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Study on the Measurement of Technological Diversity on the Subject of Green Transformation Technologies

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Abstract

There is an initiative called GX (Green Transformation) started by the Japanese government against the climate change problem. The Japanese Patent Office has released the GXTI (Green Transformation Technologies Inventory), a technology classification for technologies related to GX. In this paper, trends in the number of patent applications for the Top 5 technologies related to GXTI were analyzed. In addition, the technology diversity of the Top 5 was analyzed. For diversity analysis, taxonomic indices applying the concept of biodiversity were discussed. As a result of introducing this index, it has become possible to grasp the ratio of research and development according to the level of technological integration.

Keywords: Diversity index, Green Transformation, Patent analysis

1 Introduction

In recent years, various weather disasters have occurred not only overseas but also in Japan. It has been pointed out that each weather disaster is related to recent climate change, but the information is not reliable. However, it is clear that climate change is occurring, and there is a demand to prevent its impact. Therefore, there is a growing movement around the world to reduce greenhouse gases, which are the cause of climate change.

In October 2020, the Japanese government declared that by 2050, it would aim to "reduce total emissions of greenhouse gases to zero" and become carbon neutral. In this declaration, "greenhouse gases" include not only CO2, but also methane, N2O (dinitrogen monoxide), and CFCs. “Total emissions to zero” means “to zero the sum of emissions minus absorption and removal”. Currently, there is no prospect of reducing the emission of "greenhouse gases" to zero. Therefore, the governments of various countries, including Japan, aim to reduce "greenhouse gases" to zero by "absorbing" or "removing" the same amount as emissions. This net zero is defined as “carbon neutral”. In other words, it can be said that there are two directions for achieving “carbon neutral”. The first direction is to reduce greenhouse gas emissions. The second direction is to enhance the "absorption" or "removal" of greenhouse gases.

International frameworks on climate change issues include the Paris Agreement. This agreement is the successor to the 1997 Kyoto Protocol. This agreement was adopted in 2015. This agreement includes several agreements as global long-term goals to solve the global problem of climate change.

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For example:

- Make efforts to limit the increase in global average temperature to less than 2°C and 1.5°C above pre-industrial levels.
- Achieve a balance between greenhouse gas emissions by anthropogenic sources and removals by sinks in the second half of this century.

More than 120 countries and territories around the world have set goals to become carbon neutral by 2050.

In response to such climate change issues, the Japanese government has started an initiative called GX (Green Transformation). The Japanese government defines GX (Green Transformation) as ``transformation of the entire economic and social system by shifting the fossil fuel-centered economy and society since the industrial revolution, and the industrial structure to the clean energy-centered structure". As part of these efforts, the Japanese government has decided on a "basic policy for the realization of GX" in 2023. This GX initiative will be a major shift in industrial and energy policies. On the other hand, there are many problems that must be solved in order to realize this great transformation. That said, some of GX's efforts didn't spring out of the blue and have been going on for years. Therefore, research and development of GX-related technologies may have already begun.

In June 2022, the Japanese Patent Office released the GXTI (Green Transformation Technologies Inventory) technology category for technologies related to GX. In this GXTI, the Japan Patent Office also published patent search formulas for searching patent documents included in each category. As a result of preparing patent search formulas for each category, users searching for patents can now obtain results regardless of their skill. Furthermore, the Japan Patent Office has also begun to publish statistical information for each category. In the interim results of a statistical survey based on GXTI published in January 2023, the JPO has disclosed the number of patent applications filed from 2010 to 2021. In the report, the GXTI fields with the highest number of applications are as follows.

Table 1: GXTI TOP5 technologies

#	Code	Level 1	Level 2
1	gxB01	Energy Saving, Electrification, Demand-Supply Flexibility	Energy Saving in Buildings (ZEB, ZEH, etc.)
2	gxC01	Batteries, Energy Storage	Secondary Batteries
3	gxB05	Energy Saving, Electrification, Demand-Supply Flexibility	Electromobilities
4	gxA01	Energy Supply	Solar Photovoltaic Power Generation
5	gxA09	Energy Supply	Fuel Cells

What are the realities of these GXTI technologies? This paper quantitatively elucidates these actual conditions from the viewpoint of application trends, diversity, etc. for GXTI's TOP5 technologies.

