Mapping the Knowledge on Socio-nuclear Studies in Korea through Keyword Network Analysis

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1. Introduction

Nuclear science has enormous social and political influence [1]. Nuclear society, which has been well aware of social concerns, especially after the 2011 Fukushima accident, has a strong interest in following up on public opinion. Yet, the trend of social scientists' research on nuclear science has been largely ignored.

This research, in this context, aims to conduct meta-analysis to delineate the knowledge network of socio-nuclear studies in Korea from 1957 to 2016.

I adopted an analytical framework of keyword co-occurrences that takes its methodological origin from network science. Many attempts have been made to conduct meta-analysis through keyword network analysis in order to see how knowledge develops in diverse fields; however, there is still no literature dealing with socio-nuclear research trends. What stands out most from this research is the identification of central research topics and their development phases. The research process is fourfold as shown in Fig. 1.

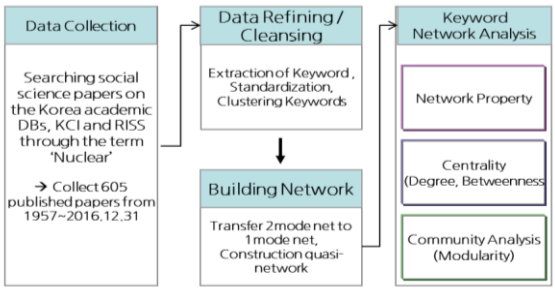


Fig. 1. Research Process

Computational network analysis was performed using Cyram Netminer 4.2(ver.) for conducting statistical analysis as well as visualizing the knowledge network.

2. Data and Methods

2.1 Data

A total of 605 research papers were collected from social science academic journals in Korea. Two academic data base systems, KCI and RISS, were used for collecting papers by searching for the word, 'NUCLEAR (*won-ja-ryuk*). Bibliographic information was extracted from the papers, such as the title, the first author and his/her affiliation, the field of the journal, and author-provided keywords.

Since 1957 when the first social science paper related to nuclear science was published, the number of paper publications has gradually increased. The trend changed noticeably from 2009 when Korea won the contract to build the first nuclear power plant in the UAE; and surged after 2011, when the Fukushima accident occurred (see Figure 2).

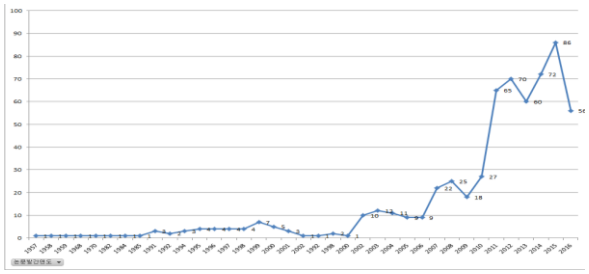


Fig. 2. Trend of Socio-nuclear Research in Korea (1957-2016)

Most significant proportion of social science research projects were conducted by researchers in the field of law (33%). The rest can be categorized as follows: public policy (26%), politics (10%), international relations (7%), communications (6%), economics (5%), business (4.8%), sociology (4.1%), and educations (4%).

Regarding the organizational distribution in terms of the first author's affiliation, socio-nuclear research was led mostly by universities. It is noteworthy that the engagement of government-funded organizations in socio-nuclear research is relatively very small, while they are predominant in terms of holding technology patents (See Table 1).

Table 1: Research Achievements in Korea by Organizational Type

Organizational Type	Socio-nuclear Paper Publications (1957-2016)	Technology Patent allocation* (1998-2009)
Public Organisation	65	217
University	508	29
Civil Research	14	n/a
Overseas	18	n/a
Total	605	847

* *Source*: Lim (2012), p.431. [2].

2.2 Methods

Among the literature collected, author-provided keywords were also extracted. The author keywords in the bibliography are an index that provides future users

with acquired information and knowledge, connotatively [3].

528 out of the 605 papers which include more than two keywords were selected for keyword data extraction. The number of raw data, i.e. a set of keywords, was 2,751; and it was trimmed down to 1,818 through data cleansing and refining processes. The processes were conducted according to the following criteria:

- Deleting singular term, 'Nuclear (*won-ja-ryuk*)'
- Unifying synonyms into the general keywords: (e.g. *haek-bal-jeon*, *won-ja-ryuk*-energy → *won-ja-ryuk-bal-jeon*)

The keyword distribution was imbalanced in terms of the frequent rate of co-occurrence. 85% of the keywords were mentioned one time, while only 15% of the keywords were constantly referred to multiple times. This imbalanced distribution of data was appropriate for building a network.

