A COMPARATIVE STUDY OF COUNTRY LEVEL IN TECHNOLOGICAL INNOVATION OF SIX RENEWABLE ENERGIES

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Abstract

Solar, Wind, Biomass, Hydro, Geothermal and Wave are six main renewable energies in the world. The main objective of this study is to investigate three issues related to technological innovation of six renewable energies based on a country level analysis. First, patent outputs are used to compare with different countries in six renewable energies. Secondly, this study constructs and compares innovation networks of six renewable energies to investigate technology development of different renewable energies. Finally, this study uses social network analysis to measure and compare network positions of different countries in six renewable energies. Empirical data are from U.S. Patents and Trademark Office (USPTO) during1976-2012.

Classification: m*anagement of technological innovation and R&D; technological change; diffusion Processes; alternative energy sources*

Keywords: *renewable energy; technological innovation; innovation network; patent and citation analysis*

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Resume

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Introduction

Owing to today's critical environmental challenges and prolonged global recession, there has been substantial investment of renewable energy in the world. In 2010 global investment in green-tech topped $211 billion, bringing green energy's portion of worldwide electricity production to 19.4% (Bierenbaum et al., 2012). Understanding technological innovation of renewable energy is very important for a country to make policies in environment preservation and sustainable development. Solar, Wind, Biomass, Hydro, Geothermal and Wave are six main renewable energies in the world (Popp, Hascic and Medhi, 2011; Ayari, Blazsek and Mendi , 2012). Patent statistics have been used to measure technology innovation for over 50 years (Schoenecker and Swanson, 2002). However, patent analysis focuses on individual technology without considering the reciprocal influences between innovation technologies, leading to the recent adoption of network-based analysis (Stuart, 1998; Thompson, 2006; Mors, 2010; Steen, Macaulay, and Kastelle, 2011). Innovation network looks like a social network and it is constructed by a political system, and exclusive innovation resources are available to the participants in the network (Benson, 1975). Network position is regarded as organization's position in an innovation network, and it influences innovation as well as facilitated the mobilization of resources for growth.

The main objective of this study is to investigate three issues related to technological innovation of six renewable energy based on a country level analysis. First, patent outputs are used to compare with different countries in six renewable energies. Secondly, this study constructs and compares innovation networks of six renewable energies to investigate technology development of different renewable energies. Finally, this study uses social network analysis (three centrality indicators) to measure and compare network positions of different countries in innovation network of six renewable energies.

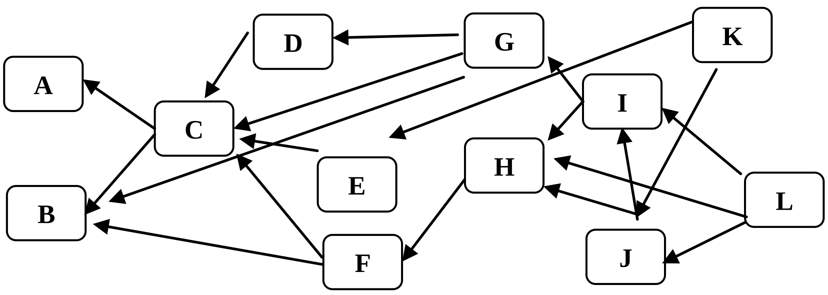
THEORETICAL INVESTIGATION AND RESEARCH METHODOLOGY

Early studies typically used a sample count of patents granted as a measure of innovation quantity. Not all patents have the same economic impact, more analyses based on citation statistics have become increasingly popular (Ernst, 2001; Hall *et al.*, 2005; Tseng, 2009). Two quantitative and qualitative analysis method based on patent output to require useful and valuable information for technology innovation. Patent quantity is measured by patent count, and patent quality is measured by citations (Tseng, 2009). Based on the country 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 six renewable energies during 1976-2012. This study adopts an International Patent Classification (IPC) system to search technological innovation of renewable energies based on the IPC Green Inventory from World Intellectual Property Organization (WIPO), please see Table 1.

