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CARBON CAPTURE AND STORAGE(CCS) RESEARCH COLLABORATION TRENDS USING NETWORK ANALYSIS OF SCI PAPERS

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Abstract

Climate change has become one of the most important global agenda, and nations worldwide are taking actions to resolve the issue and contribute to the new climate change regime. In the case of South Korea, the new goal of reducing greenhouse gas emission to 37% below BAU(Business-As-Usual) was set. As a means to achieve this goal, the Korean government is actively investing in highly effective greenhouse reduction technologies such as solar cell, fuel cell, bioenergy, secondary battery, power IT, and CCS(Carbon Capture and Storage). This paper investigates the overall trend of CCS research by examining international CCS research collaboration characteristics through network analysis of SCI papers; collaboration network of Korea is analyzed in further detail. Such analysis helps understand the status of international research in the field of CCS, especially that of Korea.

Keywords: Carbon Capture and Storage, CCS, Network Analysis, Research Collaboration

Introduction

Over the past decade, gravity of the issue of climate change has continued to increase globally on various aspects such as science, environment, politics, and economy. (Hoegh-Guldberg, 1999; Walther et al., 2002; Watson, 2003; IPCC, 2007; Li et al., 2011) As a means to resolve the issue, countries in the COP21 climate negotiations each submitted their INDC(Intended Nationally Determined Contribution) to the UNFCCC; South Korea set the goal of greenhouse gas emission reduction to 37% below

BAU(Business-As-Usual) by 2030. In order to achieve this goal, the Korean government is actively investing in highly effective greenhouse reduction technologies; the six key technologies include solar cell, fuel cell, bioenergy, secondary battery, power IT(Information Technology), and CCS(Carbon Capture and Storage). In this study, trends in CCS research is investigated through network analysis of CCS-related SCI papers over the past 3 years. This allows us to understand the status of international R&D(Research and Development) collaboration of CCS research. Finally, through seperate network analysis of SCI papers involving Korea, the state of CCS-related R&D collaboration in Korea can be examined in further detail.

Research Method

The key method in this study is Social Network Analysis(SNA), which is popularly used to map and measure the relationships and interactions among various nodes. (Yoon et al., 2012) Authors' countries were set as nodes and the links among them represent the research collaborations in publishing the papers. In addition to the visualization of the research network, measures such as centrality can be used for a quantitative and qualitative analysis.

The database of SCI papers used in this study was constructed from Web of Science provided by Thomson Reuters, an academic citation indexing and search service combined with web linking. (Cho et. al, 2013) Information such as the title, abstract, journal, publication type, authors' affiliation, country, and publication year of CCS-related SCI papers was collected. The papers used for analysis were published during the years 2012-2014; the most current annual data available was used, with 3 years being the minimum period of analysis needed to observe the trend of collaboration. Researchers and experts in the field of CCS reviewed the database to ensure the relevance of the papers and categorized them by 17 major technologies of CCS. (Table 1) Total of 9,318 papers were used for final analysis.

For network analysis of these papers, a Korean software tool NetMiner developed by Cyram was used. Analysis procedure from a previous research (Cho et. al, 2013) was followed in general. From the information collected on each paper, authors' country was selected and used for analysis; each country was set as nodes and the paper was set as links to visualize the international research collaborations. Additional network measures such betweenness centrality-a value that represents the importance of a node in bridging other nodes- was used to further describe the characteristics of the network.

Results

The number of SCI papers in the field of CCS has increased overall during the years 2012-2014. (Table 1) Research on pre-combustion CO_2 capture and post-combustion CO_2 capture was the most active; however, they showed opposite trends. The number of papers related to pre-combustion CO_2 capture was significantly higher than the others until the year 2013, but dropped rapidly in 2014. The number of papers related to post-combustion CO_2 capture increased continuously, with a rapid increase in 2014 and becoming the most actively researched field.

USA and China published the most papers, maintaining a dominant position; the number of papers published in China increased steadily while USA showed a slight decrease in 2014. (Table 2) Countries following the top runners, such as Germany, South Korea, Japan, and Spain showed similar numbers of papers. CCS research in South Korea seemed to grow rapidly in 2014, taking the place of Germany. The number of papers published in Spain and Italy decreased slightly in 2014.

