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Technology Fusion Characteristics in the Solar Photovoltaic Industry of South Korea: A Patent Network Analysis Using IPC Co-Occurrence

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Abstract: This study analyzes the technology fusion phenomena and its characteristics, focusing on the solar photovoltaic (PV) industry in South Korea. Co-occurrence networks of international patent classification (IPC) codes have been analyzed based on the photovoltaic patents in South Korea during a 15-year period (2002–2016). The results reveal that, while the strength of technology fusion has greatly increased during the period, the structural pattern of fusion has been diversified or decentralized. In the early stage, widespread emergence of new technologies has been observed but, in the later stage, the focus of fusion shifted to the utilization of existing technologies. The characteristics of key technologies also changed as the technology fusion progressed. In the early stage, product technologies such as materials and components played a central role, while operation technologies such as monitor, structure, and arrangement were the drivers of fusion during the later stage.

Keywords: solar photovoltaic industry; technology fusion; international patent classification (IPC) code co-occurrence; social network analysis; exploration and exploitation

1. Introduction

Renewable energy helps to protect our lives and the future from climate change and global warming [1,2]. For more than 20 years, many countries have made efforts to develop renewable energy technologies and support the adoption of these technologies using policy instruments [3–7]. This has resulted in a rapid increase in the quantity of energy supply provided by renewables [5–8].

In the case of South Korea, the supply of renewable energy has been increasing and the solar photovoltaic (PV) industry, in particular, has recorded rapid growth [9]. Nonetheless, the total share of PV in energy supply is still low compared to other energy sources using fossil fuels or nuclear [10]. Hence, to increase the share of renewable energy in total energy supply, continuous technology development and innovation is needed.

Technology fusion, also known as technology convergence, is defined as the combination of at least two or more separate technology areas [11–16]. Technology fusion is one of the most efficient ways to create new technology and make innovation [17,18], providing technological breakthroughs by presenting a new direction of innovation [19,20].

To understand the characteristics of technology fusion, various analyses based on patents have been attempted [13–16,20–30]. Early research on the technology innovation process using patent data has identified the aspects of fusion and the main path of technology development based on citation

information [21–24]. It helped to determine the flow of technology diffusion through technical reference and their relationships. However, as it focused on the linear flow of the patent citation perspective, it may not reflect the relationship across technology areas, thus providing a limited view of the overall technological fusion phenomena [25,26]. To overcome this limitation, network analysis including all technical areas supplied by classification codes in the patents has been undertaken [14,27–32].

This study analyzes how the technological development of the solar PV industry in South Korea progressed over time, focusing on the technology fusion phenomena. To identify the characteristics in the overall process of technological fusion in the Korean solar PV industry, we set up indicators and interpreted their meaning by applying the concept of network theory.

The remainder of this paper is organized as follows. Section 2 presents a general overview of renewable energy including the status of solar PV in Korea. The patent analysis methodology is also discussed. Section 3 describes the methodology using the international patent classification (IPC) code co-occurrence network to frame the analysis and provides an overview of the important indicators. Section 4 presents the results of the analysis. Sections 5 and 6 discuss the results and summarize the conclusions and directions for future research, respectively.

2. Context and Literature Review

2.1. Renewable Energy Trends

As concerns about the environment and sustainability rise, it is necessary to establish a transition pathway for energy supply systems to meet greenhouse gas reduction targets and to establish a low-carbon future [1,3,33]. To address these challenges, many countries have established policies that support the research, development, and deployment of renewable energy technologies [2,4–7,34–36], which has led to an increased supply of renewable energy worldwide [9,10].

Renewable energy capacity [9] indicates that the share of renewable energy has been growing across Europe, North America, and Asia (Figure 1). In particular, the growth in the Asian region has been evident in recent years. Renewable energy capacity in Asia tripled from 386.9 GW in 2010 to more than 1 TW by 2018. Asia's global share in renewable energy production rose from 31.6% to 43.5%. During the same period, the portions of other regions fell, from 26.4% to 22.8% in Europe and from 19.0% to 15.6% in North America, for example.

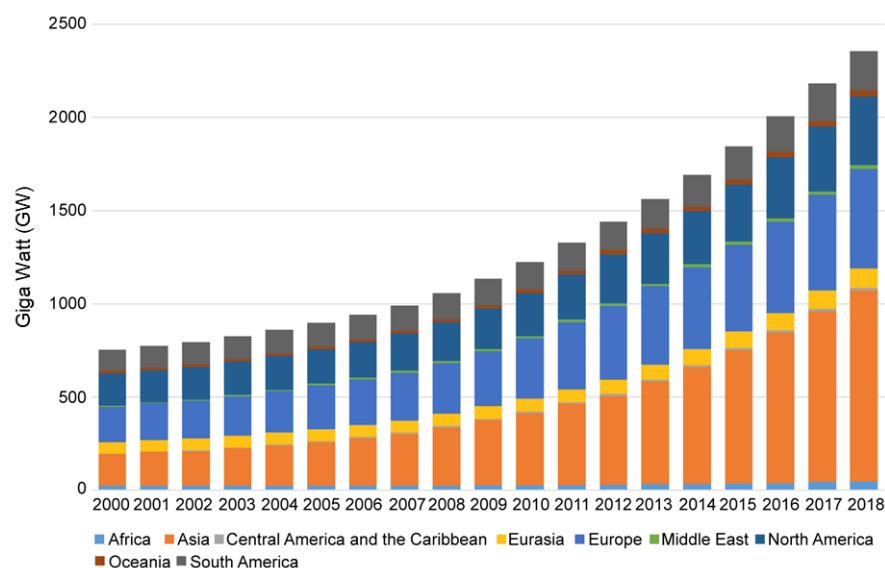


Figure 1. Global renewable energy capacity [9].

Many studies have been carried out with respect to trends and diffusion processes of renewable energy [2,6–8,35–41]. It has been shown that factors such as cost,

environment, culture, technology innovation, and policy affect renewable energy development and spread [2,6,37–43]. On the other hand, the slow development of renewable energy is attributed mainly to two factors: market failure and system failures, such as political instability [8,35,38,41].