Table 1 IPC codes of six renewable energies

Renewable energy	IPC (International Patent Classification) codes
Solar	F03G 6/00, F03G 6/02, F03G 6/06, F03G 6/08, F24J 2/00, F25B 27/00, F26B 3/28, H02N 6/00, E04D 13/18, B60L 8/00
Wind	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, B63H 13/00
Biomass	C10L 5/42, C10L 5/44, F02B 43/08, B01J 41/16, C10L 1/14,
Hydro	F03B 3/04, F03B 3/10, F03B 3/12, F03B 3/18, F03B 11/02, F03B 13/06, F03B 13/08, F03B 13/10, F03B 15/04, F03B 15/08, F03B 17/00, F03B 17/06, E02B 9/00, E02B 9/02
Geothermal	F24J 3/00, F24J 3/02, F24J 3/04, F24J 3/06, F24J 3/08, F03G 4/00, F03G 4/02, F03G 4/04, F03G 4/06, H02N 10/00
Wave	F03B 13/12, F03G 7/04, F03G 7/05, F03B 7/00, F03B 13/12, F03B 13/14, F03B 13/16, F03B 13/18, F03B 13/20, F03B 13/22, F03B 13/26, E02B 9/08

Social network perspective provides a viewable system to analyze the connection of different actors in an innovation network (Beaucage and Beaudry, 2006). Actors and their relationships are the primary elements within a network. Based on social network perspective, Figure 1 demonstrates an innovation network in which A-L represent actors and the arrows represent the relationship between actors. This study uses patent citation analysis to construct an innovation network. Actor is a patent and relationship is a citation.



Firgure 1 Innovation network and patent citation analysis

Centrality is usually used as a social network indicator demonstrating the importance of an actor in the network (Freeman, 1979; Krackhardt, 1993). An actor with higher centrality stands more closer to center and thus occupies a more powerful position. Based on social network perspective, Freeman (1979) divided centrality measures into three indicators: degree centrality, closeness centrality, and betweenness centrality. This study employs degree centrality, closeness centrality, and betweenness centrality to measure network position of a country in an innovation network of renewable energy.

Degree centrality: The higher the degree centrality is the stronger the linkages (Krackhardt, 1993). Degree centrality is the number of links incident upon an actor and it is measured by the count of patent cited.

$$Degree_i = \sum r$$

Betweenness centrality: It measures the degree of the most important position of knowledge transmission. With higher betweenness, an actor has more central vertices and spread information around in the network (Wassermann & Faust, 1994). g_{jk} is the shortest paths from patent j to patent k, and g_{ijk} is the shortest paths of patent i between patent j and k.

$$Betweenness_i = \frac{g_{jik}}{g_{jk}}$$

Closeness centrality: It is a centrality measure of the spread of information as modeled by the use of shortest paths (Sabidussi, 1966). $d(i, j)$ is the shortest geodesic from patent i to patent j.

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

EMPIRICAL RESULTS

Patent output

Figure 2 illustrates the comparison of patent count in six renewable energies from 1976 to 2012. Geothermal has the largest patent count (2,790). Wind is the second (2,677), Solar is the third (1,428) and Biomass is the least (407). There is a market growth tendency of patent in wind energy after 2009, peaking in 2012. Geothermal has large amounts of patents before 1985, but it has decreased after 1985. Table 2 displays patents and citations of top 10 countries in six renewable energies. Top 10 countries of six renewable energies are mostly from developed countries. Only Taiwan belongs to new industrial countries. Based upon patent and citation analysis, USA possesses absolute innovation strength in six renewable energies. Japan owns the second highest patents in solar, hydro, biomass and geothermal energy. United Kingdom has the second highest patents in wave energy. Germany owns the second highest patents in wind energy and the third in the solar, hydro, biomass and geothermal energies.

