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Analysis of Korean Electric Vehicle Research Trends Using Patent Data: Focusing on Network Analysis

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Abstract As reducing greenhouse gas emissions and responding to climate change have emerged as important global tasks, electric vehicles (EVs) are becoming increasingly important. While research on EVs is expanding, studies that systematically analyze the structural characteristics of EV technologies and the interaction between research topics remain limited. This study aims to identify the structural characteristics and key technologies of the EV network by conducting a network analysis in South Korea from 2011 to 2022. Specifically, the study utilizes structural indicators such as network density, transitivity, mean distance, and network diameter. Additionally, network centrality indicators such as degree, betweenness and closeness centrality were used. Theoretically, this study is meaningful because various indicators used in network analysis are applied to the EV field. Practically, it is expected to guide the establishment of long-term investment and support strategies in key areas for Korean EV-related policy formulation and industrial strategy development.

Keywords electric vehicle, patents, network analysis, network structure, centrality

I. Introduction

In recent years, the world has witnessed an increase in extreme weather events such as heatwaves, heavy snowfall, typhoons, and wildfires due to global warming (Do & Kim, 2023; Korea Energy Economics Institute, 2022; National Oceanic and Atmospheric Administration, 2021; Tradowsky et al., 2023). In Western Europe, over 200 people lost their lives due to torrential rains and floods (Tradowsky et al., 2023), while the United States suffered significant damage from deadly heatwaves and wildfires (National Oceanic and Atmospheric Administration, 2021). South Korea is also faced with challenges from tropical nights and record-breaking heatwaves (The Chosun Ilbo, 2024).

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Greenhouse gas emissions have been recognized as a major cause of these abnormal climate phenomena (Korea Energy Economics Institute, 2022).

A representative example of these efforts is the promotion of eco-friendly vehicles (Do & Kim, 2023; Ministry of Foreign Affairs, 2024). As stated by the Seoul Institute(2017), Major countries, including South Korea, are implementing transportation policies that focus on promoting vehicles that emit fewer pollutants than the permissible standards set by environmental regulations, regardless of the type of fuel (gasoline, diesel, LPG or natural gas). Particularly, it is expected that converting internal combustion engine vehicles to eco-friendly vehicles will help reduce carbon emissions generated from petroleum-based fuels (Energy Economics Institute, 2022).

Electric vehicles (EVs), as a key example of eco-friendly transportation, are powered by high-voltage batteries that supply electric energy to motors to generate driving force (Do & Kim, 2023; Seoul Institute, 2017). EVs do not use fossil fuels while driving, which means they emit no carbon dioxide and make a significant contribution to reducing greenhouse gas emissions (Do & Kim, 2023). However, EVs face challenges such as high initial purchase costs and insufficient charging infrastructure (Kim, 2020; Ministry of Foreign Affairs, 2024). Moreover, with declining initial demand and difficulties in creating new demand, the EV market has entered a chasm phase (Do & Kim, 2023).

In this context, understanding the technological trends and network structures of EV technologies is essential for effectively promoting market growth and technological advancements. Research in the EV field is being conducted in various ways including quantitative analysis of patent data. For instance, Koo et al. (2023) predict promising component technologies using time-series analysis of patent data, while Im (2021) compared and analyzed patent trends for EV drive motors. Additionally, Kim (2020) conducted an in-depth analysis of patent trends in wireless charging technology. Do and Kim (2023) analyzed secondary battery trends using topic modeling, with a particular focus on solid-state batteries, highlighting key technological advancements in this field. While these studies contribute to the advancement of EV technology by providing an in-depth understanding of specific technologies, they are limited in their ability to comprehensively capture the structural characteristics of the overall EV technology network and the interactions between technologies.

To address these limitations, this study aims to comprehensively analyze the structural characteristics of the EV technology network and the interactions among technologies. By analyzing patent data from the past 12 years (2011-2022) in the EV field, this study aims to identify key research topics and technological interactions, providing practical contributions to future EV technology research and policy development.

This study is divided into five chapters. Chapter 2 examines the concept and structure of the International Patent Classification (IPC) codes. Chapter 3 outlines data collection, preprocessing, and the network analysis methodology employed in this study. Chapter 4 presents the research trends in the EV field identified through network analysis across different time periods. Finally, Chapter 5 concludes the study and discusses its implications based on the analysis results.

II. International Patent Classification codes

Patents are a valuable resource for identifying technological trends and are widely utilized by countries and organizations to evaluate the outcomes of R&D activities (Curran and Leker, 2011; Hong and Lee, 2020). When analyzing patent data, the IPC codes serve as an essential tool for systematically categorizing and interpreting technologies (Hwang and Song, 2022; World Intellectual Property Organization, 2022).

The IPC code is a standardized system introduced through international agreements to unify the patent classification systems that were previously used differently across countries, thereby enhancing the efficiency of technology exchange and patent literature research across nations (World Intellectual Property Organization, 2022). It was first established in the 1968 European Patent Convention, revised under the Strasbourg Agreement concerning the IPC in 1971, and officially came into effect in 1975. Subsequently, major countries such as the United States, the United Kingdom, and Japan joined the system (World Intellectual Property Organization, 2022), and South Korea officially adopted the IPC system in July 1981 and became a member of the Strasbourg Agreement in 1999 (Korean Intellectual Property Office, 2020).

The IPC code is periodically updated by the IPC Expert Committee, with new versions taking effect every January 1. Due to the rapid advancement of technology, older patent classification standards struggled to clearly classify emerging technologies. To address this issue, the IPC classification system was changed from a revision cycle of every 5 or 3 years to an ad-hoc revision system starting in 2009 (Korea Institute of Patent Technology Promotion, 2020). Through these revisions, certain IPC codes are deleted or merged to better reflect the latest technological developments.