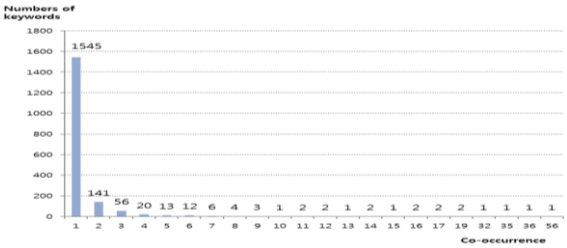


Fig. 3. Frequency Distribution of Keyword Co-occurrences in Socio-nuclear Studies in Korea

Keywords extracted from each paper were combined into a 2-mode matrix with paper as the rows and keywords as the columns. This had to be transferred artificially into a quasi-1-mode matrix [4] that provides data for building the keyword network of co-occurrence frequency in accordance with the jaccard coefficient and cosine similarity algorithm, respectively.[5].

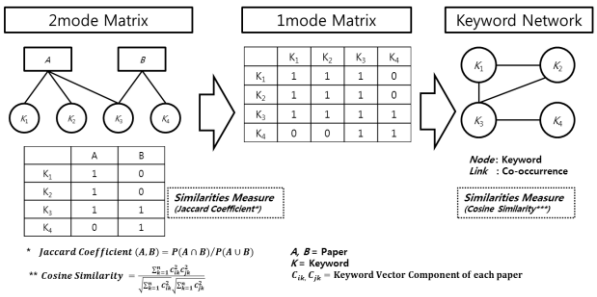


Fig. 4. Process of Constructing the Keyword Network

In the network, a keyword is a node, and a link between keywords is the relationship. The link has no direction since the relation of keywords is co-occurrence. Changing the diagonal value from 1 to 0 and reducing links on the basis of the above cosine similarities 0.1 were applied for visualizing network, respectively.

3. Analysis Results

3.1. Network properties

The knowledge network of socio-nuclear studies in Korea during 1957 to 2016 consists of 117 nodes and 199 links. The network is identified as a scale-free network since the degree frequency distribution follows Zipf's law that few minor nodes (i.e. research topics) have dominant influences to major nodes. [6].

The network properties have been expanded since 1957 (see Table 2). The growing phase of the expanding network changed remarkably after 2011. The number of links, a degree index, expanded from 26 to 363. The density, a value of every possible link divided by the real number of links, was closer to 0, which means that social scientists have engaged in more diverse topics related to nuclear science than previous period. This trend of expanding research topics was reconfirmed by the change of average degree from 1.3 in 1957-2011 to 3.9 in 2011-2016. The clique, a number of maximal complete subgraphs, expanded from 5 to 143 along with network growth. The networks in each period are visualized in Figure 6.

Table 2: Network Properties on Socio-nuclear Keyword Networks

	1957~2010	2011~2016	Total
Degree	26	363	566
Density	0.137	0.083	0.065
Average Degree	1.3	3.9	4.3
Centralization Index (%)	14	9.7	5
# of Clique (min. size: 3)	5	25	33

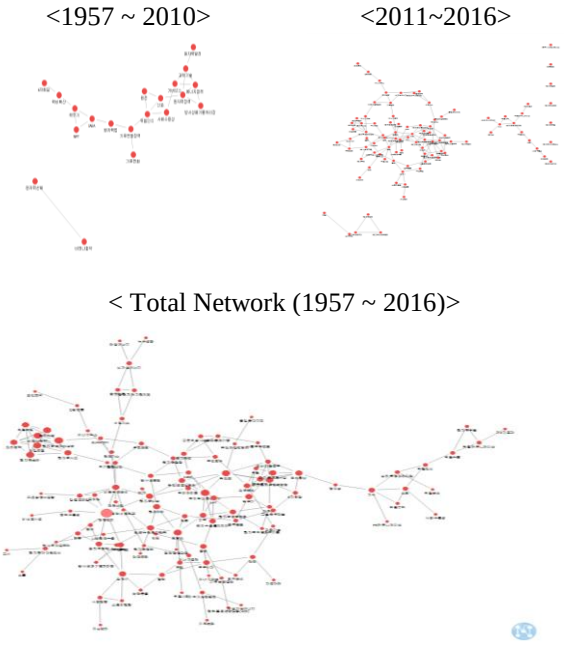


Fig. 5. Knowledge Maps on Socio-nuclear Studies in Korea

3.2. Centrality

The centrality index is a milestone that guides the central concepts in a visualized knowledge map. This research applied two centrality indicators – degree centrality and betweenness centrality [7]. Degree centrality shows what kinds of nodes have the most links with others. The higher node in degree centrality is a research topic representing its sub group. Betweenness centrality, on the other hand, is used to identify the bridge topics among different groups. Those nodes that hold higher betweenness centrality values are the research topics in which multi-disciplinary studies occurred.