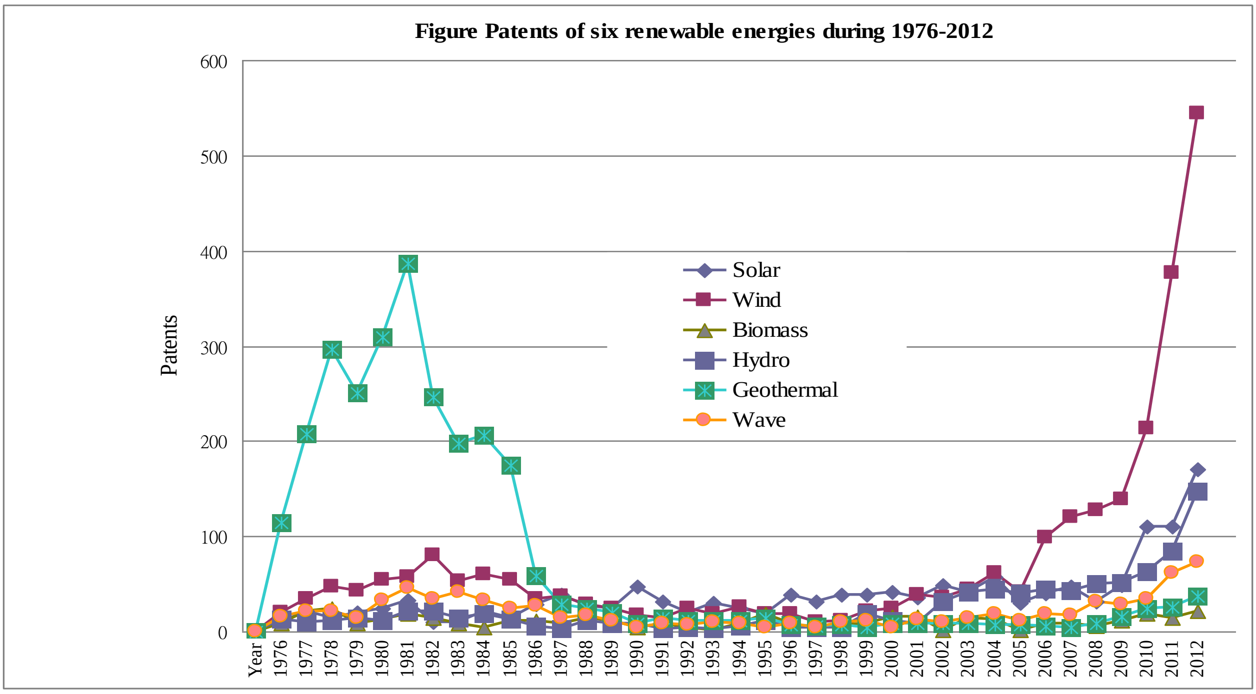


Figure. 2 Patents of six renewable energies during 1976-2012

Innovation Network

Using patent citation analysis, innovation networks of six renewable energies are shown as Figure 3. There are high interrelationships among different countries in the innovation networks of six renewable energies, especially in wind energy. There are 47 countries in the innovation network of wind energy. But only 19 countries appear in the innovation network of Biomass energy.

Table 2 Top 10 countries of six renewable energies based on patent output

	Solar					***Wind***				
Rank	Country	Patent	Percent	Citation	Percent	Country	Patent	Percent	Citation	Percent
1	USA	835	58.47%	6067	68.43%	USA	1570	58.65%	13177	71.83%
2	Japan	294	20.59%	1616	18.23%	Germany	275	10.27%	998	5.44%
3	Germany	71	4.97%	355	4.00%	Japan	178	6.65%	638	3.48%
4	Canada	27	1.89%	103	1.16%	Denmark	114	4.26%	353	1.92%
5	Taiwan	27	1.89%	60	0.68%	Canada	104	3.88%	641	3.49%
6	South Korea	21	1.47%	70	0.79%	Taiwan	76	2.84%	200	1.09%
7	Australia	20	1.40%	77	0.87%	United Kingdom	53	1.98%	430	2.34%
8	France	17	1.19%	54	0.61%	France	44	1.64%	367	2.00%
9	Sweden	17	1.19%	80	0.90%	Spain	43	1.61%	188	1.02%
10	Switzerland	14	0.98%	31	0.35%	Sweden	26	0.97%	227	1.24%
	Other	85	5.95%	353	3.98%	Other	194	7.25%	1126	6.14%
	Total	1428	100.00%	8866	100.00%	Total	2677	100.00%	18345	100.00%
	Hydro					***Biomass***				
Rank	Country	Patent	Percent	Citation	Percent	Country	Patent	Percent	Citation	Percent
1	USA	574	63.22%	3812	73.66%	USA	264	64.86%	3469	73.97%
2	Japan	51	5.62%	214	4.14%	Japan	63	15.48%	604	12.88%
3	Germany	47	5.18%	84	1.62%	Germany	30	7.37%	281	5.99%
4	United Kingdom	37	4.07%	143	2.76%	Canada	10	2.46%	95	2.03%
5	Canada	27	2.97%	125	2.42%	United Kingdom	6	1.47%	31	0.66%
6	France	24	2.64%	103	1.99%	France	5	1.23%	32	0.68%
7	Taiwan	21	2.31%	71	1.37%	Sweden	5	1.23%	47	1.00%
8	Austria	13	1.43%	73	1.41%	Switzerland	4	0.98%	55	1.17%
9	Switzerland	13	1.43%	37	0.71%	Italy	3	0.74%	12	0.26%
10	Italy	13	1.43%	23	0.44%	Taiwan	3	0.74%	12	0.26%
	Other	88	9.69%	490	9.47%	Other	14	3.44%	52	1.11%
	Total	908	100.00%	5175	100.00%	Total	407	100.00%	4690	100.00%
	Geothermal					***Wave***				
Rank	Country	Patens	Percent	Citation	Percent	Country	Patent	Percent	Citation	Percent
1	USA	2168	77.71%	21001	83.66%	USA	496	64.58%	4641	73.87%
2	Japan	103	3.69%	801	3.19%	United Kingdom	45	5.86%	316	5.03%
3	Germany	102	3.66%	584	2.33%	Japan	33	4.30%	250	3.98%
4	France	67	2.40%	481	1.92%	Canada	24	3.13%	129	2.05%
5	Japan	55	1.97%	476	1.90%	Taiwan	15	1.95%	64	1.02%
6	Israel	45	1.61%	280	1.12%	Sweden	14	1.82%	117	1.86%
7	Australia	41	1.47%	292	1.16%	Germany	13	1.69%	50	0.80%
8	United Kingdom	35	1.25%	279	1.11%	France	13	1.69%	39	0.62%
9	Switzerland	30	1.08%	177	0.71%	Norway	13	1.69%	100	1.59%
10	Sweden	29	1.04%	127	0.51%	Israel	11	1.43%	98	1.56%
	Other	115	4.12%	605	2.41%	Other	91	11.85%	479	7.62%
	Total	2790	100.00%	25103	100.00%	Total	768	100.00%	6283	100.00%