2 Previous Research on the Effectiveness of Patent Data

Regarding corporate R&D activities and patent data, it has been reported that in almost all industries in Japan, when R&D expenses rise, the number of patent applications also tends to increase. There are also results that support the credibility of the evaluation of research and development activities and results based on research (Kondo 1999) [1]. In addition, using samples of 272 companies in 35 industries for more than 19 years, we analyzed the relationship between R&D investment costs, the number of patents, and the number of new products, and found that there is a correlation between R&D investment costs and the number of patents, and the number of patents and the number of new products. (Artz 2010) [2]. Kodama (1986) used an input-output table to visualize technological trends in patent applications filed by companies, and used econometric analysis to clarify the relationship between the content of patent applications and R&D costs. It reports on the mechanism of research and development diversification [3].

Research has also been carried out on specific companies that delves deeper into the relationship between the number of patent data and technology classifications and the company's technology strategies. Tsuji (2002) and Suzuki (2004) analyze Canon's patent application technology classification and application dates, and focus on the company's establishment of a patent-centered research and development organization and the implementation of management strategies. [4] [5]. In addition, Bergek and Berggren (2004) compare the number of patent applications filed by global heavy electric companies GE and ABB over the past 15 years based on their bases in each country, and explain the differences in their international R&D strategies. However, unexpectedly, ABB has been more active in international intellectual property strategy than GE, and reports that it has achieved results evenly across regions [6].

There are also research attempts to clarify technological trends in specific technical fields and clarify the advancedness and direction of corporate research and development in those fields. Pilkington and Dyerson (2006) do not focus on the R&D activities and results of specific companies, but clarify the actual state of R&D by companies within specific technical fields [7]. This paper analyzes application data in the field of electric vehicles, and shows the content and number of patents granted by major R&D players (companies) in the technology. As a result, it is clarified that exhaust gas regulations for environmental measures have affected and accelerated the speed of research and development in this technical field. In this way, by conducting analytical research using patent data, various aspects of research and development, such as clarifying the effectiveness of a company's research and development, areas of focus, and technological strategies by comparing with competitors, can be obtained. events can be clarified.

It has also been pointed out that patents are also important in the field of marketing. For example, the role of marketing in patent management has been described including technology, positioning and licensing (Mitkova 2005) [8].

Patent data is also used as one of the methods for understanding future technological trends. Chang, S. B. (2009) showed that among many technology predictive indicators, patents and patent citations are useful and important indicators [9]. Altuntas (2015) uses patent data to forecast technology using four criteria: technology lifecycle, diffusion speed, patentability, and expandability [10]. Pavitt (1982) uses patent statistics to forecast technology and measure technological change [11]. As in this paper, there are cases where patent strategies are analyzed by focusing on the hierarchical structure of the IPC of patent classifications [12] [13].

In this way, analysis of the number of patent applications by companies is not only an important indicator of the quality and effectiveness of R&D from the perspective of correlation with R&D costs, but also predicts the future potential of R&D strategies.

3 GX Patent Analysis (Time Series Trends)

3.1 Patent data

In the interim results of a statistical survey based on GXTI published in January 2023, the JPO has disclosed the number of patent applications filed from 2010 to 2021.

The interim results are GX technologies (gxA: energy supply, gxB: energy saving, electrification, supply and demand adjustment, gxC: batteries and energy storage, gxD: CO2 reduction in non-energy fields, gxE: recovery, storage, utilization and utilization of greenhouse gases). 244811 applications (limited to Japanese nationals).

Table 2: GXTI TOP5 technologies and number of patent applications

#	Code	Level 1	Level 2	Number of patent applications
1	gxB01	Energy Saving, Electrification, Demand-Supply Flexibility	Energy Saving in Buildings (ZEB, ZEH, etc.)	60,688
2	gxC01	Batteries, Energy Storage	Secondary Batteries	56,230
3	gxB05	Energy Saving, Electrification, Demand-Supply Flexibility	Electromobilities	25,652
4	gxA01	Energy Supply	Solar Photovoltaic Power Generation	22,050
5	gxA09	Energy Supply	Fuel Cells	20,884

The interim results of the statistical survey published by the Japan Patent Office are tabulated by nationality. In this paper, the number of patent applications filed with the Japan Patent Office is recounted and analyzed for the above five technical fields. This analysis measures patents filed with the Japan Patent Office from 2000 to 2020. The Japan Patent Office has abolished republished patents in January 2022. A republished patent is information that is published again in Japan after it has been internationally published for an invention filed in Japanese with the Japanese Patent Office as the receiving office through the PCT procedure. In addition, if you file a PCT application, the deadline for domestic transition to the Japan Patent Office will be 30 months. Administrative processing time is required until the Japan Patent Office reflects the national transition. In addition, a divisional application may be filed for a patent filed in the past. In this paper, divisional patents are analyzed based on the filing date of the pre-divisional patent.

Therefore, in the second half of the analysis period of this paper, the number of applications may have decreased due to the influence of "republished patents", "PCT national phase" and "divisional applications".

