reached a 3 % of the global electricity demand in the world. There is an average annual growth of 20-30 % in the new installed wind power capacity during 1998-2012 [1]. Understanding technological innovation of wind energy is very important for a firm to build competitive advantage in the wind energy sector. Patent has been regarded as an indicator for measuring the innovation capability [2], [3]; however, more sophisticated analyses have been achieved by examining citation statistics [4]-[6]. Patent and citation analysis focuses on individual technology without considering the reciprocal influences between innovation technologies, leading to the recent adoption of network-based analysis [7]-[10]. Innovation network is helpful to understand the development of technological innovation in specific industry or technology [11], [12]. Network position is regarded as a characterization of a firm's position in an innovation network. Scholars have argued that network position influences innovation as well as facilitated the mobilization of resources for growth.

This study aims to investigate three issues related to innovation capability and network position of technological innovation in the wind energy based on a firm level analysis. First, many indicators of patent and citation are used to compare with different firms in the technological innovation capability of wind energy. Second, this study constructs an innovation networks to investigate technological development of wind energy. Finally, based on the perspectives of social network [7], [13], [14], this study uses four centrality indicators (in-degree centrality, out-degree centrality, closeness centrality and betweenness centrality) to measure and compare network positions of different firms in innovation network of wind energy.

II. Methodology

A. Innovation Capability

With examining the innovation capability, patent and analysis is the most common method to be used [2]-[6]. Patent and citation analysis is a quantitative or qualitative analysis method based on the patent data to require useful and valuable information. Innovation capability is measured by innovation quantity (Patent count) and innovation quality (forward citations) [15], [16].

B. Innovation Netwrok

"Social Network" is first used to present the social relationship among individuals. The following studies also defined social network as the assemblage of "relationship" among "actors" [17], [18]. Social network analysis provides a visible system to analyze the connection of a network [19]. There are three basic elements in network, including actors, relationship among actors, and the connection among actors. To take an actor as a node, and the relationship among actors as lines, and then these three elements form a network [20], [21] (Fig. 1).

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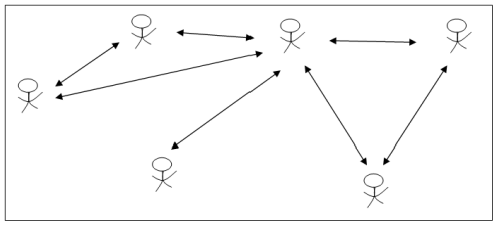
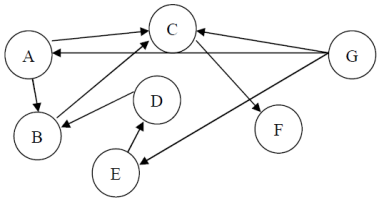


Note: is an actor; is therelationship

Figure 1. Social network

Innovation network, taking a view of social network perspective, owes various connections with others in the network of specific technology. This study investigates innovation network of wind energy based on citation network. A citation network consists of patents as nodes and citation relationships between them as links [22], [23]. The nodes (patents) and links (citations) are used to construct an innovation network (Fig.2).



Note: ○ is patents of a firm; → is citations among firms.

Figure 2. Innovation network

C. Network Position

Social network perspective utilizes "relationship" to be a tool to evaluate the status of members [24] and understand how the network influences each other [14], [25]). Centrality in the network is helpful to understand who's important based on their network position. Based on the perspectives of social network, this study uses four centrality indicators (in-degree centrality, out-degree centrality, closeness centrality and betweenness centrality) [13], [14] to measure and compare network positions of different firms in innovation network of wind energy.

$$Degree_{in}^{i} = \sum r_{in} \;;\; Degree_{out}^{i} = \sum r_{out}$$

$$Betweennes s_i = \frac{g_{jik}}{g_{jk}}$$

$$Closeness_i = \frac{1}{\sum_{i=1}^{I} d(i,j)}$$

This study measures technological innovation from patent dataset comprised of all patents granted by the U.S. Patents and Trademark Office (USPTO) to assignees in wind energy from 1976 to 2012. This study adopts an International Patent Classification (IPC) system to search technological innovation of wind energy based on the World Intellectual Property Organization (WIPO), including F03D 1/00, F03D 1/02, F03D 1/04, F03D 1/06, F03D 3/00, F03D 3/02, F03D 3/04, F03D 3/06, F03D 5/00, F03D 5/02, F03D 5/04, F03D 5/06, F03D 7/00, F03D 7/02, F03D 7/04, F03D 7/06, F03D 9/00, F03D 9/02, F03D 11/00, F03D 11/02, F03D 11/04, B60L 8/00 and B63H 13/00.

