Who owns what? The patent landscape of environmentally sound technologies

Barasha Borthakur*

Abstract

- Climate change is a common concern of humankind that should be dealt with through international cooperation. Technological innovation and the transfer of environmentally sound technologies (ESTs) are two of the most effective ways to mitigate climate change. Access to these technologies is vital for all countries, irrespective of their developmental needs.
- The current view is that such access is difficult for two reasons: (i) there is a negligible and inefficient technology transfer of ESTs due to the dearth of international legal instruments, and (ii) most ESTs are controlled by a few countries or corporations. Many developing countries demand a change in IP policies to enhance access to ESTs since existing rules are seen as a barrier to using these technologies to mitigate climate change. However, these claims lack empirical evidence.
- Through patent landscaping, collecting and analysing patent data from a set of developed and developing countries, this article provides empirical evidence to establish where the concentration of patent ownership lies and identify the dominant players in the field of ESTs.

According to the United Nations, the term 'environmentally sound technologies' (ESTs) refers to technologies that are 'less polluting, more resource-efficient, and socially acceptable',[1] and that promote sustainable patterns of consumption and production. These technologies should be accessible to all countries, particularly developing countries, to promote equitable and sustainable development.

The terms 'EST', 'green technology' and 'clean technology' are often used interchangeably, but they have slightly different meanings. Green technology, also known as environmental technology or eco-technology, generally refers to technologies that are environmentally friendly and sustainable but may not necessarily have a direct impact on reducing pollution or carbon emissions. Clean technology, also known as cleantech, specifically refers to technologies that reduce or eliminate pollution and emissions.[2] EST, as used in this article, is broader in scope than green technology or clean technology because it takes into account the entire lifecycle of a product or process, from raw material extraction to disposal.[3] This means that ESTs not only reduce pollution and emissions during the use phase of a product or process but also consider the environmental impact of production and disposal.

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To properly evaluate the influence of the global IP right (IPR) regime on the development and transfer of ESTs, it is vital to understand who generates and possesses these technologies and who the primary technology recipients are. The consensus in the literature tends to be that EST innovation is centred mostly in developed nations.[4] When it comes to the technology transfer of these ESTs,

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1 'Agenda 21' UN Conference on Environment and Development, Rio de Janeiro, 3–15 June 1992, 23 April 1992, UN Doc A.CONF/151/26 (Vol. III).

2 James Nurton, 'Get ready for the clean Tech IP Boom' (2008) 182 *Managing Intellectual Property* 40, 47.

3 Ibid.

4 Daniel Kent Neil et al., 'Challenges to Technology Transfer: A Literature Review of the Constraints on Environmental Technology Dissemination' (16 August 2009). Colorado College Working Paper No. 2009-07. Available at https://ssrn.com/abstract=1456222 or http://dx.doi.org/10.2139/ssrn.1456222 (accessed 10 May 2023).

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the benefits of the transfers are not equally distributed, as the key recipients are only a few developing nations.[5]

In the field of sustainability and IPR, the scarcity of data, specific to geographical location, technology sector or time period, is alarming. Many authors have previously noted the need for more empirical studies. Hence, this article aims to contribute to the existing literature in at least three ways. First, in contrast to previous literature in this field, the current study uses more recent data and time series to investigate the concentration of ESTs; second, the ESTs covered by this study reach beyond specific clean energy technologies, covering almost all climate-related ESTs; and third, it uses market mapping to analyse the position of owners of ESTs in the relevant market in question.

Patent data and ESTs

The study of patent data for ESTs can provide valuable insights into the development and diffusion of these technologies. According to the Organisation for Economic Co-operation and Development (OECD), patent data are particularly useful indicators of technological innovation, as they are freely available, discrete and focused on the outcomes of the inventive process,[6] even if some commercially important inventions have not been patented.[7] The OECD considers that patent data present distinct advantages compared to other measures of innovation because they are based on an objective standard, assess the intermediary results of the inventive process, are quantitative and can be compartmentalized into technological areas—an important feature if we are to study 'environmental' innovation.

The importance of using patent data to analyse ESTs can also be explained through the lenses of different theories.

The theory of market failure suggests that there may be barriers to the development and adoption of ESTs due to market inefficiencies. For example, there may be externalities associated with the use of conventional technologies, such as pollution, that are not reflected in market prices. This can make ESTs appear less competitive, even if they offer environmental benefits. By studying patent data for ESTs, researchers can gain insights into the types of technologies that are being developed and patented, as well as the companies and industries that are leading the way. This can help identify the areas where market failures may be occurring and where policy interventions may be needed to promote the development and adoption of ESTs.

According to the theory of technological innovation, the development of new technologies is a key driver of economic growth and productivity. By analysing patent data for ESTs, researchers can identify the technological trends and innovations that are driving the development of these technologies.

As per the theory of ecological modernization, technological innovation can play a key role in promoting sustainable development. By studying patent data for ESTs, researchers can gain insights into the types of technologies that are being developed and patented, as well as the companies and industries that are leading the way.

Overall, the study of patent data for ESTs can provide valuable insights into the development and diffusion of these technologies, helping policymakers identify areas where market failures may be occurring, promote further innovation and accelerate the transition to a more sustainable economy.

Methodology

This article relies on innovation performance data and patent data to understand important aspects of the development of ESTs.

Innovation performance data

The countries considered in the research were selected based on the latest report by the World Intellectual Property Organization (WIPO),[8] adopting the developed/developing country distinction according to the OECD definition for uniform application. The data used in the study were mainly drawn from the technology development dataset in the OECD Environment database and the World Bank database.[9] These indicators enable the assessment of the innovation performance of countries and companies, as well as the design of government environmental and innovation policies.

The OECD indicators are grouped into three categories—(i) technology development, (ii) international collaboration and (iii) technology diffusion.

5 Wei Zhuang, 'Introduction' in *Intellectual Property Rights and Climate Change: Interpreting the TRIPS Agreement for Environmentally Sound Technologies* (Cambridge University Press 2017) 12. Available at https://www.cambridge.org/core/books/intellectual-property-rights-and-climate-change/2F51E1A75DAD3FEA96A3A88041063BFC.