Nevertheless, the share of renewable energy continues to grow steadily. In particular, solar PV technologies have developed rapidly over the last 10 years (Figure 2) and exhibit a growing share of the global energy mix among renewable energy technologies [1,10,44,45]. Compared to the other technologies, such as solar thermal and heating, solar PV is the most efficient way to obtain energy from the sun [8,39].

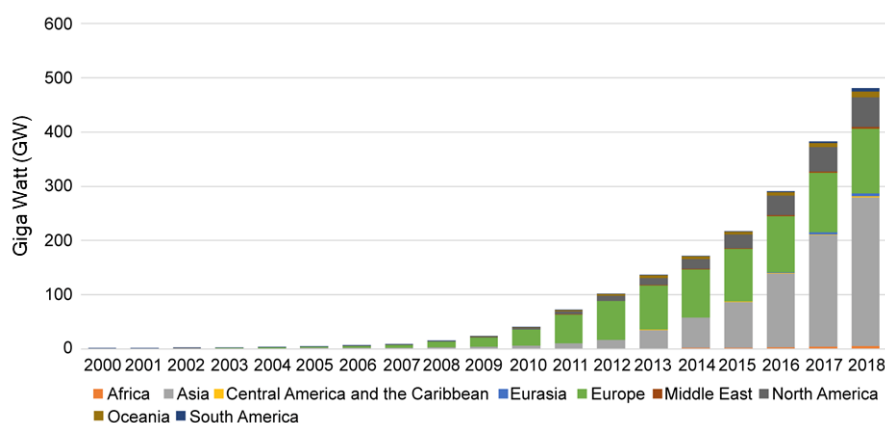


Figure 2. Global solar photovoltaic capacity [9].

2.2. Solar Photovoltaic Deployment in South Korea

The South Korean government has introduced policies such as feed-in tariffs (FIT) and renewable portfolio standards (RPS) to support the development of renewable energy over the past two decades. Due to these policies and efforts from industry, the share of renewable energy in energy supply has been growing steadily [9,10]. For the rapid deployment of renewable energy sources, government support has been mainly concentrated on solar PV [46], resulting in a sharp increase in energy produced by solar PV, compared to other renewable energy sources such as hydropower, onshore wind, and biofuel (Figure 3). In 2018, the average installed solar PV capacity for renewable energy around the world accounted for about 20.4%, but the solar PV proportion was more than 56.6% in South Korea [9,10].

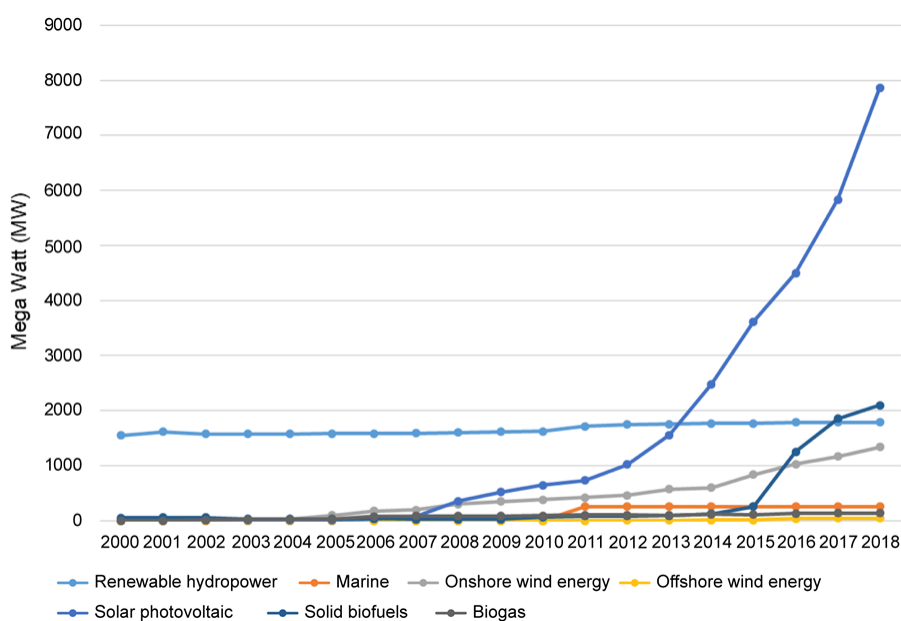


Figure 3. Renewable energy capacity in South Korea [9].

The government of South Korea set an aggressive goal for the share of renewable energy in the portfolio of power generation, the so-called 3020 Plan. It aims to increase the share of renewable energy in power generation to more than 20% by 2030, with the capacity of solar PV increasing from 5.7 GW in 2017 to 36.5 GW in 2030. To achieve this goal, continuous development and innovation of the solar PV technology is crucial. Therefore, it will be helpful to analyze the technology development and fusion characteristics of the solar PV industry.

2.3. Identifying Technology Fusion Characteristics through Patent Network Analysis

Patents are representative and reliable outputs of the research, development, and technology innovation of an industry [47], which considers both the product and process perspectives. As a result, patent analysis methodologies have been widely used to analyze technology development processes—for example, growth, fusion, and strategy [13–16,31,32,48–50]. Among the various tools and techniques for patent analysis, there are two principal approaches: text mining and visualization. The visualization approach can be further divided into two categories: network and clustering analysis [21,22].

The purpose of network analysis is to identify patterns in the overall shape of the network and interpret hidden characteristics within them. The information included in the patents network is thereby utilized to understand and interpret a structural characteristic of technology fusion and innovation process. Moreover, the network of patents provides a macroscopic view that is difficult to find in individual patent-level analysis; it presents some clues to identifying established research and development or technology strategies in the industry area [23,24].

The patent network has been used to identify the post-production relationship and diffusion route between technologies by forming a network in the cited relationship [20,24,26,27]. Since the analysis of patents based on citation networks often only provides limited insights, such as linear flow in the order of the patents [28,29], network analysis based on a classification system has attracted more attention in the literature [30,32,51]. This approach has been adopted to analyze the connection, spread, and fusion of technology areas by examining the structured IPC code.

The IPC code is one of the most popular and common ways to classify patents [16,22]. It is a hierarchical technology classification system proposed by the World Intellectual Property Organization (WIPO) under the Strasbourg Agreement (1971). It was developed to unify the proprietary patent classifications implemented in each country internationally, and patent examiners assign it according to strict guidelines.