3.2 Patent data used in this paper

The figure below shows the transition of patent applications filed with the Japan Patent Office for GXTI's TOP5 technologies from 2000 to 2020.

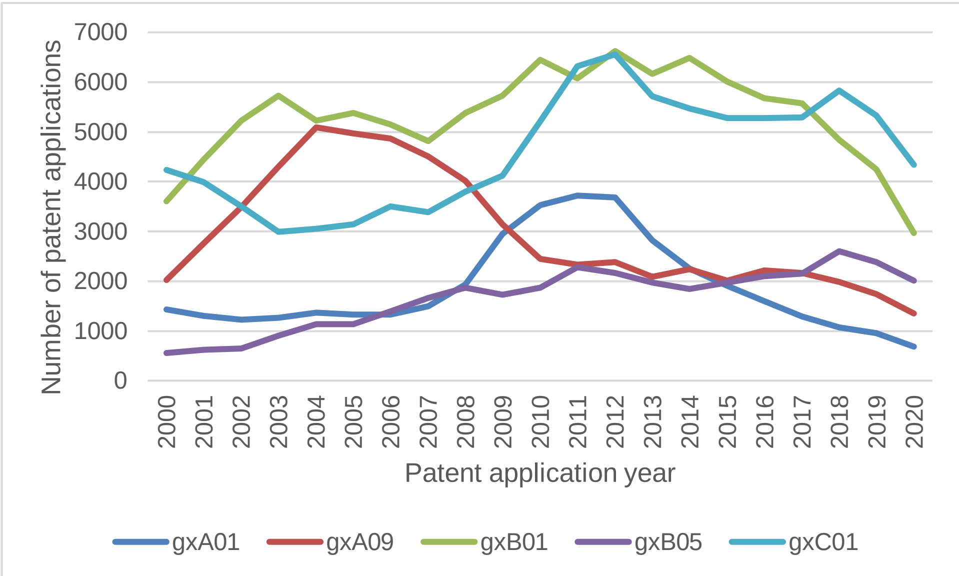

Figure 1: GXTI TOP5 technologies and number of patent applications

The table below shows the statistics of patents filed with the Japan Patent Office for GXTI's TOP5 technologies from 2000 to 2020. Of the five technologies, gxB01 had the highest total number of applications filed over the 21-year period. Of the five technologies, gxC01 had the second highest total number of applications filed over the 21-year period. gxB01 and gxC01 had a minimum of about 3000 applications. It can be seen that gxB01 and gxC01 are still actively researched and developed. On the other hand, the number of applications for gxA01 and gxA09 will be less than half in 2021 compared to the maximum filing year.

Table 3: GXTI TOP5 technologies and number of patent applications

Code	21 year total	Average	Minimum	Maximum	Maximum application year
gxA01	39101	1862.0	684	3719	2011
gxA09	62075	2956.0	1350	5091	2004
gxB01	111793	5323.5	2967	6624	2012
gxB05	34966	1665.0	556	2601	2018
gxC01	96344	4587.8	2991	6557	2012

4 GX Patent Analysis (Diversity)

4.1 International Patent Classification (IPC)

IPC is a worldwide common technology classification code given to each patent to identify the technology type. Each patent is basically assigned an IPC, but each patent is often assigned multiple IPCs. This is because each patent may not have been invented from one technical element, but may have been invented from multiple elements. Now, there are two types of IPCs assigned to each patent, depending on their roles: “main IPC” and “CO-IPC”. One main IPC is always assigned to every patent, while some patents may have multiple CO-IPCs or none at all. The main IPC literally represents the technology of the patent filed, and the patent office uses the term "principal feature". On the other hand, CO-IPC indicates that the patent simultaneously has technical characteristics different from those of the main IPC.

Next, the structure of the IPC will be described. The IPC has a hierarchical structure, with sections, subsections, classes, subclasses, main groups, and subgroups from large classifications to detailed classifications. In other words, it can be understood that two IPCs with different sections are in different fields of technology than two IPCs with the same main group but different subgroups.