The IPC code is organized hierarchically, as shown in Table 1, progressing from Section → Class → Subclass → Main Group → Subgroup. Sections are divided into eight fields, which are represented by the alphabetical symbols A to H, as shown in Table 2. The class is the second level of the IPC hierarchy, further subdividing sections. The subclass, the third level, is included within each class, with one or more subclasses. The main group, the fourth level, consists of a number on the left side of the slash (/) and “/00” on the right side.

The subgroup is the final level of the IPC code, representing a lower level within the main group, with numbers placed on both sides of the slash (/). As you move down the hierarchy, the technical details become more specific, allowing for easier identification of specific technology details and more efficient patent searches.

Table 1. IPC Code Hierarchy (Example)

<table>
<tr><th>Section</th><th>Class</th><th>Subclass</th><th>Main Group</th><th>Subgroup</th></tr>
<tr><td rowspan="4">B</td><td rowspan="4">60</td><td rowspan="4">L</td><td rowspan="3">001/00</td><td>001/02</td></tr>
<tr><td>001/14</td></tr>
<tr><td>⋮</td></tr>
<tr><td>⋮</td><td>⋮</td></tr>
<tr><td rowspan="4">Transportation</td><td rowspan="4">General Vehicles</td><td rowspan="4">Propulsion of electric vehicles. Supplying power for auxiliary devices of electric vehicles, general electric brake systems for vehicles, vehicle magnetic suspension or levitation, monitoring operational variables of electric vehicles, and electrical safety devices for electric vehicles.</td><td rowspan="3">Power supply for auxiliary devices of electric propulsion vehicles (vehicle signal or lighting devices), or their mounting, support, or general circuit arrangement.</td><td>Power Supply to Electric Heating Circuits</td></tr>
<tr><td>Power Supply to Lighting Circuits</td></tr>
<tr><td>⋮</td></tr>
<tr><td>⋮</td><td>⋮</td></tr>
</table>

Table 2. Description of Each Section in the International Patent Classification Codes

Section	Description
A	Human Necessities
B	Performing Operations; Transporting
C	Chemistry, Metallurgy
D	Textiles, Paper
E	Fixed Constructions
F	Mechanical Engineering, Lighting, Heating, Weapons
G	Physics
H	Electricity

Source: World Intellectual Property Organization (2022).

III. Data and Research Methodology

1. Data Collection and Preprocessing

Effective analysis of patent data requires systematically considering classification systems, countries, time periods, and patent statuses (application or registration) during the data collection process (Chae & Gim, 2018; Kim & Lee, 2020). This study collected patent data in the EV field and selected patents with the IPC code B60L (propulsion of EVs) for analysis.

Next, when specifying a particular country, previous studies have classified patents based on the applicant's nationality (Kim & Lee, 2020) or according to patents filed with the patent office of a specific country (World Intellectual Property Organization, 2022). However, this study focuses on understanding EV-related technologies in South Korea, rather than focusing on specific companies or individuals, so the data was extracted from the Korean Intellectual Property Office.

Additionally, considering the characteristics of the publication system, where patent applications are disclosed 18 months after filing, patents filed in 2023 or later were excluded from the analysis (United States Patent and Trademark Office, n.d.). Consequently, the study divided the data into three periods over a total of 12 years, from 2011 to 2022. Finally, it is important to decide whether to use application patents or registered patents, depending on the stage of the patent's progression. According to Yoon and Park (2004), application patents provide information on the early stages of technology development, which allows for a quicker understanding of technological trends. Therefore, this study selected application patents for analysis. In summary, this study analyzed application patents related to EV technologies, those with the IPC code B60L, filed with the Korean Intellectual Property Office from 2011 to 2022.

Patent data were extracted from WIPS (www.wipson.com) on July 30, 2024. A total of 10,172 patents were identified, and after excluding patents unrelated to the EV patents that matched only a single IPC code, they were also excluded from the analysis. As a result, 6,602 patents were ultimately selected for analysis. Additionally, the 8th edition of the IPC was used from January 1, 2006, to December 31, 2008, and the current 9th edition has been in use since January 1, 2009. This study was conducted based on the 9th edition of the IPC, which resulted in the deletion or merging of some IPC codes.

2. Co-word Network

As stated by Law & Whittaker (1992), a co-word network indicates that the higher the frequency with which two words appear together, the stronger the correlation between the related technological fields. Based on this, the study constructed a co-word network by using the IPC codes of patents as words

In the first step, the relationship between patents and IPC codes was established as a two-mode network. As shown in Figure 1, a two-mode network represents the relationships between two distinct types of entities, with connections only existing between different types of nodes (Kim and Choi, 2022).

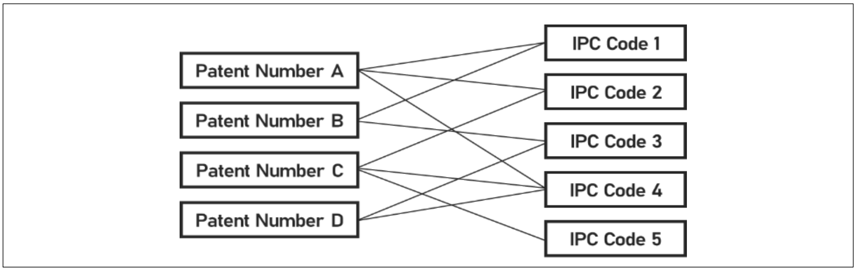

Figure 1. Concept of Two-Mode Network

Data validation was conducted in the two-mode network. Since this study has already extracted data based on subclasses, both main groups and subgroups can be considered as subjects for analysis. The main group level offers a more detailed classification of technologies than subclasses, while avoiding the excessive granularity of subgroups, thus providing an appropriate level for understanding interactions between technological fields (Gauch & Blind, 2015). According to Lee et al. (2019), the main group provides sufficient levels of detail to detect technological convergence and can serve as an appropriate unit for identifying redundancy and interactions between technologies. Therefore, this study used the main group as the unit of analysis.