In the IPC code co-occurrence network analysis, node means technology area and link means a patent that connects different nodes. Therefore, it can reveal the structural characteristics of fusion within the industry [14–16,52]. In addition, this method enables analysis with respect to a technology area unit, instead of an individual patent unit. Hence, analyzing the IPC code co-occurrence network could reveal structural characteristics of technology fusion across the technology areas, which cannot be readily identified using other statistical techniques or patent citation networks.

This study conducts a network analysis based on the IPC code to identify structural characteristics and changes in technology fusion process. The focal point of this study is to analyze and interpret the technology fusion phenomena and characteristics in the solar PV industry across defined periods.

3. Methodology and Indicators

3.1. Research Framework

Figure 4 outlines the three stages of the analysis.

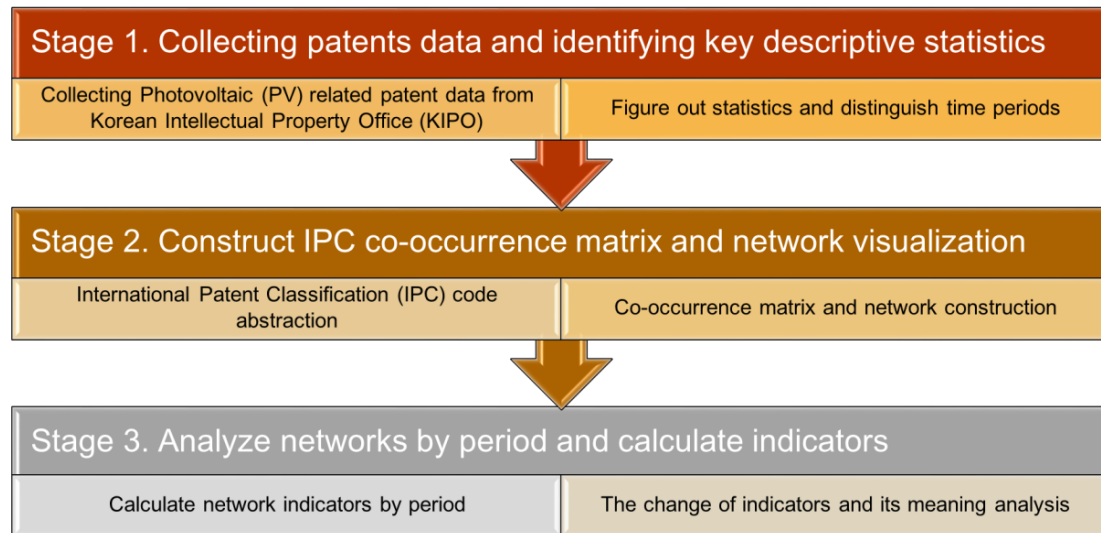


Figure 4. Analysis procedures.

First, to identify the technology growth and fusion phenomena of the PV industry in South Korea, patent data of the PV industry across 15 years (2002–2016) were collected from the Korean Intellectual Property Office (KIPO). To better analyze the technology development process focusing on the fusion characteristics over time, the data were divided into three five-year periods. The IPC codes were then extracted from the patent information and the co-occurrence matrix of the codes for each period was constructed. Finally, the technology fusion characteristics were analyzed, and the core technology areas of the fusion were investigated based on co-occurrence network structures and indicators.

3.2. Social Network Analysis Using IPC Code Co-Occurrence

3.2.1. Social Network Analysis

This study applies a social network analysis (SNA) methodology to obtain and interpret the technology fusion characteristics of PV technologies included in their respective networks. SNA is concerned with relationships and flows between nodes that represent actors or agents, such as people, groups, organizations, computers, and URLs [53,54]. It is a visualization analysis technique that allows the internal connections between individual nodes that form a network to be visualized [55]. In SNA, links show relationships or flows between the nodes.

SNA focuses on the relations among actors, not individual actors, and their attributes [56]. This methodology has been widely used to understand the complicated interactions in technological evolution [57,58] since the network structure of patents and their IPCs can explain the complicated interdependency and trends in technological development and fusion [22,32,59].

3.2.2. IPC Code Co-Occurrence Network

As shown in Figure 5, the IPC code consists of details on the section, class, sub-class, main group, and sub-groups of a technology. Depending on the depth of analysis, different levels of IPC codes can be applied. In this study, network analysis has been conducted at the main-group level, since this level has been widely accepted by previous studies [22,60,61].

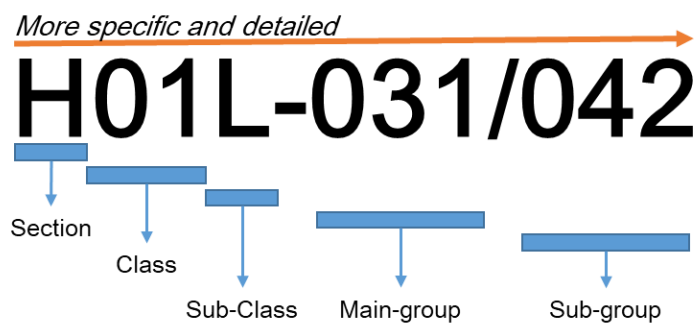


Figure 5. Example of the hierarchy of IPC code.

In general, a patent contains at least one IPC code. However, if a patent contains more than one IPC code, it can be assumed that multiple technology areas have been converged and integrated within the patent [14]. Thus, comparing the IPC code co-occurrence structure reveals connectivity and relations among the distinguished technology areas. Moreover, an IPC code that has a high centrality value in a network can be considered to be a core and main technology area [14–16,62].

Figure 6 illustrates the derivation process for IPC co-occurrence networks, where nodes are defined by IPCs and links are defined by the co-occurrence of IPCs in a patent. This assumes that if a certain IPC code co-occurs with another, there is a close relationship between the technology areas and they can be considered to be linked [63]. Forming a network with individual IPC codes as nodes has the advantage of analyzing the technology level over the patent cited level network.