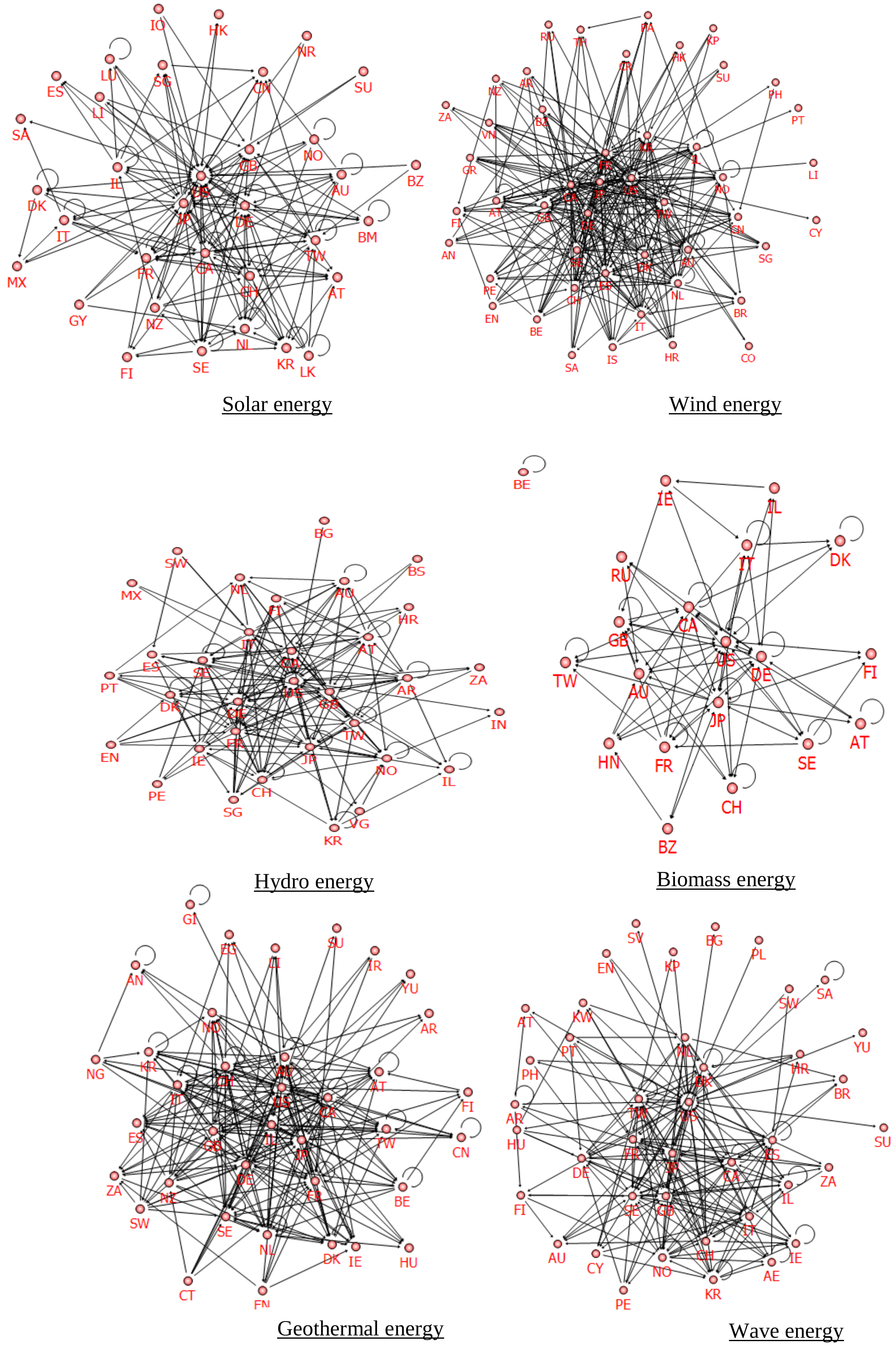


Figure 3 Innovation networks of six renewable energies

Network Position

There is a little difference among network position from results of three centrality indicators (figure 4-6). USA owns the most important network position in the analysis of three centrality indicators. On the analysis of degree centrality (figure 4), only Japan is close to the position of USA in Wind and Biomass energies, occupying the second position and Germany is the third one. The competitive position of the United Kingdom in Wave energy is similar with Japan. On the analysis of closeness centrality (figure 5), Solar, Wind, Hydro, and Wave innovation networks represent three levels of hierarchy, but Biomass and Geothermal represent only two levels. Japan and Germany separately occupy the second and third positions in Solar, Wind, Biomass and Geothermal energies. On the analysis of betweenness centrality (figure 6), six innovation networks all represent two levels of hierarchy with USA occupying the dominant position. No other countries are able to compete with USA in six renewable energies.

Conclusions and Contributions

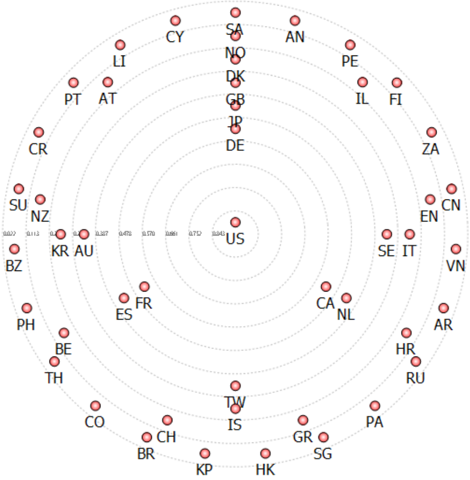
Three empirical findings were shown as follows:

(1).Technology innovation of wind energy has a significantly growth tendency after 2009. Top 10 countries of six renewable energies are mostly from developed countries. Only Taiwan belongs to new industrial countries. USA possesses absolute innovation strength in six renewable energies. Japan is the second and Germany is the third in the technology innovation of renewable energy.