In the socio-nuclear knowledge network, the most degree centralized keyword is *'Conflict Management.*' This keyword is surrounded by neighbors such as *'Policy acceptance,' 'Inhabitants' Poll,'* and *'Nuclear Wastes Disposal Facilities*.' The nonproliferation is also ranked at a higher position neighboring with the North Korea's nuclear crisis and its implications for an international nonproliferation regime. The keyword *'France,*' which ranked at fourth in degree centrality, is noteworthy. Given the fact that France and Korea share a similar industrial structure regarding nuclear power, many social scientists have set France as a target for comparative studies.

Table 3: Top 10 Keywords in Degree Centrality

No	1957-2010	2011-2016	Total
1	NPT	원전해체 (NPP Decommissioning)	갈등관리 (Conflict Management)
2	원자력정책 (Nuclear Policy)	독일 (Germany)	원자력손해배상법 (Nuclear Liability Law)
3	신뢰 (Trust)	프랑스 (France)	국제핵비확산체제 (Int'l Nonproliferation Regime)
4	IAEA	한국수력원자력㈜ (KHNP)	프랑스 (France)
5	과학기술 (Science and Technology)	핵안보 (Nuclear Security)	손해배상 (Compensation for Damage)
6	에너지정책 (Energy Policy)	미국 (U.S.A)	책임집중 (Exclusive Liability)
7	핵비확산 (Nonproliferation)	일본 (Japan)	비엔나협약 (Vienna Convention)
8	거버넌스 (Governance)	네트워크분석 (Network Analysis)	원자력손해 (Nuclear Damage)
9	핵무기 (Nuclear Weapon)	원자력손해배상법 (Nuclear Liability Law)	핵안보 (Nuclear Security)
10	위험인식 (Risk Perception)	원자력시설 (Nuclear Facility)	파이로프로세싱 (Pyro Processing)

Regarding the betweenness centrality index, 'nuclear facility' is ranked at the first, while *'Nuclear Nonproliferation,' 'Nuclear Security,' and 'Network Analysis'* follow. These betweenness keywords are at a crossroads between different sub groups. *'Nuclear Facility,'* a comprehensive keyword that includes nuclear-related infrastructures such as the NPP, a radioactive waste disposal facility, is bridging other sub research groups such as studies on nuclear safety, the environment, liability, and conflict management. Likewise, *'Nuclear Nonproliferation'* is linked between economics and nonproliferation issues such as pyro processing, ROK-US nuclear cooperation, etc.

Table 4: Top 10 Keywords in Betweenness Centrality

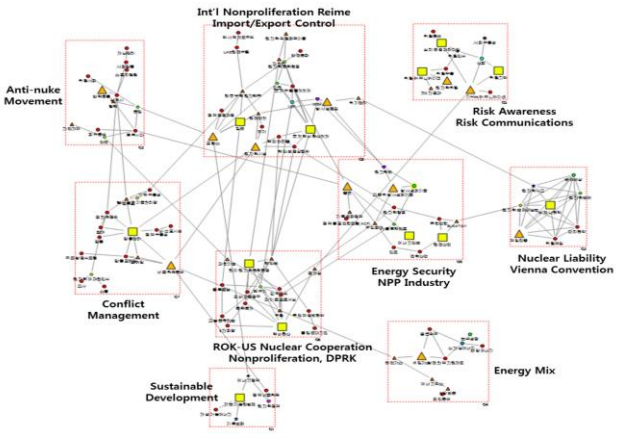
No	1957-2010	2011-2016	Total
1	NPT	원전해체 (NPP Decommissioning)	원자력시설 (Nuclear Facility)
2	원자력정책 (Nuclear Policy)	독일 (Germany)	핵비확산 (Nuclear Nonproliferation)
3	신뢰 (Trust)	프랑스 (France)	핵안보 (Nuclear Security)
4	IAEA	원자력시설 (Nuclear Facility)	네트워크 분석 (Network Analysis)
5	기후변화정책 (Climate Change policy)	미국 (U.S.A)	갈등관리 (Conflict Management)
6	위험인식 (Risk Perception)	일본 (Japan)	경제성 (Economics)
7	핵비확산 (Nonproliferation)	에너지정책 (Energy Policy)	지식 (Knowledge
8	비엔나협약 (Vienna Convention)	기후변화 (Climate Change)	핵안보정상회의 (Nuclear Security Summit)
9	원자력법 (Nuclear Law)	네트워크분석 (Network Analysis)	원전해체 (NPP Decommissioning)
10	사회수용성 (Social Acceptance)	원자력손해배상법 (Nuclear Liability Law)	프랑스 (France)

In sum, the Fukushima accident had provoked major changes for social scientists in Korea in terms of both quality and quantity of studies related to nuclear science. A set of keywords such as *'NPT,' 'Nuclear Policy,' 'Trust,' and 'Governance'* were identified as highlighted research topics from 1957 to 2010. After 2011, however, emerging research topics such as *'NPP Decommissioning,' 'Germany,'* and the NPP owner *'KHNP'* were frequently used by social scientists.