6 OECD, *Green Growth Indicators 2014* (OECD Green Growth Studies OECD Publishing Paris 2014). Available at http://dx.doi.org/10.1787/9789264202030-en (accessed 17 November 2021), citing Zvi Griliches, 'Patent statistics as economic indicators: A survey' (1990) 28 *Journal of Economic Literature* 1661–707.

7 Ibid, citing Hélène Dernis et al., 'Using patent counts for crosscountry comparisons of technology output', (STI Review, No. 27, OECD 2001). Available at https://www.oecd.org/si/inno/21682515.pdf (accessed 4 January 2022), 129–46.

8 WIPO, 'World Intellectual Property Indicators 2021' (WIPO Geneva, Switzerland 2021). Available at https://www.wipo.int/edocs/pubdocs/en/wipo_pub_941_2021.pdf (accessed 5 February 2022).

9 WIPO, 'World Intellectual Property Indicators 2020' (World Intellectual Property Organization Geneva, Switzerland 2020). Available at https://www.wipo.int/edocs/pubdocs/en/wipo_pub_941_2020.pdf (accessed 5 February 2022).

The data analysis done by the OECD Statistics refers to the period between 2000 and 2017. The choice of this time frame was determined, first, by the research objective, which required environmental patents in the long term, and, second, by the availability of comparable data. With the given data, a comparative analysis method was employed to examine development over the last 17 years. By using a patent-based approach, the study offers a quantitative perspective on current developments in environmental technology and provides indicators of future trends.

Innography® patent search data

To conduct the patent search, the Innography® software/database was used.[10]

The first step was to create a scientific patent search string to identify relevant EST patents. To enhance the significance of the patent retrieval and to achieve a more complete and correct understanding of ESTs and collect the core keywords, the author examined not only credible scientific literature, including books and articles published in multiple disciplines, but also relevant patent documents specifically linked to ESTs, which comprise the core keywords in their titles. The researcher also collected synonyms or other expression forms of the core keywords for the patent search.[11] The terms were used for the keyword search using the Boolean function 'OR' operator using general keyword search and specific keyword search.[12] Using the patent keyword search, 3 461 573 patents were generated in total.

Patent data analysis

This section provides an overview of the main insights gained from the patent data and OECD indicators.

Patents per inventor location

Geographical information in the patent data helps us understand the development trends in key global players of technological innovations. The ultimate ownership of the local technological and innovation capacities may have quite a different geographical distribution—as some patents are registered by the local subsidiaries of parent companies based in another country. For example, most patents 'originating' from China are filed by foreign subsidiaries, as evidenced by China's low share of 'parent companies of patent owners that have more than 4 patents at the time of filing'.[13] The following chart shows where in the world the inventions are actually originating from. It uses the inventor's location to avoid confusion by corporate filing strategies—for example, an organization might always file first in the USA no matter where the invention originates.

The geographical distribution of patents highlights the strength of R&D and market competitiveness in various nations and regions. Fig. 1 and 2 shows patents per inventor location from the major patent concentration regions of the world. Out of 3 461 573 ESTs patents, China is the hub with the highest number of inventors (1 662 756). The location with the second highest number of inventions related to ESTs is the USA (511 823), followed by Japan (406 845).

Amongst the top five inventor locations, one is a developing country (China), which accounts for 46 per cent of patents, and four are developed countries (Japan, USA, Germany and South Korea), accounting for 43 per cent of patents. It is interesting to note that three of the top five locations are Asian countries (China, Japan and South Korea).

Patents based on priority year and filing year

Fig. 3 is a graphical representation of the distribution of EST patents based on their priority dates in the

10 Can be accessed at https://www.innography.com/ (accessed 10 May 2023).

11 Ivan Haščič and Mauro Migotto, 'Measuring Environmental Innovation Using Patent Data' (OECD Working Paper Series No.89, 2015). Available at https://dx.doi.org/10.1787/5js009kf48xw-en (accessed 12 January 2022), 56.

12 'Renewable energy' OR 'Green technology' OR 'Clean technology' OR 'Energy efficient' OR 'Fuel efficient' OR 'non-fossil fuel' OR 'Environmentally sound' OR 'Environmentally sound technology' OR 'Environment friendly' OR 'Environmentally friendly technology' OR 'Climate change mitigation technology' OR 'Climate change mitigation' OR 'Climate mitigation' OR 'sustainable' OR 'environmental management' OR 'air pollution abatement' OR 'post combustion technology' OR 'water pollution abatement' OR 'fertilizers from wastewater' OR 'oil spill clean-up' OR 'waste management' OR 'solid waste management' OR 'material recovery' OR 'recycling' OR 'fertilizers from waste' OR 'incineration and energy recovery' OR 'soil remediation' OR 'environmental monitoring' OR 'water related adaptation technology' OR 'water conservation' OR 'drought resistant crops' OR 'climate resistant crops' OR 'underground water collection' OR 'surface water collection' OR 'rainwater water collection' OR 'desalination of sea water' OR 'biodiversity protection' OR 'ecosystem health' OR 'wind energy' OR 'solar thermal energy' OR 'solar photovoltaic energy' OR 'solar PV energy' OR 'solar thermal PV hybrid' OR 'geothermal energy' OR 'marine energy' OR 'hydro energy' OR 'fuels of non-fossil origin' OR 'biofuel' OR 'fuel from waste' OR 'combustion technologies with mitigation potential' OR 'Technologies for improved output efficiency' OR 'Technologies for improved input efficiency' OR 'nuclear energy' OR 'nuclear fusion reactors' OR 'nuclear fission reactors' OR 'technologies for an efficient electrical power generation' OR 'technologies for an efficient electrical power transmission' OR 'technologies for an efficient electrical power distribution' OR 'smart grid' OR 'energy storage' OR 'hydrogen technology' OR 'fuel cells' OR 'reducing greenhouse gas emissions' OR 'reducing GHG emissions' OR 'capture of greenhouse gases' OR 'storage of greenhouse gases' OR 'sequestration of greenhouse gases' OR 'disposal of greenhouse gases' OR 'carbon capture' OR 'carbon storage' OR 'hybrid vehicles' OR 'electric vehicles' OR 'fuel efficiency' OR 'energy efficiency'.

13 A Dechezleprêtre et al., 'Invention and transfer of climate change–mitigation technologies: A global analysis' (2011) 5 *Review of Environmental Economics and Policy* 113.