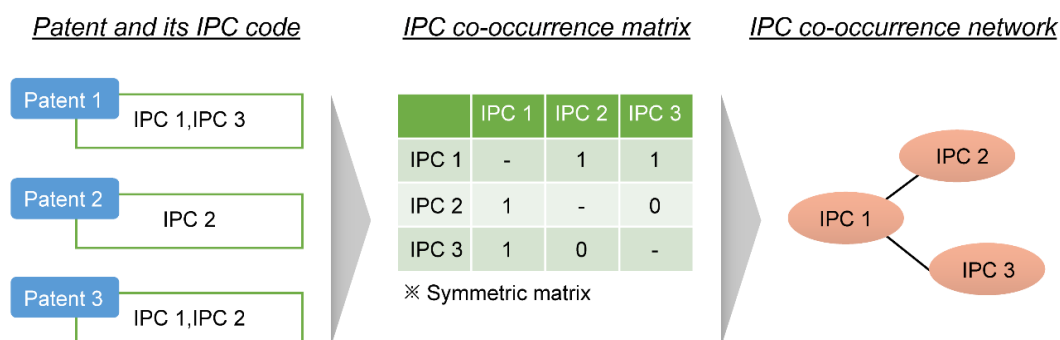


Figure 6. Derivation process of IPC co-occurrence network from the patent database.

3.3. Indicators Representing Technology Fusion

3.3.1. Network Structural Indicators

A network is defined by nodes and the connections between them, which are the links. In an IPC code co-occurrence network, a node represents an IPC and a link represents a connection between nodes. Thus, multiple and repeated co-occurrence between two (or more) IPCs can be represented by increasing the weight of the link.

The analytical indicators at a network level can show the structural characteristics of a network. Namely, “density,” which represents the connectivity of the network, refers to the degree of connectivity between the network nodes. In other words, a higher density network has more and tighter connections between nodes. This indicator explains the cohesion and complexity of the connection relationships that form a network. In relation to this, a ratio can be used to exclude a node having no connection with others in the network. That is, a node that is isolated from all of the other nodes can be identified, based on a measure of “inclusiveness.”

In addition, “centralization” refers to the tendency of a network to converge to a few specific nodes. If the density described above represents the amount of connectivity between the nodes in the

network, then centralization represents the concentration degree based on the connections that exist between several core nodes. In general, density and centralization tend to be inversely proportional, with higher density resulting in lower centralization and vice versa. However, if the network has a low density and a low tendency to focus on a few nodes, centralization will also be low.

An analytical indicator at the node level is a “degree,” which is defined by the total number of connected links of a node. The degree can also be used to represent “degree centrality,” as central nodes are likely to be active in the sense that they have the most ties to other nodes. On the other hand, a weighted degree is used in networks with weighted links, which distinguishes important and insignificant links by weight. Table 1 summarizes the network indicators described above.

Table 1. Key concepts of network indicators.

Level	Indicator	Description
Network	Density	Density is defined as the number of connections between nodes, divided by the total possible number of connections [53]. It is the value obtained by dividing the existing connection by the potential connection.
	Inclusiveness	Inclusiveness refers to the number of connected points, expressed as a proportion of the total number of points [64]. Higher inclusiveness indicates that a small fraction of isolated nodes exist in a network, which means the majority of nodes are interconnected.
	Centralization	Centralization measures how node centralities are distributed. The higher the centralization, the more centralized the network [53]. It is a network-level measurement, whereas degree centrality is a node-level measurement.
Node	Degree centrality	Degree centrality measures can identify the most prominent actors in a network that are extensively involved in relationships with other network members. Degree centrality indicates the importance and influence of actors (i.e., nodes) in a network [65,66]

3.3.2. Technology Fusion Pattern Indicators

The strategy of creating a patent can be divided into two categories: the exploitation strategy, which is focused on strengthening existing technology areas, and the exploration strategy, which is focused on finding new technology areas [67]. The process of technology fusion creates new technical knowledge mainly by combining existing skills or new knowledge [68]. To ensure that innovation continues to progress, it is ideal to pursue an exploitation strategy for short-term performance, whereas an exploratory strategy is required to ensure the long-term survival [67]. The reason for this two-pronged pursuit of strategy is that the roles of existing and new knowledge in innovation are different.

Technology fusion pattern indicators have been defined as shown in Table 2 and Figure 7. The exploration in the period t (R_t) is defined as the ratio of newly utilized IPCs (n_t^r) to the total number of IPCs (n_t) in the period. The exploitation in the period t (I_t) is defined as the ratio of IPCs utilized in both period $(t-1)$ and period t (n_t^i) to the total number of IPCs (n_t) in the period.

Table 2. Technology fusion pattern indicators.

Pattern	Definition
Exploration (in the period t)	$R_t = \frac{n_t^r}{n_t}$ where $n_t = n_t^r + n_t^i$ n_t : the total number of IPCs utilized in the period t n_t^r : the number of IPCs newly utilized in the period t
Exploitation (in the period t)	$I_t = \frac{n_t^i}{n_t}$ n_t^i : the number of IPCs utilized in both period $(t-1)$ and period t

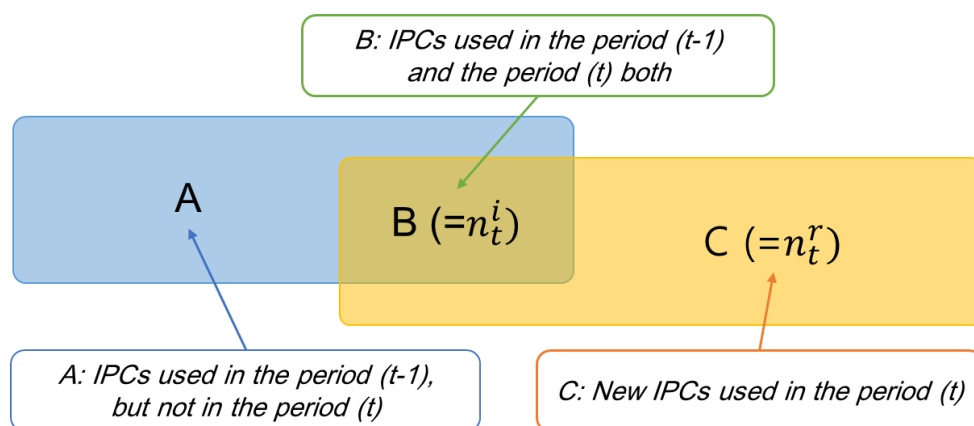


Figure 7. Classification of IPCs according to the technology fusion pattern in period t .