Table 1. Number of SCI papers published per CCS technology (2012-2014)

CCS Technologies	**Number of SCI Papers**		
	2012	**2013**	**2014**
Pre-combustion CO_2 Capture	1004	1172	240
Post-combustion CO_2 Capture	464	647	928
Chemical Conversion	281	319	593
Direct CO_2 Utilization	310	236	442
CO_2 Capture - Others	162	208	258
Photo & Electrochemical Conversion	59	56	217
Oxyfuel Combustion	31	34	172
Large-scale CO_2 Storage Facilities	71	103	111
CO_2 Leakage Monitoring & Environmental Safety	75	112	88
Biological Conversion	50	75	87
CO_2 Storage Injection Control & Behavior Observation	68	84	62
CO_2 Compression & Transportation	45	53	57
CO_2 Storage - Others	57	58	53
CO_2 Storage Design & Injection Facilities	19	29	45
CCS Convergence Technology	7	11	14
CO_2 Conversion & Utilization LCA	1	1	11
CO_2 Conversion & Utilization - Others	16	16	6
Total	**2720**	**3214**	**3384**

Table 2. Top 10 countries for CCS related SCI paper publication (2012-2014)

Country	Number of SCI Papers			
	2012	2013	2014	Total
Peoples R China	543	734	855	2132
USA	569	696	673	1938
Germany	160	182	188	530
South Korea	146	150	230	526
Japan	154	180	183	517
Spain	150	184	169	503
England	144	165	176	485
Australia	111	161	182	454
Canada	130	150	153	433
Italy	109	136	114	359

The international CCS research collaboration network for the year 2012-2014 was a single network. (Fig. 1) Node size represents the collaboration frequency of the focal country, and link width and darkness represent the total number of collaborations-papers published- with the target country. (Cho et. al, 2013)

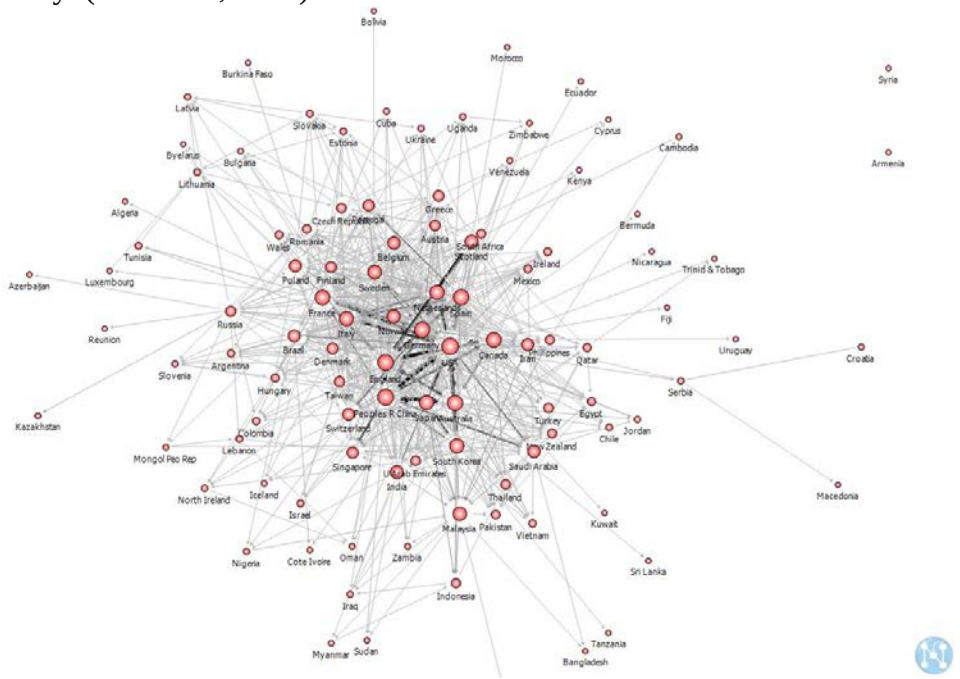

Fig. 1 International CCS research collaboration network (2012-2014)

When the network of countries with top 10 percentage collaboration was visualized separately, it could be seen that countries with high numbers of paper publication also tend to collaborate more frequently and diversely; USA and China appeared in the center of the network. (Fig. 2)

Betweenness centrality analysis also showed that USA played the most important role in connecting the other countries in the CCS research network. (Table 3) Although France wasn't one of the top 10 countries in terms of the number of papers published, it had a strong influence on the network.