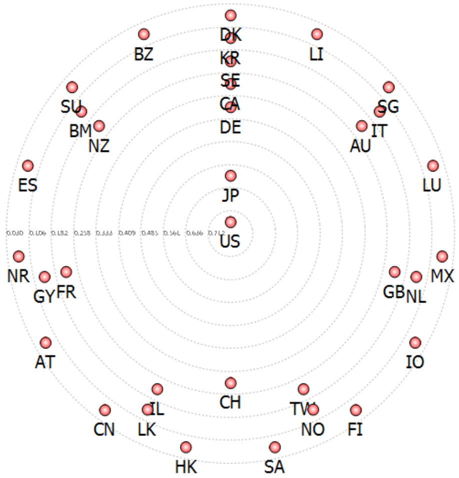
(2).There is high interrelationships among different countries in the innovation networks of six renewable energies, especially in wind energy.

(3).There is a little difference among network position from results of three centrality indicators. USA owns the most important network position in the analysis of three centrality indicators. Only Japan is close to the position of USA in Wind and Biomass energies. There are two or three levels of hierarchy of network positions in the innovation networks

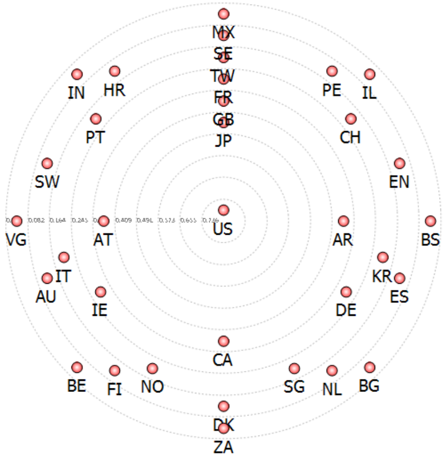
This study made various contributions for government and academy. First, understanding innovation network and network position in six renewable energies is very import for a country to maintain a competitive advantage in renewable energy and establish a renewable energy policy. Secondly, using patent citation analysis to construct an innovation network is an available and practicable method for academy to demonstrate development of technological innovation in specific industry or technology. Finally, although patent and citation are traditional indicators of innovation (Griches, 1990; Hall et al, 2005), it has some shortcomings (Yoon & Park, 2004). Network position by social network analysis is a validity method to measure technological innovation**.**