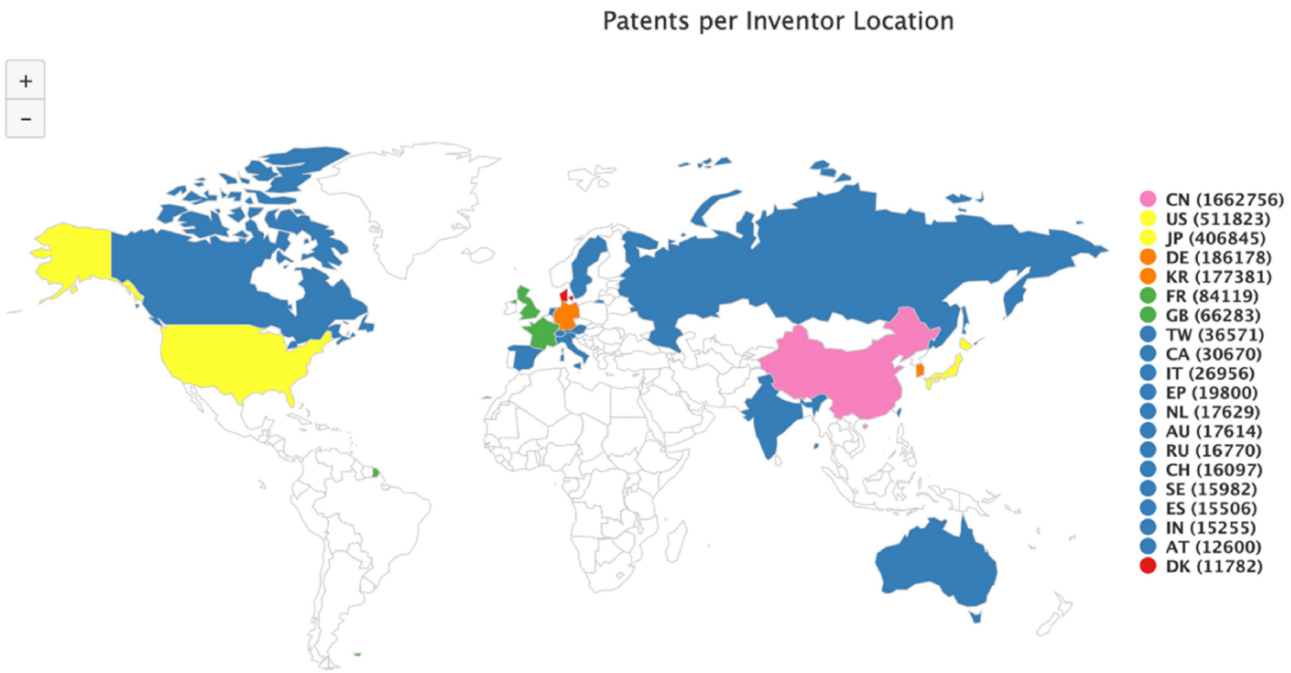

Figure 1. Patents per inventor location.
Source: Chart generated from Innography®, calculated and analysed by the researcher.

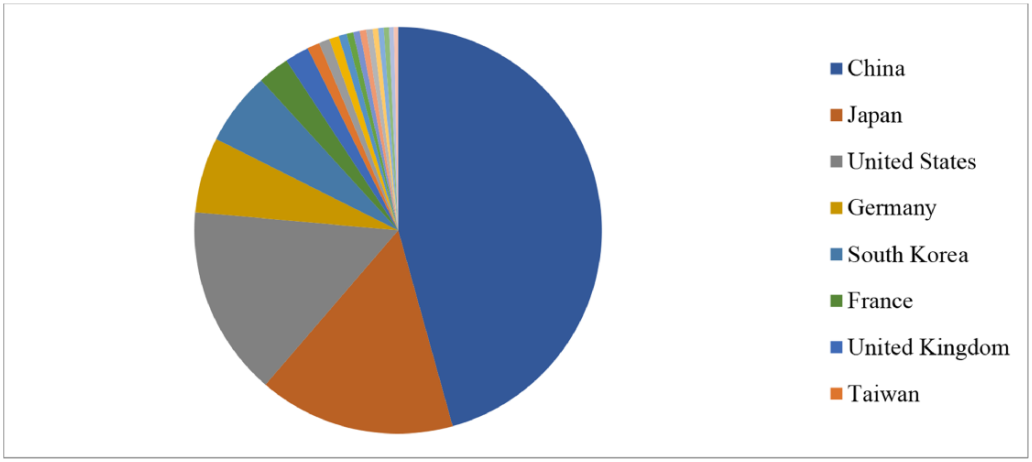

Figure 2. Percentage of patents per inventor location (top 20).
Source: Innography®, calculated and analysed by the researcher.

developed countries (Australia, Canada, France, Germany, the UK and the USA). Amongst them, the USA had the majority of patents granted in the field of EST followed by Germany, France, the UK, Canada and Australia.

Fig. 4 represents the patent distribution based on the priority date in the Brazil, Russia, India and China (BRIC) countries. Compared to Brazil, Russia and India, which had a gradual or stable pattern, China saw a very visible increase in the priority date of EST patents, especially between 2004 and 2017. The increase in green technology patents in China started in the early 2000s, with a significant uptick in the mid-to-late 2000s. China has implemented a number of policies to support the development and deployment of green technology, which have contributed to the increase in green technology patents in the country. For instance, in 2005, China passed the Renewable Energy Law, which established targets for renewable energy development and provided financial incentives for companies and individuals to invest in renewable energy