South Korea collaborated diversely with various countries on CCS research, but worked intensively with a small group of countries; the link with USA appeared to be especially strong. (Fig. 3) Considering that South Korea published a relatively high number of papers, betweenness centrality was lower with a value of 0.032504 and a ranking of 13th place.

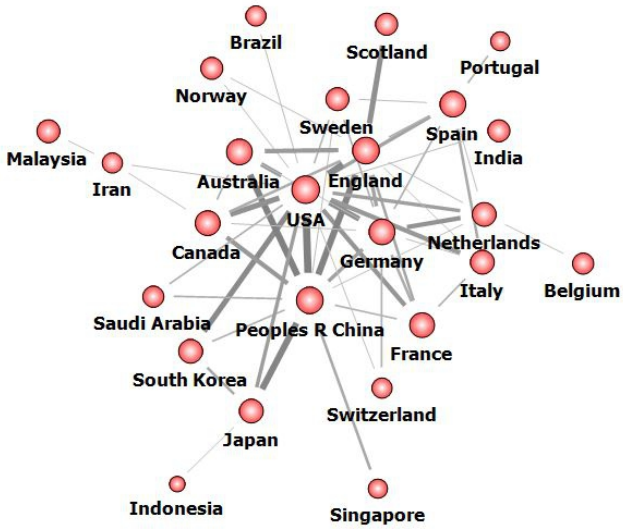

Fig. 2 International CCS research collaboration network – upper 10% collaboration (2012-2014)

Table 3. Countries with top 5 betweenness centrality in the CCS research network

Country	Betweenness Centrality (CCS)
USA	0.240171
France	0.115879
Spain	0.081405
England	0.070563
Sweden	0.051301

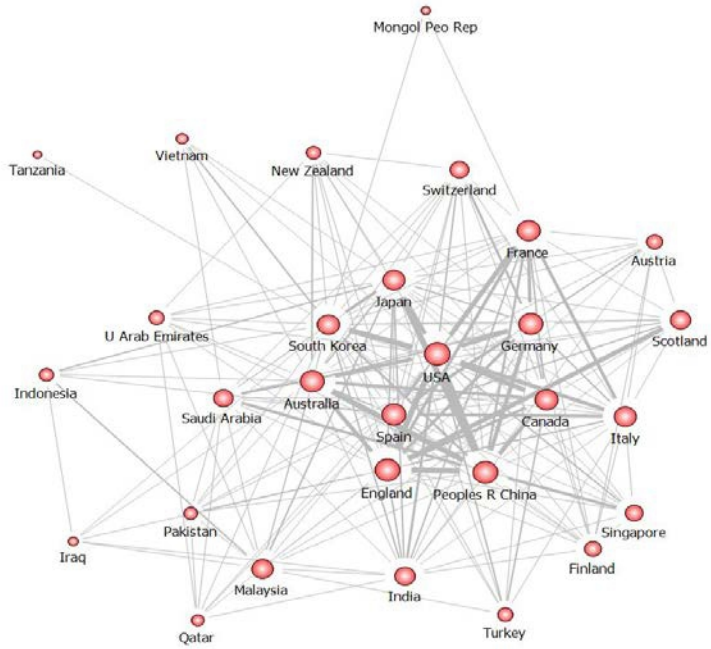

Fig. 3 International CCS research collaboration network of South Korea (2012-2014)

Networks of two most actively researched areas in CCS – pre and post combustion CO_2 capture- were both single network groups, but showed some differences. In the field of pre-combustion CO_2 capture, countries worked with various partners while links between USA and China, China and Australia, and USA and England stood out. (Fig. 4) In the field of post-combustion CO_2 capture, China and USA showed multiple strong collaborations. (Fig. 5)

Betweenness centrality analysis confirmed that USA played the most important role in connecting the other countries in the pre and post-combustion CO_2 capture research networks. (Table 4) In the field of pre-combustion CO_2 capture, England and Japan stood out as one of the key players in the network. In the field of post-combustion CO_2 capture, unlike the general CCS research network, Malaysia stood out as a key player.