4. Empirical Analysis and Results: The Case of PV in South Korea

4.1. Patent Data and Descriptive Statistics of IPC Codes

According to data from the International Renewable Energy Agency, the number of solar PV patents registered in South Korea has risen steadily since the mid-2000s. For this study, a total of 11,655 patents in the PV industry from 2002 to 2016 were extracted from the KIPO.

Figure 8 shows the number of registered PV-related patents per year from 2002 to 2016. The growth rate of PV patent by research and development was slow in Period 1 (2002–2006) but became rapid in Period 2 (2007–2011), before maintaining high growth in Period 3 (2012–2016). The decrease in the number of patents since 2015 could be due to the delay in time between patent application and registration. The continuous accumulation of these patent quantities can be regarded as the accumulation of PV technology innovational capacity in South Korea.

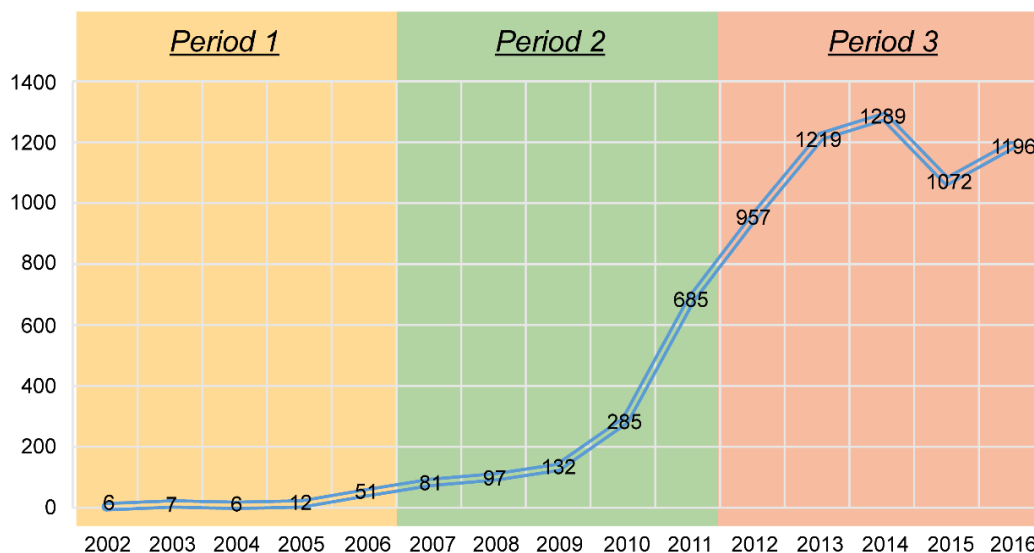


Figure 8. PV-related patents per year from 2002 to 2016.

Figure 9 shows the percentages of the number of IPC codes included in a patent from 2002 to 2016. During the first period (2002–2006), most patents have up to just one IPC code. In other words, the technical combination of different technology areas is rare during this period. During the second period (2007–2011), the fraction of patents with multiple IPC codes increased and this trend continued and strengthened throughout the third period (2012–2016). The graph shows the decreasing proportion

of patents that have only one IPC code as time progresses, and the increasing proportion of patents that have more than one IPC code. In the last period, most patents have two or more IPC codes; more than 80% of patents have multiple IPC codes in 2016.

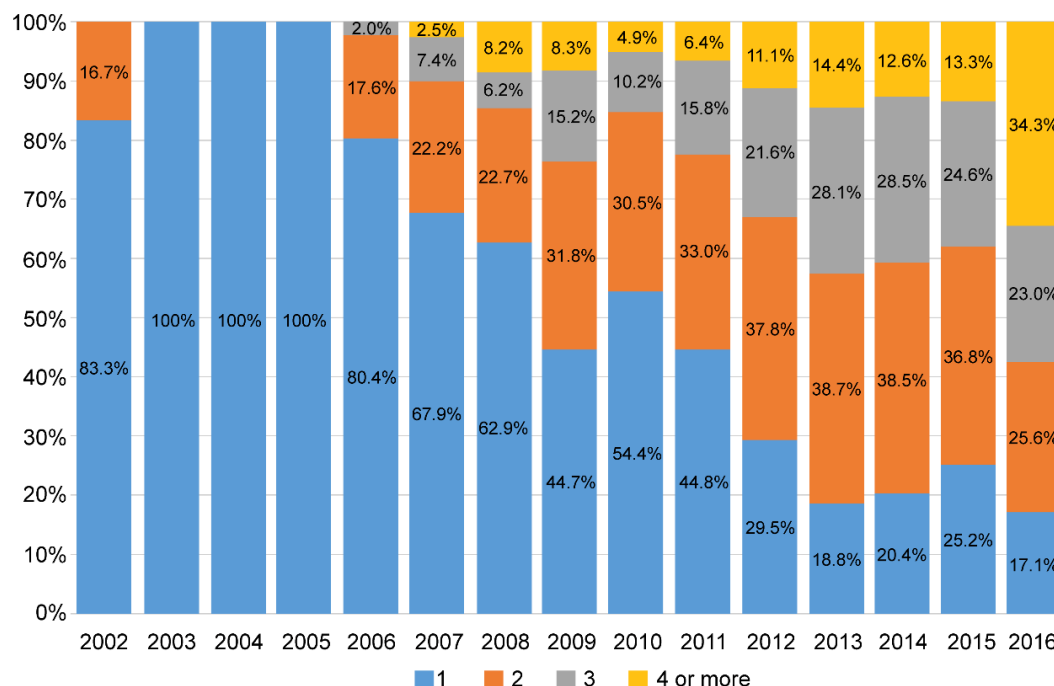


Figure 9. Trends in the number of IPC codes included in the patents.

4.2. IPC Code Co-Occurrence Networks and Their Structural Indicators

This section describes the visualization and analysis results of the IPC code co-occurrence networks during the three periods. The IPC networks of each period are analyzed using SNA software program (Net-Miner 4) with the Fruchterman–Reingold algorithm [69], as shown in Figures 10–12. To distinguish the core technology areas in each period, the IPCs with high degree centrality are shown in blue, while the rest are shown in red.