To reduce complexity and emphasize significant relationships, a cutoff value was applied (Ding et al., 2001). The cutoff value was set to remove connections between IPC codes with frequencies below a certain threshold from the 6,602 patents analyzed. As a result of applying the cutoff value, 139 IPC codes, mentioned more than 10 times out of the total 615 IPC codes, were selected for analysis, as shown in Figure 2.

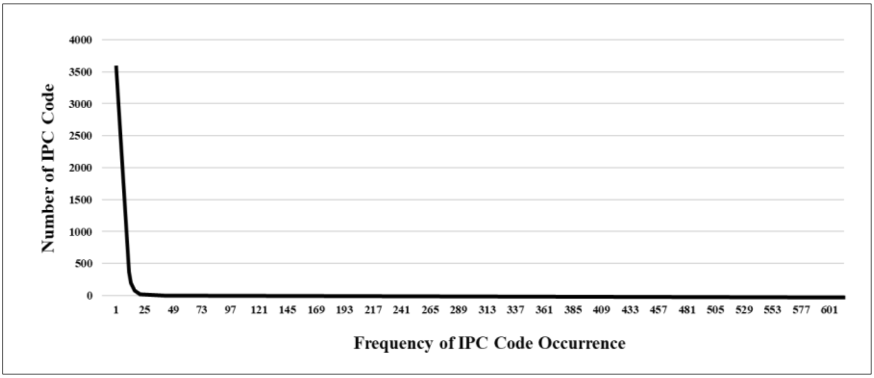

Figure 2. Frequency Distribution of IPC Codes

3. Network Structure Analysis

Network structure analysis quantitatively represents the overall characteristics of a graph and provides valuable insights into the structural features of the network. (Butts, 2010; Anderson et al., 1999). In this study, density, transitivity, mean distance, and diameter were used to examine the interactions and connections within the network (Freeman, 2002; Wasserman, 1994).

Density is an indicator that represents the degree of connection between nodes in a network, calculated by dividing the total number of links by the total number of possible links within the network (Anderson et al., 1999). A high network density indicates that there are many connections between nodes, suggesting that they are closely connected and that there is a high level of mutual assistance and interaction. Transitivity is an important attribute that considers triadic relationships within a network, referring to the pattern of relationships among three actors or three nodes in a graph. The average distance refers to the average of the connection distances between all pairs of nodes in the network, where the connection distance represents the length between two specific nodes and also indicates the number of steps. The diameter is the maximum number of connections (or steps) required for any node to reach another node in the entire network. For detailed formulas, refer to the literature (Wasserman, 1994).

4. Identification of Key Technologies in the Network

According to Freeman (2002), centrality is widely used to identify key technologies within a network; common measures of centrality are degree centrality, betweenness centrality, and closeness centrality.

Degree centrality is measured by the total number of edges connected to the subject node, which reflects the number of direct connections it has to neighboring nodes (Wasserman, 1994). It indicates how related the central node is to its surrounding nodes based on the number of adjacent nodes it is connected to. Connectivity can be defined as the number of links a node has. Degree centrality (C_D) can be calculated by summing the shortest distances (L_{ij}) between the central node (i) and its neighboring nodes (j). Betweenness centrality can be expressed by the following formula.

$$C_D(i) = \sum_{j}^{n} L_{ij}$$

Betweenness centrality is calculated by counting the number of shortest paths between two nodes that pass through the node of subject (Wasserman, 1994). In other words, it serves as an indicator of nodes that function as intermediaries. Betweenness centrality (C_B) is obtained by summing the number of paths passing through node (i) among the shortest paths (σ_{st}) from node (s) to node (t). Betweenness centrality can be expressed by the following formula.

$$C_B(i) = \sum_{j}^{n} \frac{\sigma_{st}(i)}{\sigma_{st}}, (s \neq t \neq i)$$

Closeness centrality measures how close a node of a subject is to all other nodes in the network. A node with high closeness centrality indicates that it has a short connection distance to other nodes, meaning it is structurally central in the text network (Wasserman, 1994). Closeness is defined as the inverse of distance. Therefore, closeness centrality can be calculated as the inverse of the sum of the shortest path lengths between the node and all other nodes. Closeness centrality (C_C) can be obtained by averaging the shortest path lengths (L_{ij}) from a reference node (i) to all other nodes (j), excluding itself (n-1), and then taking the inverse of that value. Closeness centrality can be expressed by the following formula.

$$C_C(i) = \frac{1}{\frac{1}{n-1}\sum_{i \neq j} L_{i,j}}$$

5. CONCOR(Convergence of Iterated Correlations) Analysis

CONCOR analysis is a method for analyzing relationship patterns among nodes in a network based on structural equivalence. Structural equivalence refers to the degree to which two nodes have identical relationships with other nodes in the same manner. Through CONCOR analysis, nodes exhibiting similar relationship patterns can be classified into the same cluster (Wasserman & Faust, 1994). CONCOR analysis is performed by repeatedly calculating correlations between nodes until the correlation values converge. Through this process, technologies with structurally similar patterns can be grouped, providing a clearer understanding of the role a particular technology plays within the network (Choi Cheol-min et al., 2022).

IV. Analysis Results

1. Network Structure Analysis

In this study, NetMiner, which is highly regarded for its user-friendliness and functionality among various software solutions , including Ucinet, Pajek, STRUCTURE, StOCNET, MultiNet, SIENA, and KrackPlot, was used for network structure analysis (Son & Kang, 2019; Kim & Choi, 2022). In the network structure analysis, the structural characteristics of the network were examined using the indicators presented in Chapter 3. These indicators represent specific characteristics of the network, but a benchmark is needed to evaluate them as ‘high’ or ‘low’.

In this study, the Markov Chain Monte Carlo (MCMC) method was used to evaluate the relative magnitude of the indicator values by comparing them with networks generated through multiple simulations (10,000 iterations in this study) (Wasserman, 1994). This method is widely used in social network analysis and is very useful for determining the statistical significance of a network (Kim & Lee, 2020; Wasserman, 1994). However, for density, since the same nodes and links have the same characteristics, MCMC was not applied for its analysis.