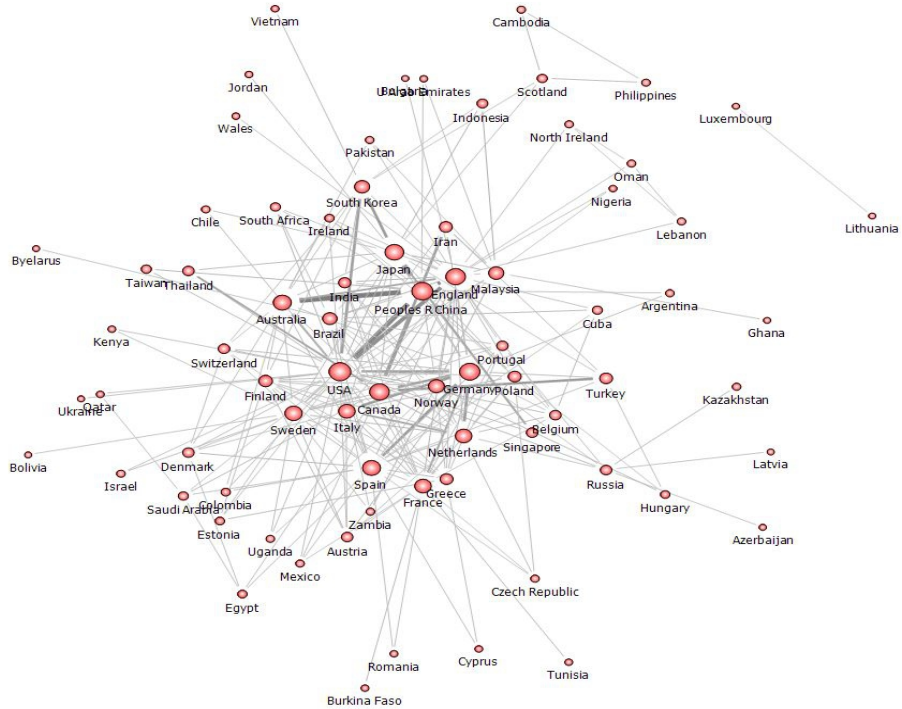

Fig. 4 International collaboration network of pre-combustion CO_2 capture research (2012-2014)

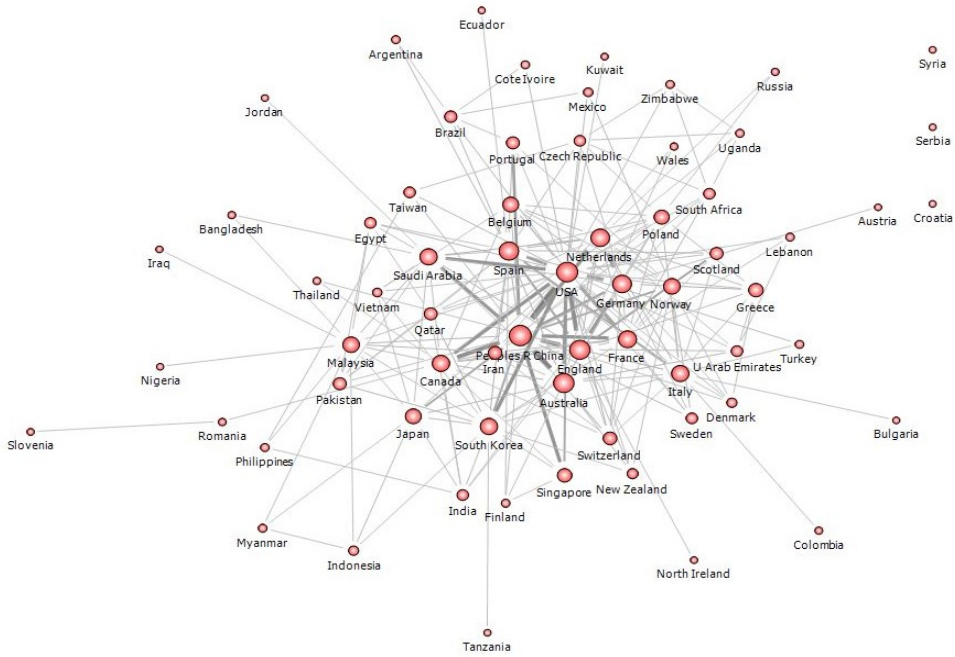

Fig. 5 International collaboration network of post-combustion CO_2 capture research (2012-2014)