III. Results

A. Innovation Capability

There was a marked growth tendency of patents in wind energy after 2006, peaking in 2012 (Fig. 3). Table I and Table II display top 10 firms (or assignees) of innovation capability in wind energy based on innovation quantity (Patent count) and innovation quality (forward citations). The *General Electric* (330), *Vestas Wind Systems* (72), *Mitsubishi Heavy Industries* (63), *Siemens* (47) and *United Technologies* (40) are top 5 firms in innovation capability of wind energy based on the analysis of patents. However, top 5 firms in innovation capability based on the analysis of citations are *General Electric* (824), *United Technologies* (733), *U.S. Windpower* (473), *Grumman Aerospace* (186) and *Northern Power Systems* (185).

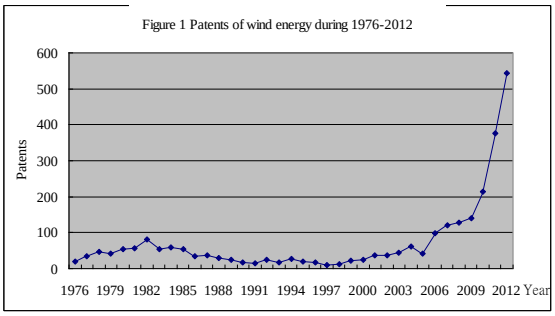


Figure 3. Patents of wind energy during 1976-2012

TABLE I. Top 10 Firms (Or Assignees) of Innovation Capability Based on Patents

Innovation Quantity			
Rank	Firm (or Assignee)	Patents	Percent
1	General Electric	330	12.30%
2	Vestas Wind Systems	83	3.10%
3	Wobben, Aloys	72	2.70%
4	Mitsubishi Heavy Industries	63	2.40%
5	Siemens A.G.	47	1.80%
6	United Technologies	40	1.50%
7	Nordex Energy GmbH	31	1.20%
8	Hitahi, Ltd.	20	0.70%
9	Repower Systems AG	20	0.70%
10	Gamesa Innovation & Technology	17	0.60%
	Others	1954	72.99%
	Total	2677	100.00%

TABLE II. Top 10 Firms (Or Assignees) of Innovation Capability Based on Citations

Innovation Quality			
Rank	Firm (or Assignee)	Citations	Percent
1	General Electric	824	4.49%
2	United Technologies	733	4.00%
3	U.S. Windpower	473	2.58%
4	Grumman Aerospace	186	1.01%
5	Northern Power Systems	185	1.01%
6	The Boeing Company	177	0.96%
7	Hickey, John J.	140	0.76%
8	Appa, Kari	132	0.72%
9	Wobben, Aloys	132	0.72%
10	Clipper Windpower Technology	108	0.59%
	Others	15255	83.16%
		18345	100.00%

B. Innovation Network

There are 1573 firms (or assignees) in the innovation network of wind energy. Using citation network analysis, innovation network of wind energy is shown as Fig. 4. There are high interrelationships among different firms (or assignees) in the innovation network of wind energy.