In the case of density, there was a tendency for it to decrease from period 1 to period 2, and then increase again from period 2 to period 3. This indicates that, as the study progressed from period 1 to period 2, the tight connections between research topics weakened, but starting from period 3, the connections between research topics were strengthened once again. Transitivity is greater than the expected value in all periods from period 1 to period 3. This indicates low transitivity, suggesting that the network is loosely connected, with relatively weak relationships between specific nodes or the need for intermediary nodes. In the case of average distance, it can be observed that the measured value is greater than the expected value in period 3 compared to periods 1 and 2. This indicates that the average distance has increased over time, suggesting that the network is becoming more dispersed and that the accessibility between IPC codes is lower. In period 1, the expected value of the network diameter was large, but in period 3, the measured value was larger. This indicates that the shortest path length between the two most distant nodes in the network has increased.

Table 3. Network structural characteristic measurement indicators

Category		Measured value(Obs)	Expected value(Exp)	P(Obs<Exp)	P(Obs=Exp)	P(Obs>Exp)
Density	Period 1	0.055	0.055	0	1	0
	Period 2	0.047	0.047	0	1	0
	Period 3	0.059	0.059	0	1	0
Transitivity	Period 1	0.171	0.192	0.989	0	0.011
	Period 2	0.101	0.122	1	0	0
	Period 3	0.144	0.157	1	0	0
Mean distance	Period 1	2.326	2.308	0.116	0.013	0.871
	Period 2	2.161	2.145	0.175	0	0.825
	Period 3	2.054	2.032	0	0	1
Diameter	Period 1	4	4.544	0.544	0.456	0
	Period 2	4	4	0	1	0
	Period 3	4	3.445	0	0.445	0.555

2. Centrality Analysis

The study examined degree centrality, betweenness centrality, and closeness centrality for top IPC codes in each period. All three centralities are meaningful not as absolute values, but through relative comparisons between the values to derive rankings. Therefore, in this study, rankings were made based on the 74 IPC codes that appeared across all three periods, and further analysis was conducted on the top 10 IPC codes. In addition, refer to Appendix 1 for the definitions of all IPC codes.

2.1 Degree Centrality

In this study, we extracted IPC codes with high Degree Centrality and compared and analyzed their rank changes. First, the top IPC codes and their Degree Centrality values for each period were analyzed as shown in Table 4. In Period 1, ‘B60L-011 (power supply for auxiliary devices of electric propulsion vehicles),’ ‘H02J-007 (circuit devices for charging or discharging storage batteries or for supplying power to loads from storage batteries),’ and ‘B60L-005 (current collectors for electric propulsion vehicles)’ were identified as having the highest degree centrality. In Period 2, the highest Degree Centrality was in the order of ‘B60L-011 (power supply for auxiliary devices of electric propulsion vehicles),' 'B60L-050 (electric propulsion devices with power supply sources inside vehicles),' and 'B60L-003 (electrical devices for safety purposes in electric propulsion vehicles)'. In Period 3, the highest Degree Centrality was in the order of 'B60L-053 (battery charging methods),' 'B60L-058 (methods or circuit devices for monitoring or controlling batteries or fuel cells suitable for EVs),' and 'B60L-003 (electrical devices for safety purposes in electric propulsion vehicles)'.

Additionally, the rank changes of the IPC codes that appeared during all periods were analyzed as shown in Table 5. 'B60L-050 (electric propulsion devices with power supply sources inside vehicles)' was ranked 20th in Period 1, but it rose to 2nd and 4th in Periods 2 and 3, respectively, indicating an increase in the importance of patents in this field. On the other hand, 'H02J-007 (circuit devices for charging or discharging storage batteries or for supplying power to loads from storage batteries)' was ranked 2nd in Period 1, but dropped to 12th in Period 3, indicating a decrease in the relative importance of this patent.

Table 4. Extracted IPC Codes by Period

Rank	Period 1		Period 2		Period 3	
	IPC Code	Degree Centrality	IPC Code	Degree Centrality	IPC Code	Degree Centrality
1	B60L-011	14.03659	B60L-011	15.17094	B60L-053	24.07576
2	H02J-007	5.670732	B60L-050	7.136752	B60L-058	15.73485
3	B60L-005	2.060976	B60L-003	5.213675	B60L-003	11.75758
4	B60L-015	1.95122	B60L-015	4.512821	B60L-050	11.67424
5	B60L-007	1.439024	H01M-010	3.247863	B60L-015	5.469697
6	H02J-017	1.280488	H02J-007	3.025641	B60L-007	2.674242
7	B60L-003	1.195122	B60L-007	2.615385	G01R-031	2.431818
8	B60L-013	0.902439	B60W-010	1.564103	H02J-050	2.340909
9	H01M-008	0.829268	B60L-008	1.358974	B60L-008	2.045455
10	B60W-010	0.817073	H01M-008	1.299145	H01M-010	1.886364

Table 5. Ranking Changes of IPC Codes Appearing in All Periods Rank

IPC Code	Rank in Period 1	Rank in Period 2	Rank in Period 3
B60L-003	7	3	3
B60L-015	4	4	5
B60L-007	5	7	6
H02J-007	2	6	12
B60L-050	20	2	4
H01M-010	15	5	10
H01M-008	9	10	11
B60L-008	13	9	9
B60L-005	3	20	13
G01R-031	21	11	7

2.2 Betweenness Centrality

We extracted IPC codes with high betweenness centrality, compared them by period, and analyzed the changes in IPC codes that play a role in connecting and mediating technologies within the network. First, the top 10 IPC codes with the highest betweenness centrality for each period were selected as shown in Table 6. In Period 1, the IPC codes with the highest betweenness centrality were 'B60L-011 (power supply for auxiliary devices of electric propulsion vehicles),' 'B60L-015 (methods, circuits, or devices for controlling propulsion of electric propulsion vehicles),' and 'B60L-003 (electrical devices for safety purposes in electric propulsion vehicles)'. In Period 2, the IPC codes with the highest betweenness centrality were in the order of 'B60L-011 (power supply for auxiliary devices of electric propulsion vehicles),' 'B60L-050 (electric propulsion devices with power supply sources inside vehicles),' and 'B60L-015 (methods, circuits, or devices for controlling propulsion of electric propulsion vehicles)'. In Period 3, the IPC codes with the highest betweenness centrality were in the order of 'B60L-053 (battery charging methods),' 'B60L-050 (electric propulsion devices with power supply sources inside vehicles),' and 'B60L-015 (methods, circuits, or devices for controlling propulsion of electric propulsion vehicles)'.