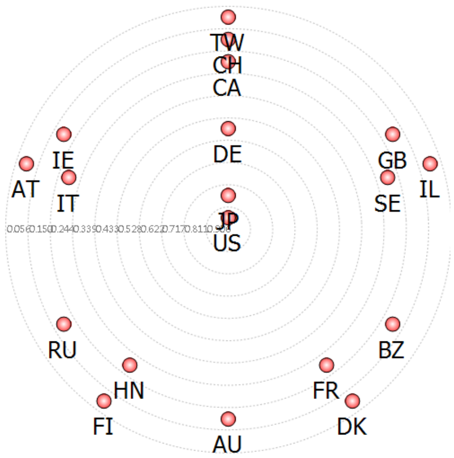
Solar energy



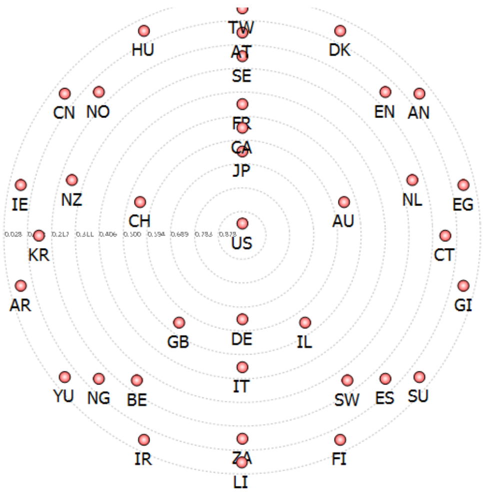
Wind energy



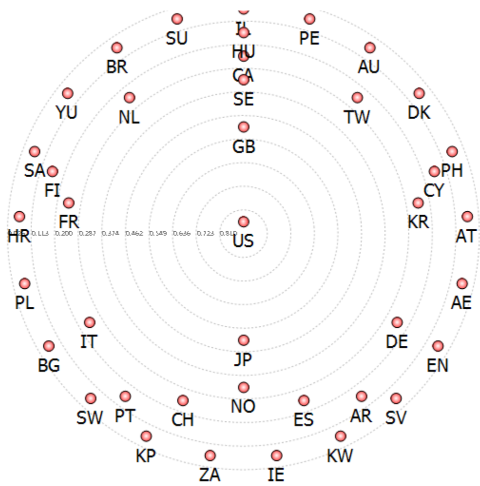
Hydro energy



Biomass energy



Geothermal energy



Wave energy

Figure 4 Network positions of different countries in six innovation networks – based on the analysis of degree centrality