Table 4. Countries with top 5 betweenness centralities in pre&post-combustion CO_2 capture research networks

Country	Betweenness Centrality (Pre-Combustion CO_2 Capture)
USA	0.257737
England	0.161626
Japan	0.094834
Russia	0.066575
Spain	0.064000

Country	Betweenness Centrality (Post-Combustion CO_2 Capture)
USA	0.310101
Malaysia	0.100953
Spain	0.084160
England	0.075088
Canada	0.074928

In the case of South Korea, collaboration network was more diverse in the field of post-combustion CO_2 capture (Fig. 6(b)), where the main partner was USA. South Korea showed a strong link with Japan and USA in the field of pre-combustion CO_2 capture (Fig. 6(a)). Betweenness centrality of South Korea in pre and post-combustion CO_2 capture were 0.04657(ranking 9th) and 0.058733(ranking 8th) respectively; both networks appeared slightly higher than the value in the general CCS research network.

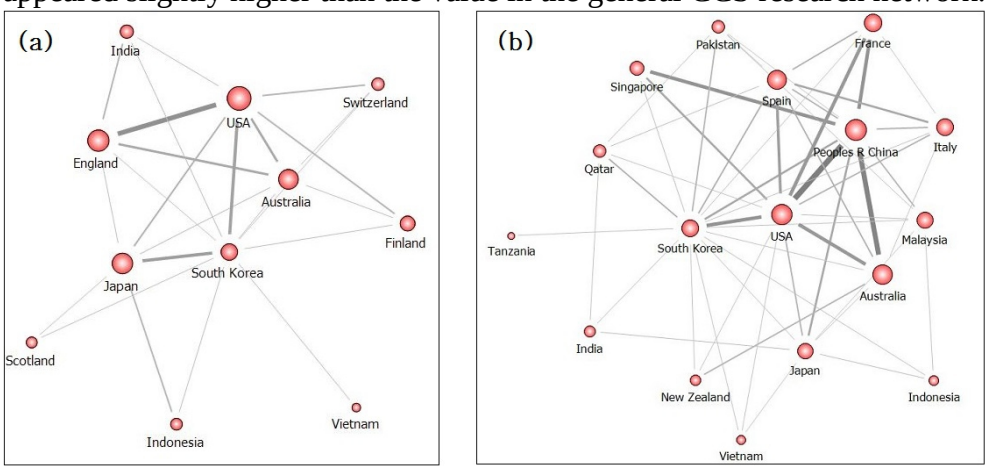

Fig. 6 International collaboration network of pre&post-combustion CO_2 capture research of South Korea (2012-2014)

Conclusion

To investigate the research trend of CCS, network analysis of CCS-related SCI papers published in 2012-2014 was conducted. The number of SCI papers published on CCS research increased steadily, with China and USA holding the lead. In terms of centrality, USA was the most influential country in the CCS research network, followed by France. South Korea tended to collaborate intensively with a small group of countries, especially USA.

Research on pre-combustion CO_2 capture and post-combustion CO_2 capture was the most active. In terms of centrality, USA was the most influential country in these networks as well. In the field of pre-combustion CO_2 capture, England and Japan also stood out as one of the key players in the network. In the field of post-combustion CO_2 capture, unlike the general CCS research network, Malaysia stood out as a key player. South Korea showed a strong link with Japan and USA in pre-combustion CO_2 capture research, while showing a more diverse network in post-combustion CO_2 capture research.

From these results, it can be suggested that diversification of CCS research network can help improve the effectiveness of CCS R&D in South Korea. Considering the quantity of papers published, collaboration with various countries could enhance the influence of CCS research conducted in South Korea.

Further analysis using additional network measures and detailed investigation on each of 17 major CCS related categories would yield a more accurate representation of CCS research trend. The interesting shift in the field of pre and post combustion CO_2 capture would also need to be explored further for a more specific and detailed explanation.

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