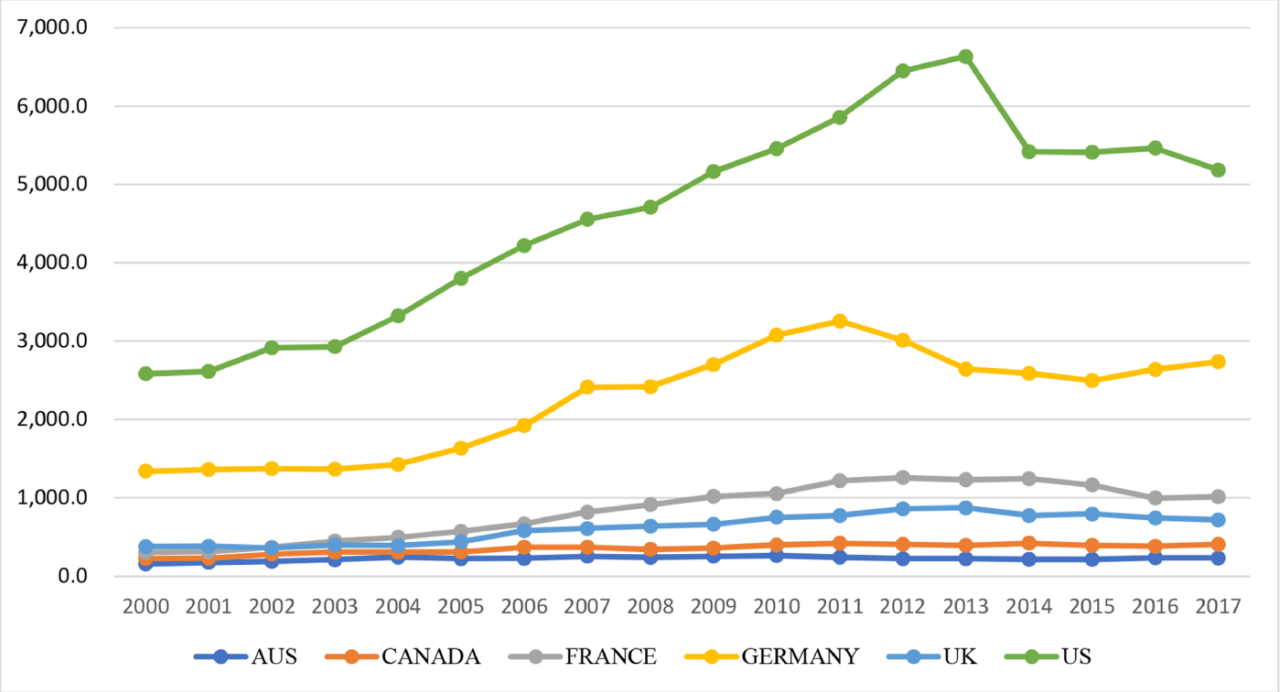

Figure 3. EST patents based on priority date (developed countries).
Source: OECD Statistics database, calculated and analysed by the researcher.

projects.[14] In 2006, the Chinese government released the National Medium- and Long-Term Plan for Science and Technology Development, which included specific targets for the development of clean energy technologies, such as wind, solar and nuclear power. Other such plans include the 12th Five-Year Plan for Energy Conservation and Emission Reduction and the Belt-Road Initiative.

In comparing Fig. 3 to Fig. 4, the OECD data show that the developed countries have more EST patents based on priority dates than the BRIC countries. Since the data collected from the OECD are limited to certain categories of ESTs as mentioned earlier, the author has accessed the Innography® database to corroborate the patenting trends of ESTs amongst the various countries.

Developing countries

The data collected from 1 753 606 patents relating to ESTs from 2010 to 2021 in China (Fig 5) evidence an increase in patent applications and grants from 2010 to 2018. The patent applications saw a gradual decrease from 2018 and patent applications saw a decrease from 2020 to 2021. The priority year of patent grants in China was the highest during the year 2020 (174 158).

Over the previous decade, China had been the greatest investor in renewable energy, investing $758 billion, more than double the USA's $356 billion. Solar power was shown to draw the most patent filings, accounting for 57 per cent of all green energy patents according to a study that examines patents for solar power, wind energy, biofuels, hydropower, geothermal energy and waste-generated energy.[15]

The developing countries showed a similar trend of a gradual decrease in patent grants and applications from 2010 to 2021 (Fig 6). India showed a deviant trend where the year 2017 had the highest patent applications from the mentioned time frame and then saw a gradual decrease.

Developed countries

About 224 330 patent grants and 166 618 patent applications relating to ESTs were collected based on their priority year from 2010 to 2021 in the USA (Fig 8). This shows a similar gradual decreasing slope to China. From the year 2016, the decreasing trend began and continued till the year 2021. Fig 7–17 represents the patenting trend of ESTs in developed countries.

Patents per source per filing year

The filing year patterns follow similar patenting trends based on the EST patents per source per priority year (Fig 18).

14 Renewable Energy Law of the People's Republic of China. Available at http://www.npc.gov.cn/zgdw/englishnpc/Law/2007-12/13/content_1384096.htm (accessed 2 January 2023).

15 Science Business Reporting, Green energy patents filed globaly jump 28% in a year. Available at https://sciencebusiness.net/news-byte/green-energy-patents-filed-gl"bally-jump-28-year (accessed 3 December 2022).