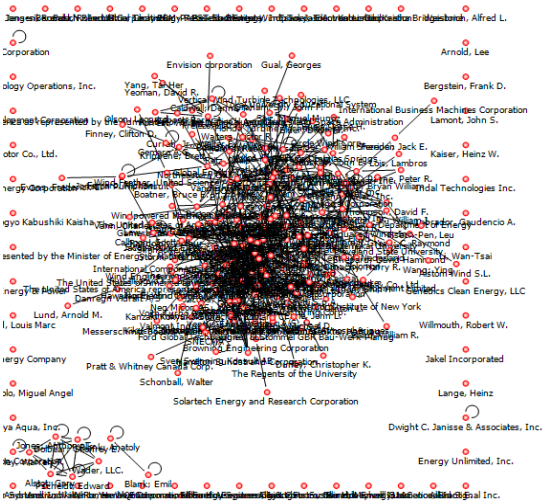


Figure 4. The Innovation network of wind energy

C. Network Position

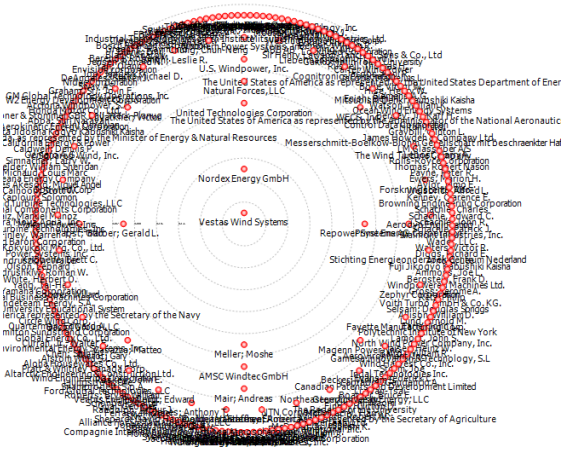


Figure 5. Network position of wind energy in the analysis of in-degree centrality

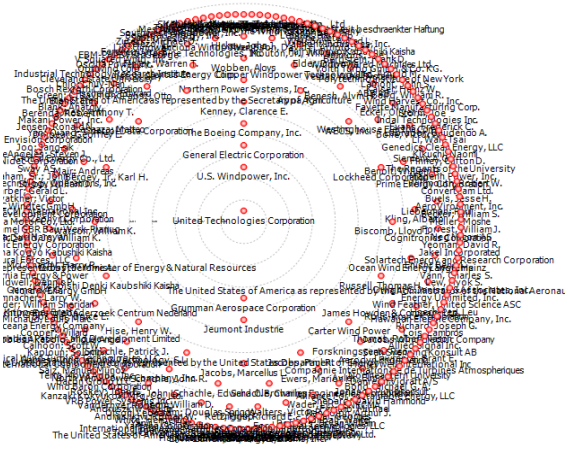


Figure 6. Network position of wind energy in the analysis of out-degree centrality

There are obviously differences among network position from results of four centrality indicators (Fig. 5-Fig. 8). *United Technologies* firm owns the most important network position in the analysis of out-degree centrality and betweenness centrality. *Vestas Wind Systems* firm occupies the most important network position in the analysis of in-degree centrality and closeness centrality. *General Electric* firm doesn't own the important network position from four centrality indicators.

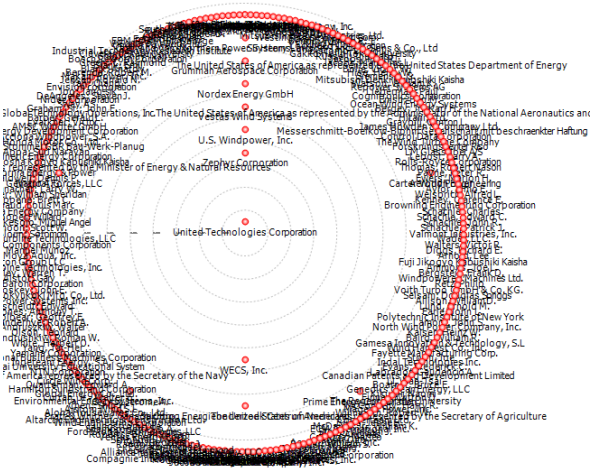


Figure 7. Network position of wind energy in the analysis of betweenness centrality

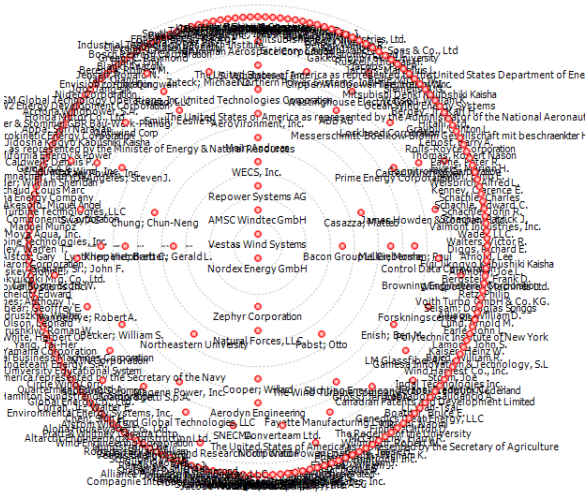


Figure 8. Network position of wind energy in the analysis of closeness centrality