Table 4: Hierarchical structure of the International Patent Classification IPC (description using G02B11/02)

#	Hierarchical name	Number of characters in classification code	Example	Symbol meaning
1	Section	The first character	G	PHYSICS
2	Class	Up to the third character	G02	OPTICS
3	Sub Class	Up to the fourth character	G02B	OPTICAL ELEMENTS, SYSTEMS OR APPARATUS
4	Main Group	Up to the character before the slash	G02B11	Optical objectives characterised by the total number of simple and compound lenses forming the objective and their arrangement
5	Sub Group	All characters	G02B11/02	having two lenses only

4.2 Diversity index considering taxonomy

Regarding diversity, there is a method of measuring only the number of IPCs in the technical classification assigned to a single patent. However, technical classification has a hierarchical structure. Continuing only the number of technical classifications assigned to a single patent may not necessarily give an accurate picture of diversity. For example, when measuring the diversity of the same IPC number, “Patents with different IPCs in the upper hierarchy’" should be more diverse than “Patents with different IPCs in the lower hierarchy”. Therefore, this analysis introduces a scale to measure the diversity considering the hierarchical structure of the technology classification IPC.

Biology is one of the fields that studies diversity. In biology, one measure of biodiversity is Simpson's Diversity Index. The Simpson Diversity Index uses only species and population numbers for measurement. In other words, the Simpsons diversity index is an index that does not take into account the above hierarchical structure. The types of organisms are classified according to class by taxonomy. For example, the hierarchy includes kingdom, phylum, class, order, family, genus, species, etc. in descending order. Therefore, when measuring the diversity index of 5 different species, the results of “5 species in the same genus” and “5 species in different genus” indicate that the latter result has high diversity.

Therefore, an index that takes into account this taxonomy has been devised by Warwick [14].

A feature of this index is the use of taxonomic distances. For example, Warwick defined the taxonomic distance (ωij the distance between i and j species) in the taxonomic hierarchy as follows:

If it is the same "species", the taxonomic distance is "0".

If it is the same "genus" and different "species", the taxonomic distance is "1".

If it is the same "family" and different "genus", the taxonomic distance is "2".

Thus, for each higher level, the taxonomic distance increases by one. Based on this idea, the diversity index "Δ+" is calculated. The fractional numerator of the diversity index is the sum of all 'ωij' in one sample. The denominator of the fraction of the diversity index is the number of combinations in one sample. In this paper, the idea of an index that considers this taxonomy is applied to the technological diversity of each patent. Each patent is assigned a patent classification. There are several types of patent classifications used around the world (IPC, CPC, FI, F-Term, etc.). In this paper, IPCs assigned to patents around the world are used. One or more IPCs are assigned to each patent. A patent with multiple IPCs means a patent that covers multiple technical fields. In other words, measuring the IPC granted to patents means measuring the diversity of technology. On the other hand, similar to the hierarchy in biology, the IPC has a hierarchical structure. For example, in the hierarchical structure of IPC, there are Section, Class, Sub-Class, Main-Group, and Sub-Group in order of higher layers. In this paper, Warwick's diversity index is applied to the hierarchical structure of the IPC. In this paper, the taxonomic distance is defined as follows.

If it is the same "Sub-Group", the taxonomic distance is "0".

If it is the same "Main-Group" and different "Sub-Group", the taxonomic distance is "1".

If it is the same "Sub-Class" and different "Main-Group", the taxonomic distance is "2".

If it is the same "Class" and different "Sub-Class", the taxonomic distance is "3".

If the same "Section" and different "Class", the taxonomic distance is "4".

If it is a different "Section", the taxonomic distance is "5".

This made it possible to measure the diversity of each patent considering the taxonomy of the IPC. The "S" in the formula is the number of IPCs granted to each patent.

$$\Delta^{+} = \sum_{i=1}^{S} \sum_{j=1}^{S} \frac{\omega ij}{\frac{S(S-1)}{2}}$$

$$i \geq j, \qquad 1 \leq \Delta^{+} \leq 5$$

Figure 2: Diversity index for patents considering taxonomy

4.3 Diversity index results and analysis

This analysis applied this taxonomically-accepted diversity index to each of the five technical areas of GX. Diversity index is calculated for all patents for each technology. The calculated index is a value between 0 and 5. Create a stacked line graph from index 0 to index 5, with the total number of patent applications for each technology set as 100%. In this graph, it is possible to see the percentage of diversity index for each technology.