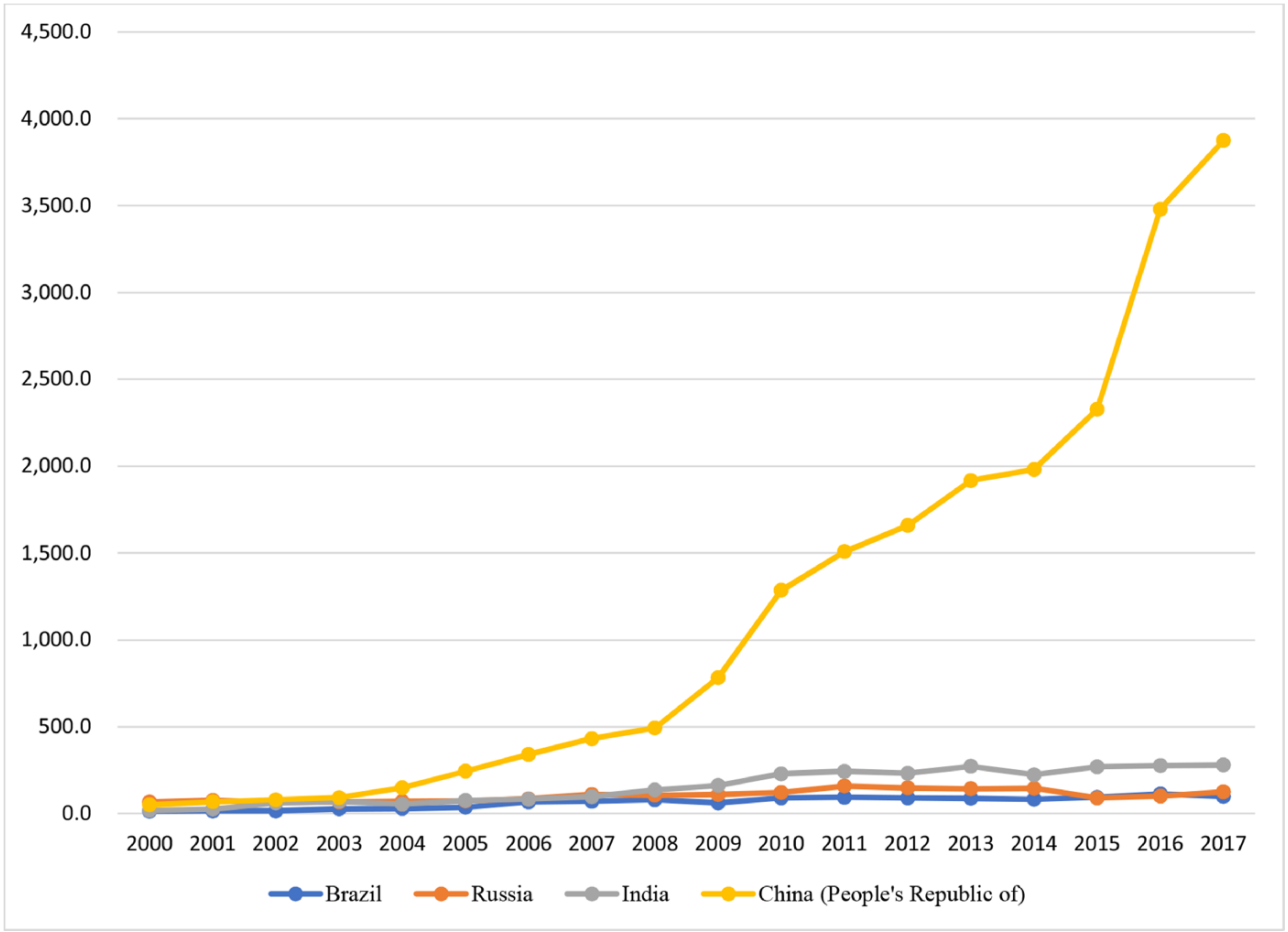

Figure 4. EST patents based on priority date (BRIC countries).
Source: OECD Statistics database, calculated and analysed by the researcher.

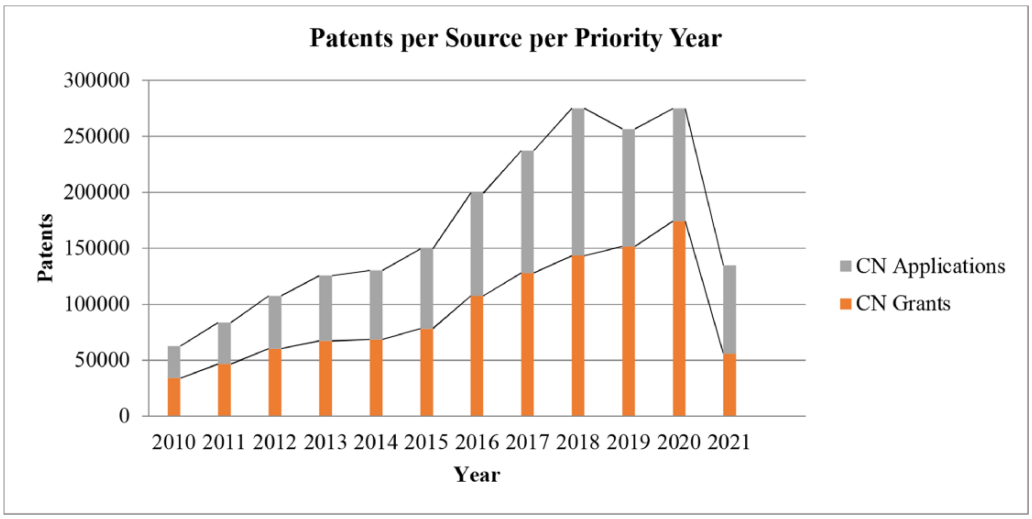

Figure 5. China's EST patent applications and grants from 2010 to 2021.
Source: Chart generated from Innography®, calculated and analysed by the researcher.

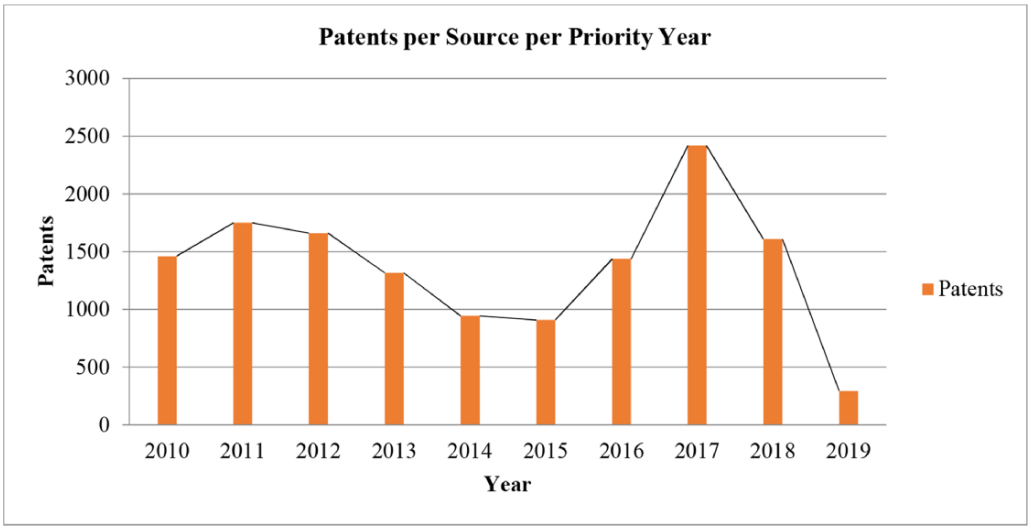

Figure 6. India's EST patent applications from 2010 to 2021.
Source: Chart generated from Innography®, calculated and analysed by the researcher.