IV. Conclusions

Firstly, there was a marked growth tendency of patents in wind energy after 2006. *General Electric* firm owns the greatest innovation capability in wind energy. Secondly, there are high interrelationships among different firms in the innovation network of wind energy. Finally, there are obviously differences among network position from results of four centrality indicators. *United Technologies* firm owns the most important network position in innovation network of wind energy from two centrality indicators, and *Vestas Wind Systems* firm

occupies the most important network position from the other two centrality indicators. *General Electric* firm doesn't own the important network position from four centrality indicators.

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REFERENCES

[1] The World Wind Energy Association, "World Wind Energy Report 2012," 2013.
[2] Z. Griches, "Patent statistics as a economic indicators: A survey," *Journal of Economic Literature*, vol. 28, pp. 1661-1707, 1990.
[3] M. Trajtenberg, "A penny for your quotes: Patent citations and the value of innovation," *RANF Journal of Economics*, vol. 21, no. 1, pp.172-187, 1990.
[4] H. Ernst, "Patent applications and subsequent changes of performance: Evidence from time-series cross-section analyses on the firm level," *Research Policy*, vol. 30, pp. 143-157, 2001.
[5] G. Z. Hu and A. Jaffe, "Patent citations and international knowledge flow: The cases of Korea and Taiwan," *International Journal of Industrial Organization*, vol. 21, pp. 849-880, 2003.
[6] B. H. Hall, A. Jaffe, and M. Trajtenberg, "Market value and patent citations," *Rand Journal of Economy*, vol. 36, no. 1, pp. 16-38, 2005.
[7] T. E. Stuart, "Network position and propensities to collaborate: An investigation of strategic alliance formation in a high-technology industry," *Administrative Science Quarterly*, vol. 43, pp. 668-698, 1998.
[8] P. Thompson, "Patent citations and the geography of knowledge spillovers: Evidence from Inventor- and examiner-added Citations," *Review of Economics and Statistics*, vol. 88, no. 2, pp. 383-388, 2006.
[9] M. H. Mors, "Innovation in a global consulting firm: When the problem is too much diversity," *Strategic Management Journal*, vol. 31, pp. 841-872, 2010.
[10] J. Steen, S. Macaulay, and T. Kastelle, "Small worlds: The best network structure for innovation," *Prometheus*, vol. 29, no. 1, pp. 39-50, 2011.
[11] T. E. Stuart and J. M. Podolny, "Local search and the evolution of technological capabilities," *Strategic Management Journal*, vol. 17, pp. 21-38, 1996.
[12] J. Owen-Smith and W. W. Powell, "Knowledge networks as channels and conduits: The effects of spillovers in the boston biotechnology community," *Organization Science*, vol. 15, no. 1, pp. 5-21, 2004.
[13] L. C. Freeman, "Centrality in social network: I. conceptual clarification," *Social Networks*, vol. 1, pp. 215-239, 1979.
[14] S. Wassermann and K. Faust, *Social Network Analysis Methods and Applications*, Cambridge: Cambridge University Press, 1994.
[15] C. Tseng, "Technological innovation and knowledge network in Asia: Evidence from comparison of information and communication technologies among six countries," *Technological Forecasting & Social Change*, vol. 76, no. 5, pp. 654-663, 2009.
[16] D. C. Pai, C. Tseng, and C. Liou, "Collaborative innovation in emerging economies: The case of India and China," *Innovation: Management, Policy & Practice*, vol. 14, no. 3, pp. 470-479, 2012.

Chun-Yao Tseng is a professor at the department of Business Administration, Tunghai University, Taiwan. He holds a Ph.D. in Business Administration from the Taipei University, Taiwan. He had been a visiting professor at the school of management, Massey University, New Zealand. His research is in the areas of technology and innovation management. His papers have been accepted or published in a variety of journals.