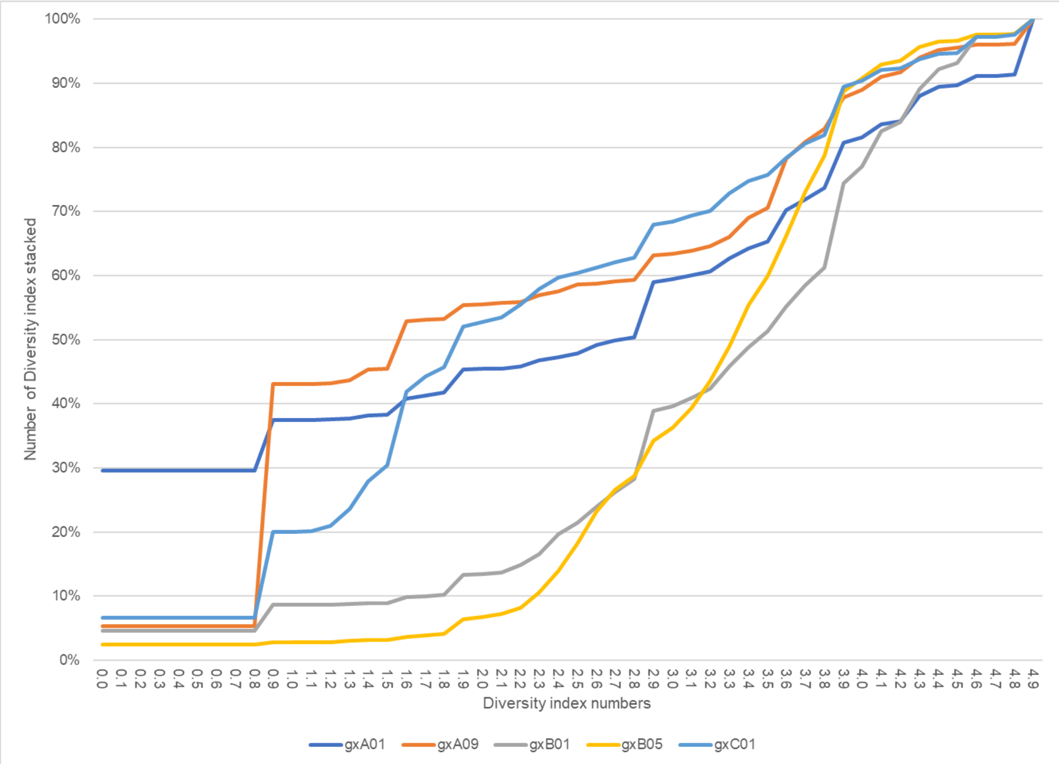

Figure 3: Diversity index stacked line graph (GXTI TOP5 technologies)

gxA01 already shows a proportion of nearly 30% when the diversity index is 0. This means that a large percentage of gxA01 patents have only one granted IPC. The fact that only a single IPC is granted indicates a high proportion of elemental technology R&D. gxA01 shows a proportion of nearly 10% with a diversity index of 5. This indicates that the gxA01 patent has multiple IPCs that differ at the Section level. gxA01 shows that the ratio of research and development of elemental technology is high, but the ratio of research and development of applied technology that is technology fusion with other fields is also high. Thus, gxA01 was found to be a unique technology area with high R&D ratios at both the upper and lower ends of the diversity index.

gxA09 shows a proportion of nearly 40% with a diversity index of 1. This means that the gxA09 patent has a high proportion of multiple IPCs differing at the Sub-Group level. The IPC Sub-Group is the most detailed level in the IPC hierarchy. gxA09 shows a high proportion of research and development of elemental technologies.

The graph curves of gxB01 and gxB05 are the slowest to rise. This indicates that the gxB01 patent and the gxB05 patent have a high percentage of research and development of applied technology that is technology fusion with other fields among the five GX technology fields.

gxC01 shows a proportion of nearly 20% with a diversity index of 1. This means that the gxA09 patent has a high proportion of multiple IPCs differing at the Sub-Group level. Like gxA09, gxC01 shows a high ratio of research and development of elemental technologies.

In this way, by using the diversity index that considers the classification structure, it is now possible to grasp the ratio of research and development according to the level of the degree of fusion.

5 Summary

There is an initiative called GX (Green Transformation) started by the Japanese government against the climate change problem. The Japanese Patent Office has released the GXTI (Green Transformation Technologies Inventory), a technology classification for technologies related to GX. In this paper, trends in the number of patent applications for the Top 5 technologies related to GXTI were analyzed. In addition, the technology diversity of the Top 5 was analyzed. For diversity analysis, taxonomic indices applying the concept of biodiversity were discussed. As a result of introducing this index, it has become possible to grasp the ratio of research and development according to the level of technological integration.

This paper was a comparison of diversity between GX technologies. In future studies, a comparison of diversity could be made for the same technology and with different applicants. Such a comparison would clearly identify whether the emphasis is on research into single elements in the relevant technology or on applied research involving complex technologies. Similarly, in future research, diversity comparisons could be made in the same technology and in the industries of different applicants. It is also conceivable that diversity comparisons could be made between existing players and new entrants in the same technology.

From a different perspective, a comparison of changes in application years could be used to identify changes in the diversity of the technology itself over time, which could then be used to predict the future.

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