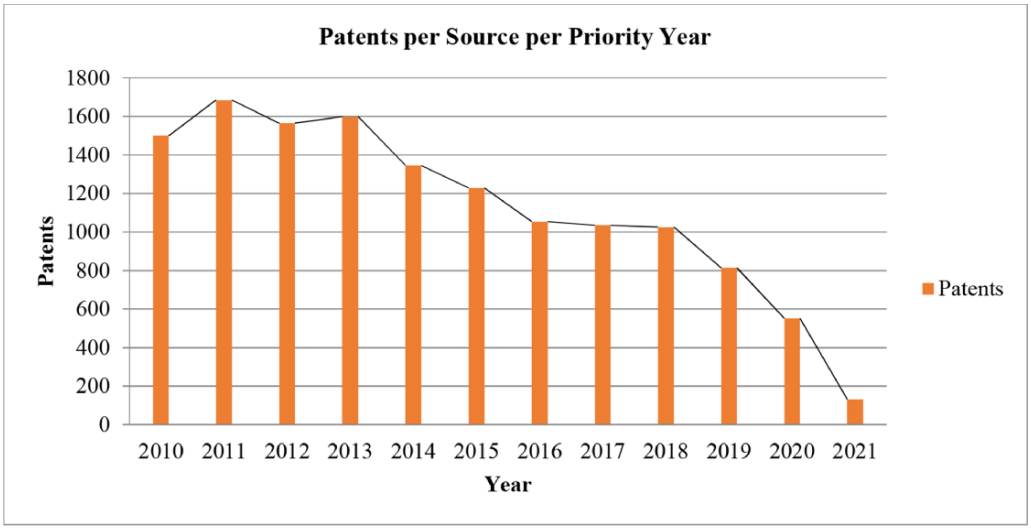

Figure 7. Taiwan's EST patent grants from 2010 to 2021.
Source: Chart generated from Innography®, calculated and analysed by the researcher.

The results calculated and analysed in this article differ to some extent from the existing literature surrounding the ownership of ESTs based on geographical location. The top 10 reported locations of patent assignees or owners according to the study conducted by Chatham House and Cambridge IP were primarily OECD countries—the USA, Germany, Japan, Denmark and South Korea.[16] The United Nations Environment Programme, European Patent Office and International Centre for Trade and Sustainable Development Report found that the leading six countries—Japan, the USA, Germany, Korea, the UK and France—accounted for almost 80 per cent of all patent applications in Clean Energy Technologies.[17] Another important research found that nearly 90 per cent of all inventions in climate-mitigation technology between 2000 and 2005 were concentrated in 12 countries: nine OECD countries (Japan, the USA, Germany, South Korea, Australia, France, the

16 Bernice Lee et al., *Who Owns Our Low Carbon Future?* (Intellectual Property and Energy Technologies Chatham House 2009) 9.

17 UNEP, EPO and ICTSD, 'Patents and clean energy: Bridging the gap between evidence and policy' (Munich Germany Mediengruppe Universal 2010) 9.

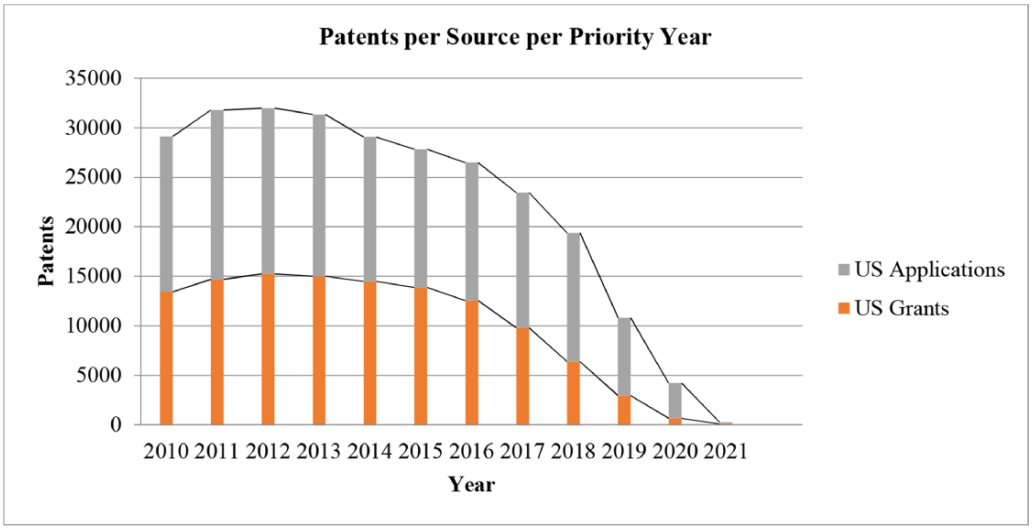

Figure 8. The USA's EST patent applications and grants from 2010 to 2021.
Source: Chart generated from Innography®, calculated and analysed by the researcher.

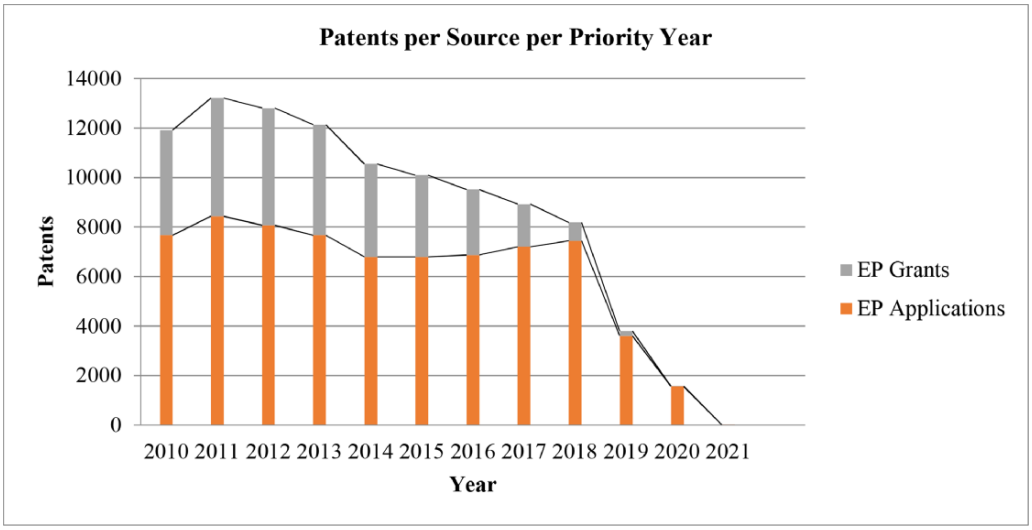

Figure 9. EPO's EST patent grants and applications from 2010 to 2021.
Source: Chart generated from Innography®, calculated and analysed by the researcher.