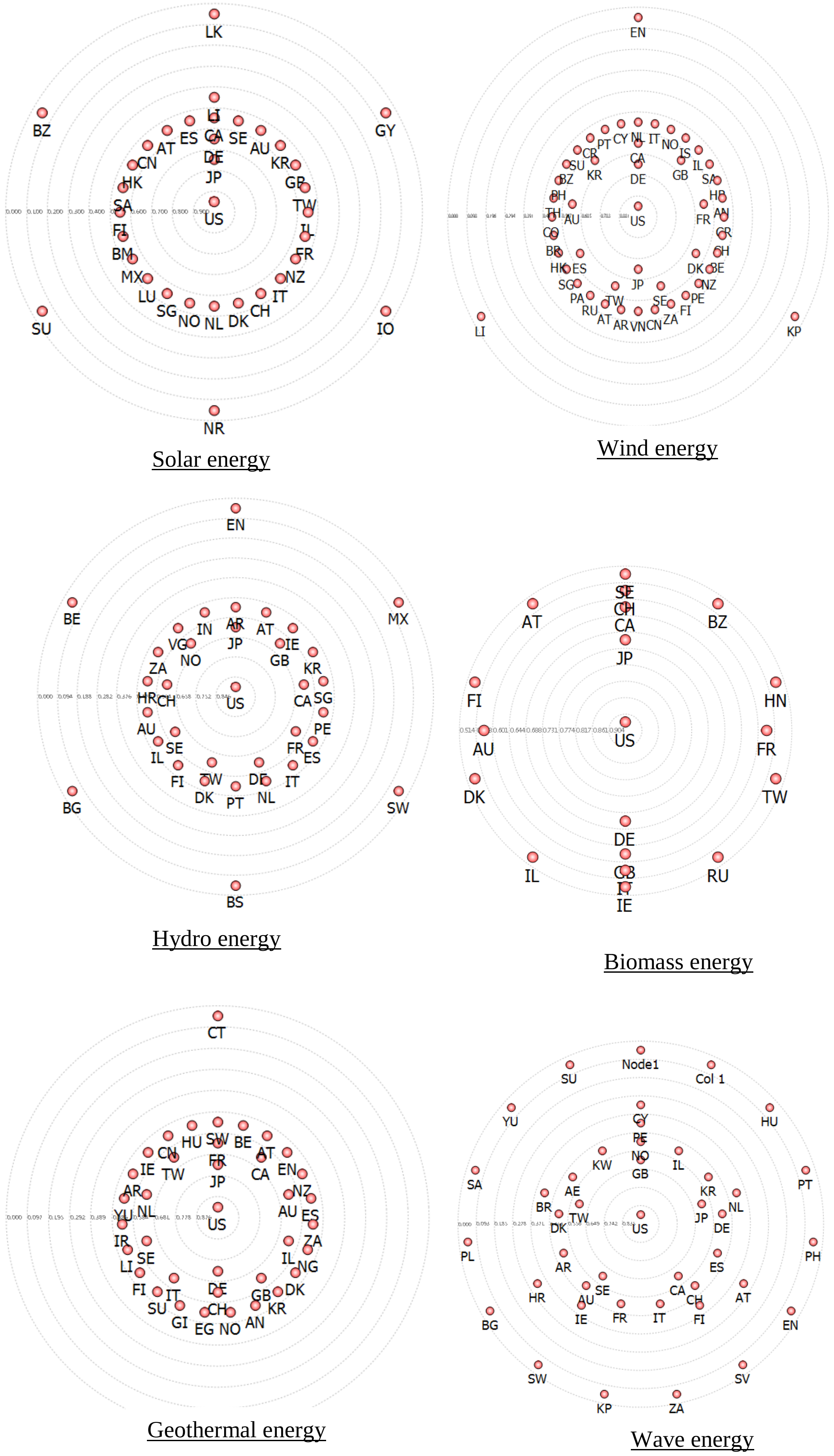


Figure 5 Network positions of different countries in six innovation networks – based on the analysis of closeness centrality