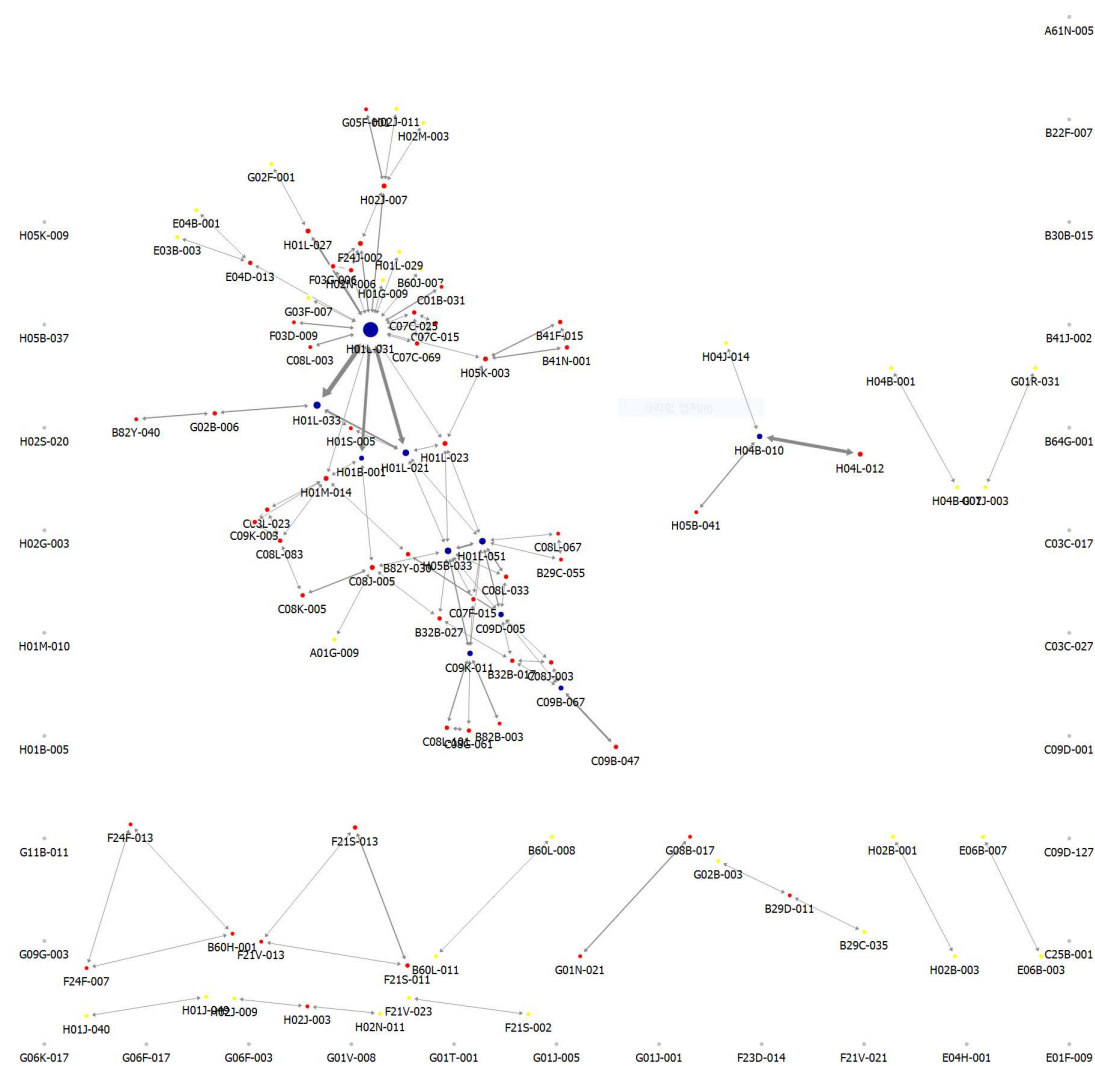
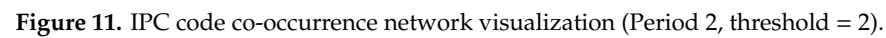


Figure 10. IPC code co-occurrence network visualization (Period 1, threshold = 1).