Additionally, the rank changes of the IPC codes that appeared across all periods were analyzed as shown in Table 7. 'B60L-015 (methods, circuits, or devices for controlling propulsion of electric propulsion vehicles)' maintained a rank within the top 3 in all periods, confirming that it consistently had a high influence within the network. On the other hand, 'B60L-013 (electric propulsion devices for monorail vehicles, vehicle lifting vehicles, and rack railways)' was ranked 5th and 4th in Periods 1 and 2, respectively, placing it in the top ranks.

However, in Period 3, it dropped to 11th, indicating a decrease in the relative importance of this IPC code.

Table 6. Extracted IPC Codes by Period

Rank	Period 1		Period 2		Period 3	
	IPC Code	Betweenness Centrality	IPC Code	Betweenness Centrality	IPC Code	Betweenness Centrality
1	B60L-011	0.667867	B60L-011	0.448537	B60L-053	0.366856
2	B60L-015	0.133682	B60L-050	0.25587	B60L-050	0.274993
3	B60L-003	0.104844	B60L-015	0.21621	B60L-015	0.110847
4	B60L-007	0.085613	B60L-013	0.072459	B60L-058	0.100695
5	B60L-013	0.082301	B60L-003	0.066341	B60L-003	0.082906
6	B60L-009	0.074454	B60L-008	0.053767	B60L-008	0.064131
7	B60L-005	0.063782	B60L-007	0.047357	B60L-007	0.033709
8	B60L-008	0.049275	B60L-005	0.011759	B60L-011	0.011
9	G06Q-050	0.049014	B60L-009	0.004622	B60L-001	0.009168
10	B60L-053	0.02439	B60L-001	0.001204	B60L-005	0.008737

Table 7. Ranking Changes of IPC Codes Appearing in All Periods Rank

IPC Code	Rank in Period 1	Rank in Period 2	Rank in Period 3
B60L-015	2	3	3
B60L-011	1	1	8
B60L-003	3	5	5
B60L-050	12	2	2
B60L-007	4	7	7
B60L-008	8	6	6
B60L-013	5	4	11
B60L-005	7	8	10
B60L-009	6	9	12
B60L-001	13	10	9

2.3 Closeness Centrality

We extracted IPC codes with high closeness centrality to analyze how close specific IPC codes are to other codes within the network, that is, how efficiently they can transmit information across the entire network. First, the top 10 IPC codes with the highest closeness centrality for each period were selected, as shown in Table 8. In Period 1, the IPC codes with the highest closeness centrality were in the order of 'B60L-011 (power supply for auxiliary devices of electric propulsion vehicles),' 'B60L-003 (methods or circuit devices for monitoring or controlling batteries or fuel cells suitable for EVs),' and 'B60L-009 (electric propulsion devices for supplying power from outside the vehicle)'. In Period 2, the IPC codes with the highest closeness centrality were in the order of 'B60L-011 (power supply for auxiliary devices of electric propulsion vehicles,' 'B60L-050 (electric propulsion devices with power supply sources inside vehicles),' and 'B60L-015 (methods, circuits, or devices for controlling propulsion of electric propulsion vehicles)'. In Period 3, the IPC codes with the highest closeness centrality were in the order of 'B60L-053 (battery charging methods),' 'B60L-050 (electric propulsion devices with power supply sources inside vehicles)', and 'B60L-058 (methods or circuit devices for monitoring or controlling batteries or fuel cells suitable for EVs)'.

Additionally, the rank changes of the IPC codes that appeared across all periods were analyzed as shown in Table 9. 'B60L-003 (electrical devices for safety purposes in electric propulsion vehicles)' ranked 2nd, 4th, and 4th in each period, confirming that it consistently had a high level of influence. On the other hand, 'B60L-009 (electric propulsion devices for supplying power from outside the vehicle)' was ranked 3rd and 8th in Periods 1 and 2, respectively, but dropped significantly to 17th in Period 3.

Table 8. Extracted IPC Codes by Period

Rank	Period 1		Period 2		Period 3	
	IPC Code	Closeness Centrality	IPC Code	Closeness Centrality	IPC Code	Closeness Centrality
1	B60L-011	0.773585	B60L-011	0.795918	B60L-053	0.840764
2	B60L-003	0.577465	B60L-050	0.672414	B60L-050	0.8
3	B60L-009	0.554054	B60L-015	0.657303	B60L-058	0.676923
4	B60L-007	0.546667	B60L-003	0.6	B60L-003	0.653465
5	B60L-015	0.535948	B60L-007	0.565217	B60L-015	0.637681
6	B60L-005	0.535948	B60L-008	0.536697	B60L-008	0.571429
7	H02J-007	0.522293	B60L-005	0.529412	B60L-007	0.564103
8	B60L-001	0.509317	B60L-009	0.517699	B60L-001	0.55
9	B60L-013	0.49697	B60L-013	0.513158	B60L-005	0.538776
10	G01R-031	0.493976	H02J-007	0.506494	H02J-007	0.519685

Table 9. Ranking Changes of IPC Codes Appearing in All Periods Rank

IPC Code	Rank in Period 1	Rank in Period 2	Rank in Period 3
B60L-003	2	4	4
B60L-015	5	3	5
B60L-007	4	5	7

B60L-005	5	7	9
H02J-007	7	10	10
B60L-009	3	8	17
B60L-013	9	9	11
B60L-001	8	15	8
B60L-008	23	6	6
B60W-010	12	12	11

3. CONCOR Analysis

As a result of the CONCOR analysis, electric vehicle-related IPC codes with similar characteristics were classified into five clusters, as shown in Figure 1.