UK, Canada and the Netherlands) and three emerging economies (China, Brazil and Russia).[18]

However, in the present-day scenario, as per Fig. 19, China's application and grants, Japan's applications and the USA's grants of EST patents constitute the top four sources by priority year.

Patent strength

Innography®'s PatentStrength®, also known as patent valuation algorithms, is used to assess the strength score of a patent based on various indicators such as the number of patent claims, the types and the number of patent citations, the number of different International Patent Classifications, the location of the patent assignee and any combination of these. The information collected from a patent document, as well as other information connected to a patent document, can be utilized to determine the patent's strength score. This provides evidence of the benefits of a patent and serves as a necessary element

18 A Dechezleprêtre et al., 'Invention and transfer of climate change–mitigation technologies: A global analysis' (2011) 5 *Review of Environmental Economics and Policy* 113.

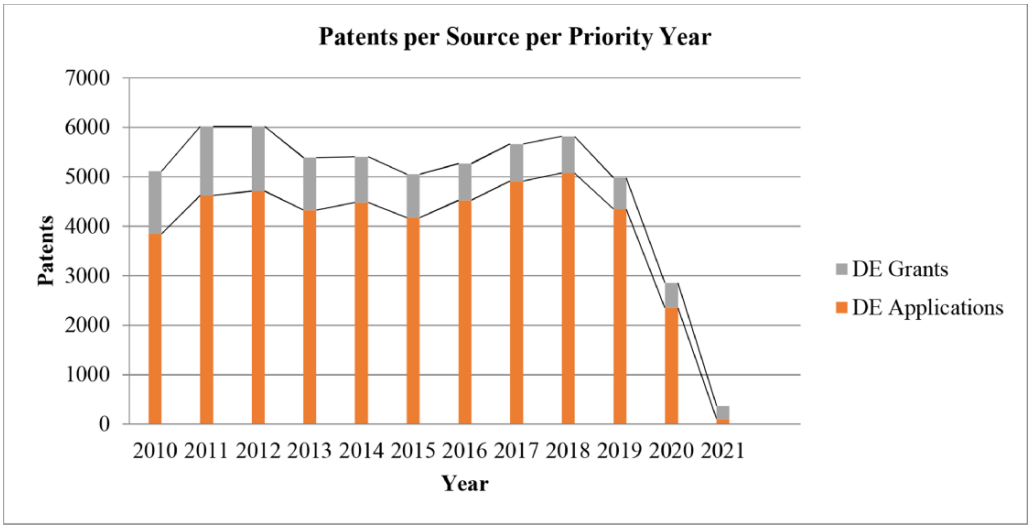

Figure 10. Germany's EST patent grants and applications from 2010 to 2021.
Source: Chart generated from Innography®, calculated and analysed by the researcher.

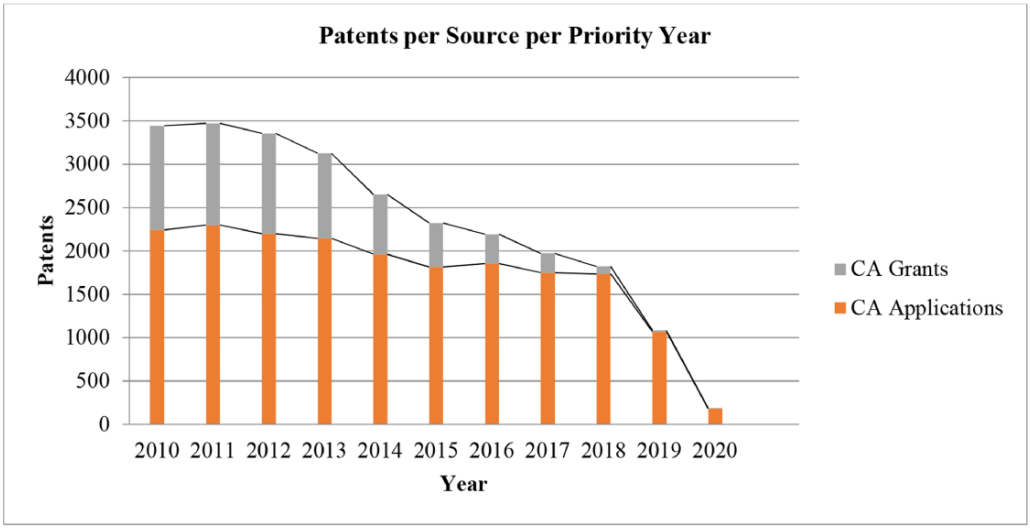

Figure 11. Canada's EST patent grants and applications from 2010 to 2021.
Source: Chart generated from Innography®, calculated and analysed by the researcher.

for patent ranking. Innography® created a patent strength scale ranging from 1 to 100, with 1 representing the weakest degree of patent strength and 100 representing a true advance.

From the patent data in Fig. 20 regarding ESTs of developed countries, most EST patents in the USA are distributed on a scale of 30–100. Provided that the patent would be regarded as an important patent if its patent strength is more than 80, the USA has some of its patents on that scale. EPO, Canada and Germany have minuscule numbers of EST patents with a patent strength of 90–100. Apart from that, most of the patents of the other countries are concentrated on the weaker end of the strength scale.

Patents per organization

The chart in Fig. 21 shows the top 20 organizations that hold patents in the dataset from the total 3 461 573 patents analysed and the Innography® application displays them according to the proportion of patents in that dataset that they filed.