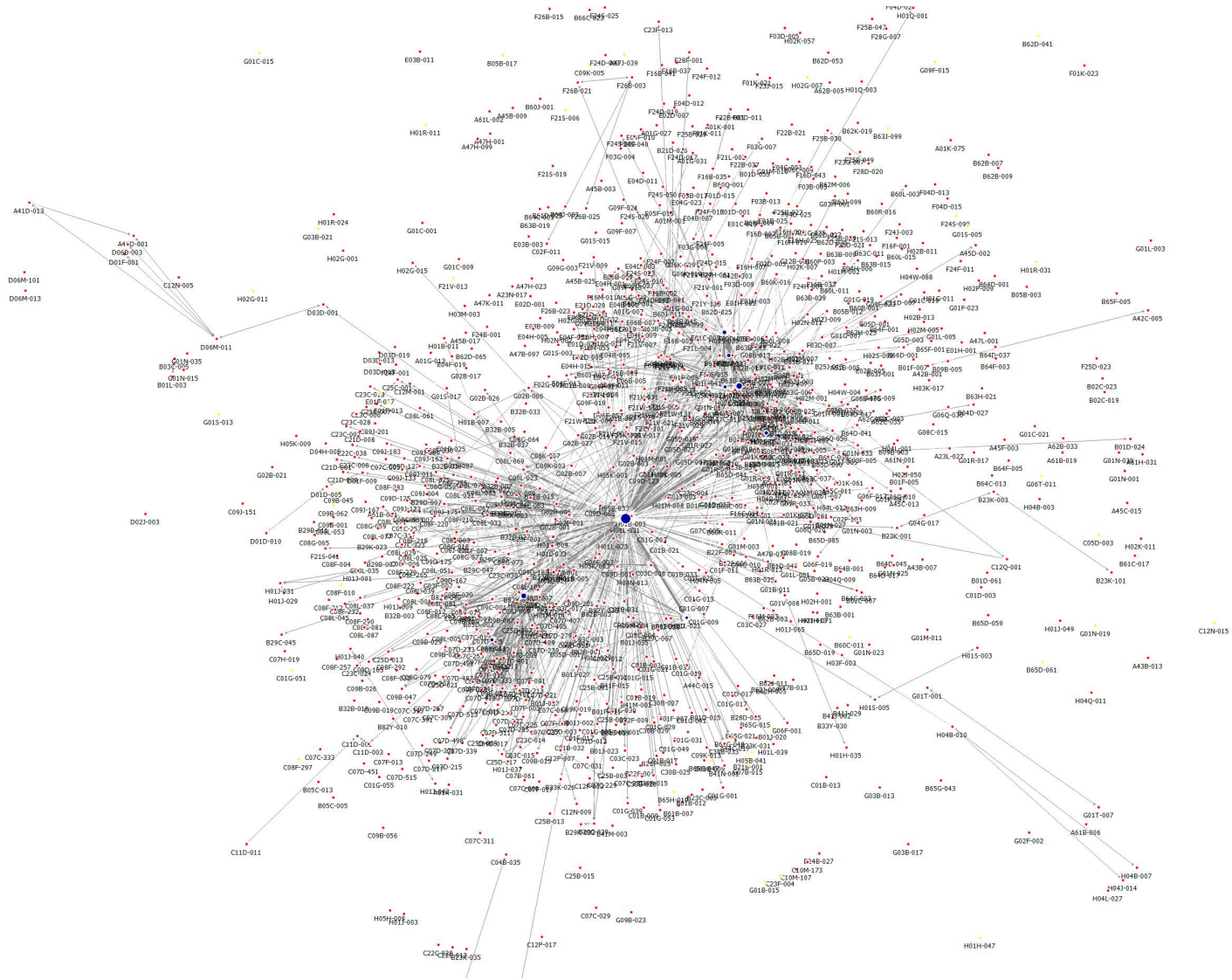


Figure 12. IPC code co-occurrence network visualization (Period 3, threshold = 3).

Figure 10 shows the structure of the IPC code co-occurrence network for the first period (2002–2006). The network can be identified as a scale-free network, characterized by a power law distribution, where the probability that a node has k links is proportional to $k^{-\alpha}$, where α is the degree exponent. This means that a few key technologies account for most of the links.

Furthermore, it is observed that the network is partially fragmented, with loosely connected components on the periphery, which indicates that technologies patented during this period have been only partially connected. There are a total 118 nodes and they are connected by 224 links. This results in a network density of 0.024. The centralization of the network is 0.043 and the inclusiveness is 75.4%. Therefore, one-fourth of the IPCs in Period 1 are not involved in the process of technology fusion yet.

Figure 11 shows the structure of the IPC code co-occurrence network for the second period. Compared with the previous period, the network exhibits the emergence of new technologies, as well as enhanced fusion of technologies. This is exemplified by the increase in the number of nodes and by the inclusiveness indicator, which increased by 21% compared to the previous period. In addition, the centralization in the second period (0.014) is lower than in the first (0.043), which indicates the sharing of links with new technology areas.

Figure 12 shows the structure of the IPC code co-occurrence network for the third period. Compared with the second period, the network density has increased by 62.5%, while the centralization has decreased by 25.5%. Through the density increase from 0.024 to 0.039, it can be observed that the fusion has strengthened. Since centralization has decreased from 0.014 to 0.01, the degree of diversification is slightly strengthened.

The network structural indicators for each period are summarized in Table 3. It can be seen that the network size, represented by the number of nodes, increased sharply during the second period. The size continued to increase in the third period, but the rate of increase slowed. On the other hand, the number of links has increased sharply during the third period, resulting in the rapid growth of density in this period. This shows that the emergence of new technology areas was the dominant trend in the second period, whereas technology fusion strengthened in the third period.

Table 3. IPC co-occurrence network structural indicators.

Network Structure Indicator		Period 1 (2002–2006)	Period 2 (2007–2011)	Period 3 (2012–2016)
Size	Number of nodes	118	685	1060
	Number of links (weighted)	224 (336)	3868 (11,244)	10,904 (43,892)
Composition	Density	0.0243	0.0239	0.0391
	Inclusiveness	0.754	0.964	0.993
	Centralization	0.043	0.014	0.01
Scale-free	Degree exponent	2.94	2.59	2.24
	(Adj. R square)	(0.941)	(0.942)	(0.935)

Meanwhile, the network analysis of degree centrality can identify core technology areas in technology fusion of each period. The highest degree of a particular IPC code in the network means that the respective technology area plays a key role in technology fusion during that period. Table 4 summarizes the top 10 nodes with the highest weighted degree centrality values over time. These are core IPCs that are most frequently utilized in the network at a main-group level. This table shows which technology areas have been centered within or over periods and which have faded out or newly emerged. Major areas in technology fusion will be discussed in detail in Section 5.

Table 4. Top 10 IPC codes showing high degree centrality over the three periods.

Degree Rank	Period 1		Period 2		Period 3	
	IPC Code	Weighted Degree	IPC Code	Weighted Degree	IPC Code (Main Group)	Weighted Degree
1	H01L-031	47	H01L-031	2609	H01L-031	6321
2	H01L-033	16	F24J-002	455	H02S-040	2994
3	H01L-021	14	H01L-051	306	H01L-051	2214
4	H01L-051	14	H01L-021	304	H02S-020	1542
5	H05B-033	13	H01B-001	240	H02S-050	1077
6	C09D-005	9	H01L-033	225	H02S-030	1071
7	C09K-011	9	H02J-007	186	G01R-031	883
8	H04B-010	9	C08J-005	181	C09K-011	839
9	C09B-067	7	F21S-009	168	H02S-010	659
10	H01B-001	7	C09K-011	152	H01L-021	529

4.3. Technology Fusion Pattern Indicators

As can be seen from the network-related indicators, in Periods 2 and 3, almost all of the technology areas included in the patent were used for technology fusion. To further investigate the pattern of technology fusion, the exploitation and exploration indicators in Section 3.3.2 have been applied to Periods 2 and 3.