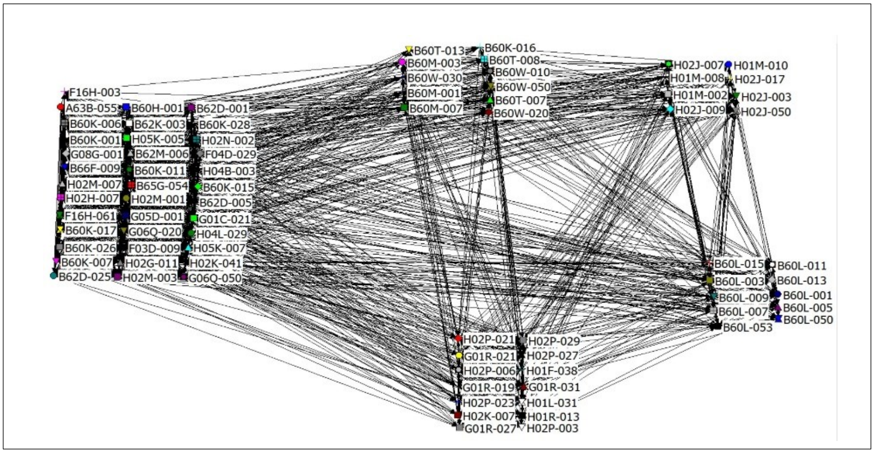

Figure 3. CONCOR Analysis Results

The first cluster, located in the upper left, consists of ‘G08G-001 (Traffic Control Systems),’ ‘G05D-001 (Automatic Control),’ ‘H02H-007 (Emergency Protection Circuit Devices),’ ‘H02M-001 (Power Conversion Devices),’ and ‘H04B-003 (Wired Transmission Systems). This cluster includes smart mobility and power conversion technologies through the convergence of electric vehicle and IoT technologies, with a focus on research related to the development of autonomous driving, smart transportation systems, and energy conversion technologies for electric vehicles

The second cluster is located at the top center and consists of ‘B60M-001 (Power Supply Devices),’ ‘B60M-007 (Power Supply Lines for Electrically Propelled Vehicles of Special Forms),’ ‘B60T-007 (Vehicle Brake Control

Devices),' 'B60T-008 (Brake Force Adjustment Devices),' and 'B60W-020 (Control Systems).' This cluster includes the development of electric vehicle charging infrastructure, communication technologies between vehicles and charging systems, as well as intensive research on the optimization of electric vehicle charging technologies and battery management systems.

The third cluster is located at the bottom center and consists of 'G01R-031 (Devices for Testing Electrical Properties),' 'H02K-007 (Devices for Handling Mechanical Energy),' 'H02K-041 (Drive Devices),' 'H02P-003 (Reduction Devices),' and 'H02P-027 (Control Devices).' This cluster includes technologies related to the power conversion and control systems of electric vehicles, optimization of drive devices, and focuses on research in power flow control, drive device optimization, and power conversion technologies aimed at improving power efficiency.

The fourth cluster is located at the top right and consists of 'H01M-010 (Secondary Batteries),' 'H02J-003 (Circuit Devices for AC Distribution Networks),' 'H02J-007 (Circuit Devices for Power Supply),' 'H02J-009 (Circuit Devices for Emergency Power Supply),' and 'H02J-050 (Power Distribution Systems).' This cluster includes technologies related to the extension of electric vehicle driving range, improvement of charging efficiency, and optimization of energy management, with a focus on research into maximizing battery efficiency, improving charging speed, and optimizing power distribution.

The fifth cluster is located at the center-right and consists of 'B60L-003 (Electrical Devices for Safety Purposes),' 'B60L-009 (Electrical Propulsion Devices Supplying Power from External Sources to Vehicles),' 'B60L-011 (Power Supply to Auxiliary Devices of Electric Propulsion Vehicles),' 'B60L-050 (Electrical Propulsion Devices with Power Supply Sources Inside the Vehicle),' and 'B60L-053 (Battery Charging Methods).' This cluster includes technologies related to electric vehicle power supply systems, power conversion devices, and propulsion, with research focusing on improving the efficiency of electric vehicle power systems, optimizing battery charging, and developing power conversion devices.

Table 10. Key IPC Codes by Cluster

Cluster 1	A63B-055, B60H-001, B60K-001, B60K-006, B60K-007, B60K-011, B60K-015, B60K-017, B60K-026, B60K-028, B62D-001, B62D-005, B62D-025, B62K-003, B62M-006, B65G-054, B66F-009, F03D-009, F04D-029, F16H-003, F16H-061, G01C-021, G05D-001, G06Q-020, G06Q-050, G08G-001, H02G-011, H02H-007, H02K-041, H02M-001, H02M-003, H02M-007, H02N-002, H04B-003, H04L-029, H05K-005, H05K-007
Cluster 2	B60K-016, B60M-001, B60M-003, B60M-007, B60T-007, B60T-008, B60T-013, B60W-010, B60W-020, B60W-030, B60W-050
Cluster 3	G01R-019, G01R-021, G01R-027, G01R-031, H01F-038, H01L-031, H01R-013, H02K-007, H02K-041, H02P-003, H02P-006, H02P-021, H02P-023, H02P-027, H02P-029
Cluster 4	H01M-002, H01M-008, H01M-010, H02J-003, H02J-007, H02J-009, H02J-017, H02J-050
Cluster 5	B60L-001, B60L-003, B60L-005, B60L-007, B60L-009, B60L-011, B60L-013, B60L-015, B60L-050, B60L-053

V. Conclusion

1. Summary of Findings

1.1 Network Structure

This study aims to analyze patent data in the EV field filed in Korea from 2011 to 2022, to understand the structural characteristics of the network and the trends in research and development, and to provide implications for future research and policy formulation. To achieve this, network analysis was conducted on EV patents using WIPS. The results are as follows.