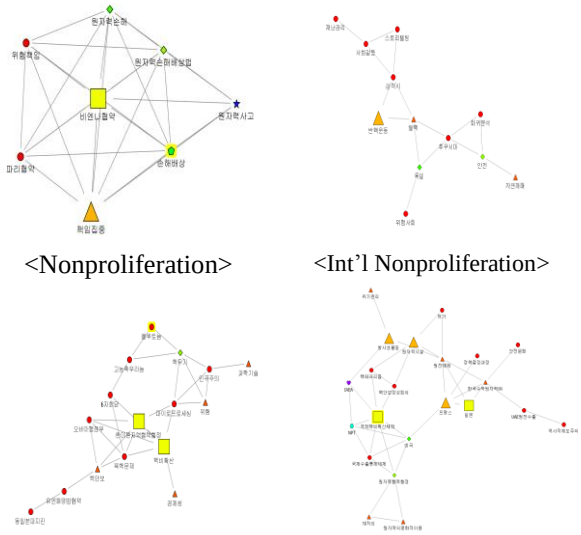
3.3 Sub-communities

To identify the sub-communities, I set the optimal modularity value of 0.73 as a reference point for network cohesion. The nine communities were then identified, as Figure 6 shows.

The groups have central topics such as *'International Nonproliferation Regime,' 'Nonproliferation,' 'Risk Communications,' 'Anti-nuke Movement,' 'Nuclear Liability,' 'Energy Security,' 'Conflict Management,' 'Sustainable Development,'* and *'Energy Mix.'*



<Nuclear Law> <Anti-nuke Movement>



<Nonproliferation> <Int'l Nonproliferation>

Fig. 6. Sub-communities in the Socio-nuclear Knowledge Network

Table 5: Network Properties of Sub Communities

Group (Centralized Topic*)	# of nodes	Degree	SMI	Cohesion Index	E-I Index
Sub-group 1: Sustainable Development (Sustainable Development)	6	0.047	0.982	55.5	-0.429
Sub-group 2: Nuclear Law (Vienna Convention)	8	0.297	0.995	202.429	-0.857
Sub-group 3: Anti-nuke (Anti-nuke Movement)	12	0.038	0.966	28.636	-0.5
Sub-group 4: Energy Mix (Shale Gas)	10	0.056	0.992	130.778	-0.833
Sub-group 5: Risk Management (Risk Perception)	12	0.029	0.993	133.636	-0.867
Sub-group 6: Nonproliferation (Nuclear Nonproliferation)	16	0.041	0.946	18.18	-0.459
Sub-group 7: Conflict Management (Conflict Management)	16	0.031	0.956	22.124	-0.533
Sub-group 8: Int'l Nonproliferation (ROK-US Nuclear Cooperation)	22	0.024	0.906	10.179	-0.385
Sub-group 9: Energy Security (Energy Security)	15	0.026	0.934	14.571	-0.333

* The highest topic in the group in terms of degree centralization.

Among communities, the nuclear law community is the most closed group with a 0.297 density property. The low-density groups deal with sustainable development and energy mix. Nonproliferation has two sub communities; one is dealing mostly with security studies, another is focused on global nonproliferation and nuclear security regimes including the regime on nuclear import and export control.

4. Conclusion

This research has attempted to establish a socio-nuclear knowledge network from 1957 to 2016 in Korea, to analyze its properties, and to identify central topics as well as sub communities.

The findings lead to several straightforward conclusions, as follows. First, socio-nuclear studies including policy research have mostly been conducted by universities, while technology developments have been led by public organizations. Second, it is apparent that the Fukushima accident has provoked major engagement among social scientists in nuclear issues as the remarkable growth of the knowledge network after 2011 signify. Third, the research topics have been diversified as a result of growing multi-disciplinary research projects. Finally, there is certain gap between sub communities in the socio-nuclear knowledge network in terms of network properties.

This article provides a stepping stone for future researchers with a wealth of information concerning the status of socio-nuclear studies. For policy makers, this meta-analysis is likely to provide guidance on what we need and do not need.

It remains to be seen whether the socio-nuclear knowledge network in Korea is well-structured or not. I hope that this article will be able to provide an impetus for comparative studies with overseas cases in order to evaluate the network and its soundness.

Any inaccuracies which remain are, of course, my own.

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