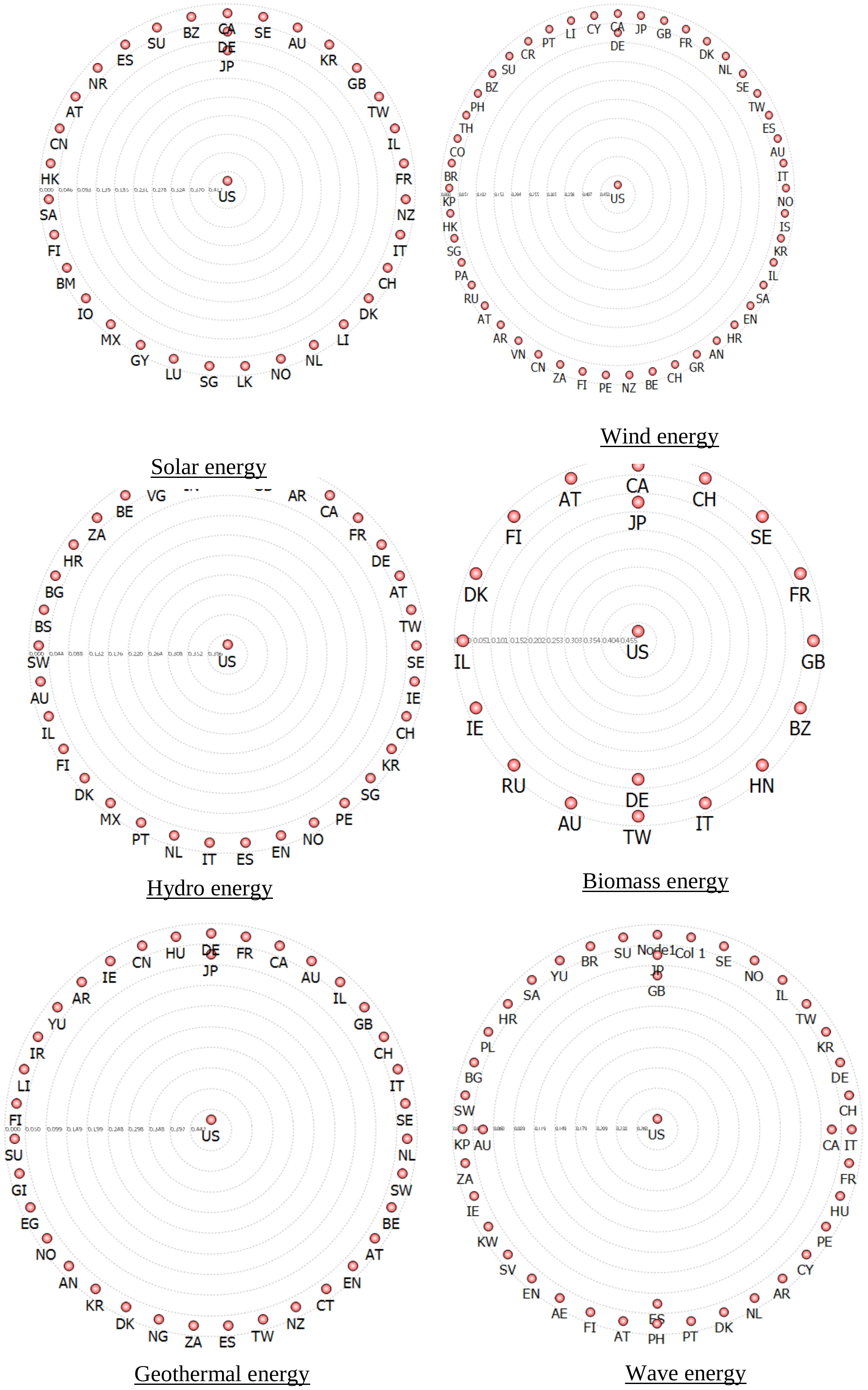


Figure 6 Network positions of different countries in six innovation networks – based on the analysis of betweenness centrality

References

Ayari, N., Blazsek, S. and Mendi, P. (2012). “Renewable energy innovations in Europe: a dynamic panel data approach.” *Applied Economics*, 44(24), 3135-3147.

Benson, J. K. (1975). "The interorganizational network as a political economy." *Administrative Science Quarterly*, 20(2): 229-249.

Bierenbaum, D., Frank, M. M., Lenox, M. and Maheshwari, R. (2012): *Winning the Green Innovation Economy: An Analysis of Worldwide Patenting*. Batten Briefing, Transforming Society through Entrepreneurship and Innovation. Charlottesville, VA: Batten Institute.

Ernst, H. (2001). “Patent applications and subsequent changes of performance: evidence from time-series cross-section analyses on the firm level.” *Research Policy*, 30, 143-157.

Freeman, L. (1979). “Centrality in social network: conceptual clarification.” *Social Networks*, 1, 215-239.

Griliches, Z. (1990). “Patent statistics as economic indicators: A survey.” *Journal of Economic Literature*, 28, 1661-1707.

Hall, B. H., Jaffe, A. and Trajtenberg, M. (2005). "Market value and patent citations." *RAND Journal of Economics*, 36(1), 16-38.

Krackhardt, D. (1993). “Crisis in a Cluster: Simmelian Ties in Organizations”. *International Social Networks Conference*, Tampa, Florida, February.

Mors, M. H. (2010). “Innovation in a global consulting firm: when the problem is too much diversity.” *Strategic Management Journal*, 31, 841-872.

Popp, D. and Hascic, I. and Medhi, N. (2011). "Technology and the diffusion of renewable energy." *Energy Economics*, 33(4), 648-662.

Sabidussi, G. (1966). "The centrality index of a graph." *Psychometrika* 31, 581--603.

Schoenecker, T. and Swanson, L. (2002). "Indicators of firm technological capability: Validity and performance implications." *IEEE Transactions on Engineering Management*, 49 (1), 36-44.

Steen, J., Macaulay, S. and Kastelle, T.(2011). “Small worlds: the best network structure for innovation,” *Prometheus*, 29(1), 39-50.

Stuart, T. E. (1998). *Network Positions and Propensities to collaborate: An Investigation of Strategic Alliance Formation in High-Technology Industry*. Working Paper, Graduate School of Business in University of Chicago.

Thompson, P.; (2006). “Patent Citations and the Geography of Knowledge Spillovers: Evidence from Inventor- and Examiner-added Citations.” *Review of Economics and Statistics*, 88 (2), 383-388.

Tseng, C. Y. (2009). “Technology development and knowledge spillover in Africa: evidence using patent and citation data.” *International Journal of Technology Management*, 45(1/2), 50-61.

Wassermann, S., and Faust, K. (1994). *Social Network Analysis Methods and Applications*, Cambridge University Press, Cambridge.

Yoon, B. and Park, Y. (2004). "A text-mining-based patent network: Analytical tool for high-technology trends." *The Journal of High Technology Management Research*, 15(1) 37-50.