First, the network density decreased from Period 1 to Period 2, which indicates that during Period 2, technologies (IPC codes) became more diversified or distributed, leading to weaker connections between them. On the other hand, the density increased again in Period 3, suggesting that there may have been active collaboration or integration between technologies, or that connections concentrated around specific themes. Second, transitivity was higher than the expected value in all periods. This suggests that the triangular relationships between nodes are fewer than in a random network, implying that some technologies are not directly connected. Additionally, the results indicate that the technology network is becoming more decentralized. Third, the average distance shows that the measured value is increasing compared to the expected value over time. This indicates that accessibility between IPC codes is weakening, and interactions between technologies are becoming relatively more complex. Finally, the measured value of the network diameter is getting larger than the expected value over time. This suggests that the technology network is becoming more decentralized, and connections are more frequently made through indirect paths rather than direct links between specific technologies.

1.2 Key Technologies

From the perspective of key technologies, the degree centrality analysis revealed that in Period 1, 'B60L-011 (power supply for auxiliary devices of electric propulsion vehicles)' was identified as a central technology. However, in Period 3, new technologies such as 'B60L-053 (battery charging methods)' emerged as central. This indicates that the focus of EV-related technologies has shifted from vehicle propulsion and safety to charging efficiency and infrastructure improvements.

B60L-050 (electric propulsion device with onboard power source), which experienced a rapid rise in betweenness centrality rankings, emerged as a pivotal technology that fosters collaboration and convergence among technologies. Its central role persisted through Period 3. In contrast, 'B60L-009 (electric propulsion devices for supplying power from outside the vehicle)' saw a decline in centrality over time, indicating a decrease in the relative importance of this technology. Additionally, the closeness centrality analysis showed that 'B60L-003 (electrical devices for safety purposes in electric propulsion vehicles)' consistently ranked 2nd, 4th, and 4th across periods, maintaining a high level of influence throughout.

2. Implications

Implications of this study highlight several key aspects of technological development and strategic priorities in the EV sector. First, the development of technologies in the EV sector initially focused on vehicle propulsion and safety, but over time, the technological priorities have shifted towards charging efficiency and infrastructure improvements. This suggests that when formulating technology development strategies, it is important to adjust the direction of technological innovation according to new technological demands as the initial core technologies reach maturity (Curran & Leker, 2011; Gauch & Blind, 2015; Kim & Lee, 2020). B60L-053 (battery charging methods) is anticipated to serve as a cornerstone for future EV research and development, necessitating policy support and long-term investment plans.

Second, structural network analysis revealed that connectivity among EV technologies has been strengthening over time, fostering research collaboration and technological convergence. This indicates the need for research strategies that go beyond individual technology-centered studies and promote multi-dimensional technological convergence (Gauch & Blind, 2015; Lee et al., 2019). Technologies that enhance user convenience and sustainability, such as charging infrastructure, battery lifespan, and charging speed, will emerge as key factors in determining the competitiveness of the EV market in the future (Kim, 2020).

3. Limitations

This study has the following limitations. First, since the analysis was conducted on domestic patent filings, it does not include foreign patents, which limits the discussion to domestic research. Future studies that incorporate foreign research trends for comparison with domestic trends would be a meaningful attempt. Second, this study focused on quantitative analysis and did not include qualitative analysis. Future research should combine both quantitative and qualitative analyses to more deeply examine the impact of EV patents on industry and policy. This approach could enhance the practical applicability of the research results.

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Appendix 1. Key International Patent Classification codes and their descriptions

IPC Code	Description
B60L-001	Supplying electric power to the auxiliary equipment of electrically-propelled vehicles
B60L-003	Electrical devices for safety purposes in electric propulsion vehicles
B60L-005	Current collectors for electric propulsion vehicles
B60L-007	Electrodynamic brake systems for vehicles in general
B60L-008	Electric propulsion with power supply from forces of nature
B60L-009	Electric propulsion devices for supplying power from outside the vehicle
B60L-011	Power supply for auxiliary devices of electric propulsion vehicles
B60L-013	Electric propulsion devices for monorail vehicles, vehicle lifting vehicles, and rack railways
B60L-015	Methods, circuits, or devices for controlling propulsion of electric propulsion vehicles
B60L-050	Electric propulsion devices with power supply sources inside vehicles
B60L-053	Battery charging methods
B60L-058	Methods or circuit devices for monitoring or controlling batteries or fuel cells suitable for EVs
B60W-010	Conjoint control of vehicle sub-units of different types or different functions
G01R-031	Arrangements for testing electric properties
G06Q-050	Information and communication technology [ICT] specially adapted for the implementation of business processes of specific business sectors
H02J-007	Circuit devices for charging or discharging storage batteries or for supplying power to loads from storage batteries
H02J-017	Circuit arrangements or systems for supplying or distributing electric power by means of electromagnetic waves
H02J-050	Circuit arrangements or systems for wireless supply or distribution of electric power
H01M-008	Fuel cells
H01M-010	Secondary cells

References

Anderson, B.S., Butts, C., and Carley, K. (1999). The Interaction of Size and Density with Graph-Level Indices, Social Networks, 21, 239-267.

Butts, C.T. (2010). Tools for Social Network Analysis, R Package Version 2.

Chae, S.H., & Gim, J. (2018). A Study of CPC-based Technology Classification Analysis Model of Patents. The Journal of the Korea Contents Association, 18(10), 443-452.