As shown in Table 5, the exploration was dominant in Period 2, whereby this observation is driven by the massive emergence of new technology areas. On the contrary, in Period 3, the emergence of new technologies was decreased compared to the previous period while the exploitation significantly increased. This indicates that the focus of technology fusion has shifted to the utilization of existing technologies in Period 3.

Table 5. Technology fusion pattern.

Technology Fusion Pattern	Period 2	Period 3
Exploration (in the period t)	0.87	0.58
Exploitation (in the period t)	0.13	0.42

5. Discussion

The Korean PV industry has grown rapidly in the past two decades. This was clearly evidenced by the patent statistics whereby the technology development has been actively pursued in terms of the IPC codes being applied to patents. The concentration of central codes clearly increased during this period.

5.1. Network-Level Characteristics

Over all three periods, the density increased by a total of 62.5%, which indicates that more IPCs became interconnected with each other. The increased interconnections between technology areas are also confirmed by the inclusiveness measure, which increased from 0.754 in Period 1 to 0.993 in Period 3. Thus, in the last period, almost all technology areas are interconnected with each other.

However, the decrease in centralization across the three periods is interesting. While there were only a relatively small number of IPCs located at the center of the network in Period 1, the role of the central technology has become more evenly distributed to some other nodes in Periods 2 and 3. This shows the expansion and diversification of core technology roles in technology fusion phenomena.

As mentioned in Section 4, the networks of all periods have been identified as scale-free networks. This means that a few key technology areas account for most of the links. However, the degree exponent of the network decreased across the three study periods, which means that the imbalance of the distribution of links between nodes decreased. This observation can be verified based on the decrease in centralization over the three periods. The decreased degree exponents and centralization indicate that the core technology area role of technology fusion has become more expanded and diversified across the three periods.

5.2. Node-Level Characteristics

In Period 2, the exploratory pattern was the driving factor for technology fusion. At the sub-class level, four new technology areas emerged and entered the top 10 rankings. As shown in Table 6, “C08J-005,” “F21S-009,” “F24J-002,” and “H02J-007” were shown to have increased their degree centrality. These technologies are related to the manufacturing processes and systematic structure. This phenomenon is similar to the general process where product-driven innovation, such as devices, occurs first, and innovation in the system-level areas occurs over time.

Table 6. New core technology areas in Period 2.

Definition	Sub-Class	Main Group	World Intellectual Property Organization (WIPO) Definition (2017 Version)
New core technology area in the Period 2	C08J	005	Manufacture of articles or shaped materials containing macromolecular substances
	F21S	009	Lighting devices with a built-in power supply; systems employing lighting devices with a built-in power supply
	F24J	002	Use of solar heat, e.g., solar heat collectors
	H02J	007	Circuit arrangements for charging or depolarizing batteries or for supplying loads from batteries

On the other hand, in Period 3, exploratory and exploitation patterns for technology fusion were conducted evenly, with some extensions to the use of existing technologies being developed. As a result, two new sub-class level technologies became listed in the top ten. These sub-classes can be divided into “H02S” and “G01R”, as shown in Table 7.

Table 7. New core technology areas in Period 3.

Definition	Sub-Class	Main Group	WIPO Definition (2017 Version)
New technology area in Period 3	H02S	010	PV power plants; combinations of PV energy systems with other systems for the generation of electric power
		020	Supporting structures for PV modules
		030	Structural details of PV modules other than those related to light conversion
		040	Components or accessories in combination with PV modules, not provided for in groups
		050	Monitoring or testing of PV systems, e.g., load balancing or fault identification
	G01R	031	Arrangements for testing electric properties; arrangements for locating electric faults; arrangements for electrical testing characterized by what is being tested and not provided for elsewhere

The sub-class “H02S” is a technology area related to infrastructure configuration from a system perspective, and the main group “G01R-031” is a technology related to arrangements for testing. Throughout Period 3, new technologies emerged with respect to PV system structure and accessories, as well as monitoring and testing aspects.

In all periods, the “H01L-031” technology has the highest weighted degree centrality. The “H01L-051” technology has been also highly ranked; it has been ranked top 3 to 4. These technologies played a central role in technology fusion during the entire study period. They are essential technological devices in PV systems, which are used to operate the system and improve their energy efficiency. The detailed definition of the IPC codes is presented in Table 8.

Table 8. Definition of sustained core technologies.

Definition	Sub-Class	Main Group	WIPO Definition (2017 Version)
Sustained core technology areas during all periods	H01L	031	Semiconductor devices sensitive to infra-red radiation, light, electromagnetic radiation of shorter wavelength, or corpuscular radiation and specially adapted either for the conversion of the energy of such radiation into electrical energy or for the control of electrical energy by such radiation
		051	Solid state devices using organic materials as the active part, or using a combination of organic materials with other materials as the active part

6. Conclusions

This research conducted an IPC code co-occurrence network analysis of PV patents over a 15-year period to analyze the technology fusion in the PV industry. To do so, the KIPO database was used to extract patent data and network analysis was applied. The results of our study are as follows: the rate of technology fusion was shown to increase with different characteristics over time. While the strength of technology fusion has greatly increased during the period, the structural pattern of fusion has been diversified or decentralized. In Periods 1 and 2, technology fusion is attempted based on the exploration of new technology areas, showing the widespread emergence of new technologies. In Period 3, however, technology fusion is based on the exploitation of existing key technology areas, which implies that the focus of fusion shifted to the utilization of existing technologies.

In addition, our analysis identified key technology areas in fusion of the PV industry. The device-related technology, represented by sub-class “H01L,” is centrally located throughout the entire period, whereas the system-level technologies, represented by sub-class “H02S” and “G01R,” have progressed over time. In other words, core areas in technology fusion were expanded from the device-level technology areas into the module and system-level technology areas. This study is meaningful in that it presents an extensive empirical analysis of technology fusion characteristics in Korea’s photovoltaic industry across time and at the technology areas.

Although this study presents a comprehensive analysis of the technology fusion in the PV industry, it would be worthwhile to further expand the scope of the analysis. Thus, a comparative analysis of top leading countries in the PV industry would be a suitable future research topic. As our study focused on the analysis of past patent data, it has a limit in terms of predicting the progress of PV technologies. Therefore, another future research topic would be forecasting the technology fusion trends or trajectories by utilizing link prediction methods.

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