Choi, C.M., Lee, J.H, Machado, J., and Kim, G.W. (2022). Big-Data-Based Text Mining and Social Network Analysis of Landscape Response to Future Environmental Change, Land, 11(12), 2183.

Curran, S., and Leker, J. (2011). Patent indicators for monitoring convergence – Examples from NFF and ICT, Technological Forecasting and Social Change, 78(2), 256-273.

Ding, Y., Chowdhury, G.G., and Foo, S. (2001). Bibliometric Cartography of Information Retrieval Research by Using Co-Word Analysis, Information Processing & Management, 37, 817-842.

Do, C., & Kim, Y.J. (2023). Analysis of Secondary Battery Trends Using Topic Modeling: Focusing on Solid-State Batteries. Asian Journal of Innovation and Policy, 12, 345-362.

Freeman, L.C. (2002). Centrality in Social Networks: Conceptual Clarification, Social Network: Critical Concepts in Sociology, 1, 238-263. London: Routledge.

Gauch, S., and Blind, K. (2015). Technological Convergence and the Absorptive Capacity of Standardization, Technological Forecasting and Social Change, 91, 236-249.

Hong, H.J., and Lee, J.H. (2020). A Study on the Development of National R&D Patent Performance Evaluation Indicators and Evaluation Models, Journal of the Korea Convergence Society, 11(4), 1-9

Hwang, I.B., and Song, S.H. (2022). The study for logistics technology trends by the method of patent network analysis and Word2Vec, Journal of the Korea Academia-Industrial cooperation Society, 11(4), 1-9

Im, Y.-H. (2021). Patent trend analysis of traction motor for electric vehicles. Journal of Korean Institute of Electrical Engineers, 70(11), 16-21.

Kim, B.-N. (2020). Trend of patent for EV wireless charging technology. Auto Journal, 2020(12), 66-70.

Kim, Y.J., and Choi, H.C. (2022). A Case Study on the Impact of Organizational Restructuring on Technology Collaboration Structures: Focusing on Research Group A at Korea Research Institute of Chemical Technology, Journal of Technology Innovation Society, 25, 83-100.

Kim, Y.J., and Lee, D.H. (2020). Technology Convergence Networks for Flexible Display Application: A Comparative Analysis of Latecomers and Leaders, Japan and the World Economy, 55, 101025.

Koo, M., Hwang, H., & Jeon, J. (2023). Analysis of patent trends of electric vehicle in Korea using network analysis. J. Korea Acad.-Ind. Coop. Soc, 24(3), 13-23.

Korea Energy Economics Institute (2022). Global Trends in Eco-Friendly Vehicle Adoption and Policy Implications from Major Environmental Regulations.
Korea Institute of Patent Technology Promotion. (2020). Overview of IPC Revision System Changes. Retrieved from https://plus.kipris.or.kr/portal/bbs/view.do?bbsId=B0000006&delCode=0&menuNo=200021&nttId=29&pageIndex=2
Korean Intellectual Property Office. (2020). 2020 Annual Report. Retrieved from https://kipo.go.kr/en/HtmlApp?c=60114&catmenu=ek07_01_01_20
Law, J., and Whittaker, J. (1992). Mapping Acidification Research: A Test of the Co-Word Method, Scientometrics, 23, 417-461.
Lee, C., Kogler, D.F., and Lee, D. (2019). Capturing Information on Technology Convergence, International Collaboration, and Knowledge Flow from Patent Documents: A Case of Information and Communication Technology, Information Processing & Management, 56, 1576-1591.
Ministry of Foreign Affairs (2024). Economic Security Review 24-15, Key Trends in Electric Vehicle Policies in Major Countries, EU Commission Policy Guidelines, and African Critical Minerals Development.
National Oceanic and Atmospheric Administration. (2021, July 20). U.S. West hit with extreme heat, drought and unrelenting wildfires in July. Retrieved from https://www.noaa.gov/news/us-west-hit-with-extreme-heat-drought-and-unrelenting-wildfires-in-july
Seoul Institute. (2017). Recent Trend of Environmentally Friendly Vehicles and Seoul Policy Directions. Retrieved from https://global.si.re.kr/content/recent-trend-environmentally-friendly-vehicles-and-seoul-policy-directions
Son, Y., and Kang, H.S. (2019). A Text Mining Analysis of HPV Vaccination Research Trends, Child Health Nursing Research, 25, 458-467.
The Chosun Ilbo. (2024, August 26). South Korea breaks heatwave records with 14.8 days of extreme heat in August. Retrieved from https://www.chosun.com/english/nationalen/2024/08/26/43C4KVPZOFCNVIJRYVGB56IVAQ/
Tradowsky, J. S., Philip, S. Y., Kreienkamp, F., Kew, S. F., Lorenz, P., Arrighi, J., ... & Wanders, N. (2023). Attribution of the heavy rainfall events leading to severe flooding in Western Europe during July 2021. Climatic Change, 176(7), 90.
United States Patent and Trademark Office. (n.d.). Eighteen-Month Publication of Patent Applications. Retrieved from https://www.uspto.gov/web/offices/pac/mpep/s1120.html
Wasserman, S. (1994). Social Network Analysis: Methods and Applications, The Press Syndicate of the University of Cambridge.
Wasserman, S. and Faust, K. (1994), Social Network Analysis : Methods and Applications, Cambridge University Press
WIPS. (n.d.). Worldwide Intellectual Property Search. Retrieved from https://www.wipson.com
World Intellectual Property Organization. (2022). International Patent Classification (IPC) (WIPO Publication No. RN2022/7). Retrieved from https://www.wipo.int/edocs/pubdocs/en/wipo-rn2022-7-en-international-patent-classification-ipc.pdf
Yoon, B., & Park, Y. (2004). A text-mining-based patent network: Analytical tool for high-technology trend. Journal of High Technology Management Research, 15(1), 37–50.