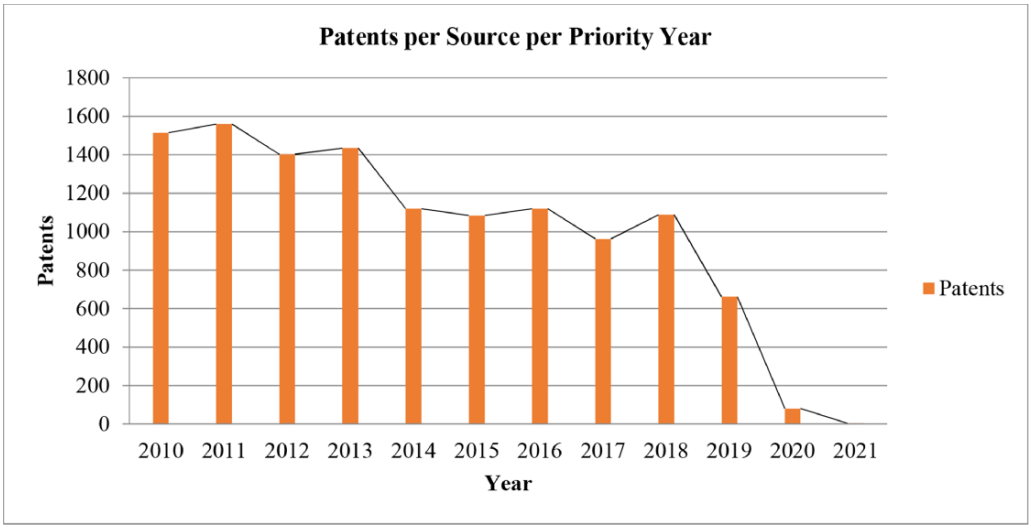

Figure 12. Australia's EST patent applications from 2010 to 2021.
Source: Chart generated from Innography®, calculated and analysed by the researcher.

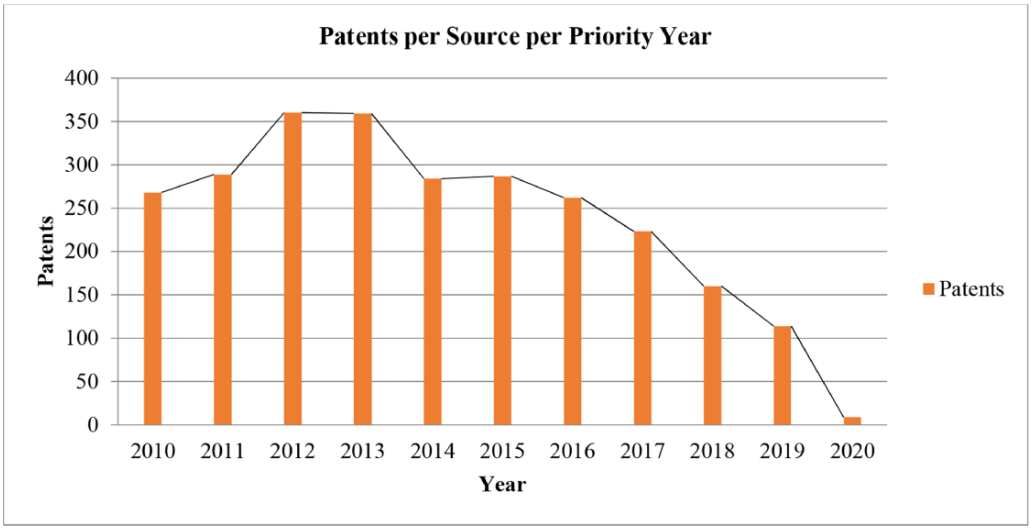

Figure 13. UK's EST patent grants from 2010 to 2021.
Source: Chart generated from Innography®, calculated and analysed by the researcher.

It is interesting to note that from these top six organizations having the highest percentage of patents in ESTs, five of them—namely, Panasonic Corporation, Honda Motor Co. Ltd, Toyota Motor Corporation, Hitachi Ltd and Nissan Motor Co. Ltd—have the highest application success rate in patent prosecution (in Fig. 23).

From Fig. 22, it can be seen that Toyota Motor Corporation has the highest number of EST patents and generates revenues of over $275 billion, whereas China Petrochemical Corporation (Sinopec Group) has 11,485 EST patents but generates the highest revenue compared to the top 20 organizations that worth over $419 billion.

Fig. 23 represents the top five organizations out of 20 675 organizations involved in patent-related prosecutions and their application success rates. About 95 312 EST-related patents were involved in patent application prosecutions out of these organizations and amongst them, Honda Motors Co. Ltd had a 100 per cent application success rate for the 1882 patents in question, as did Panasonic Corporation, Hitachi Ltd and Nissan Motor Co. Ltd Toyota Motor Corporation have

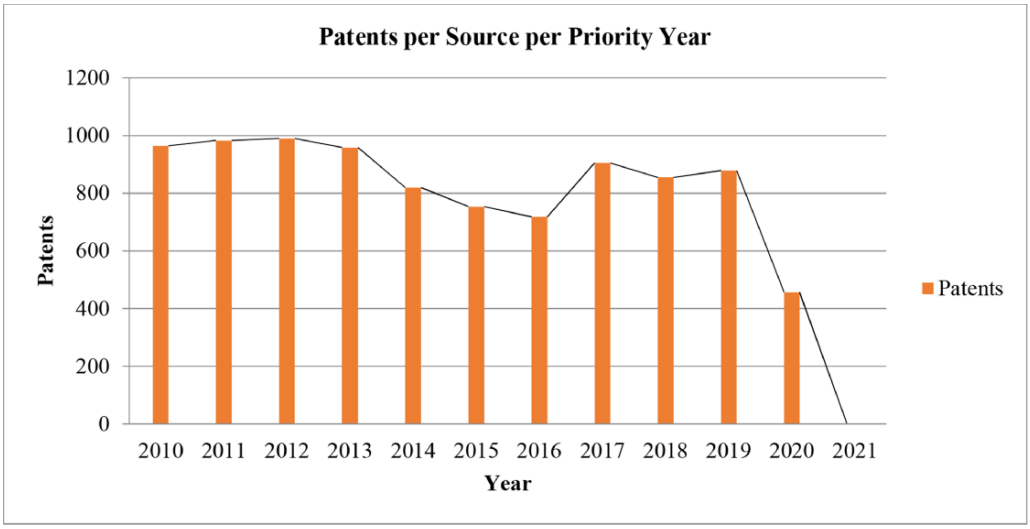

Figure 14. France's EST applications from 2010 to 2021.
Source: Chart generated from Innography®, calculated and analysed by the researcher.

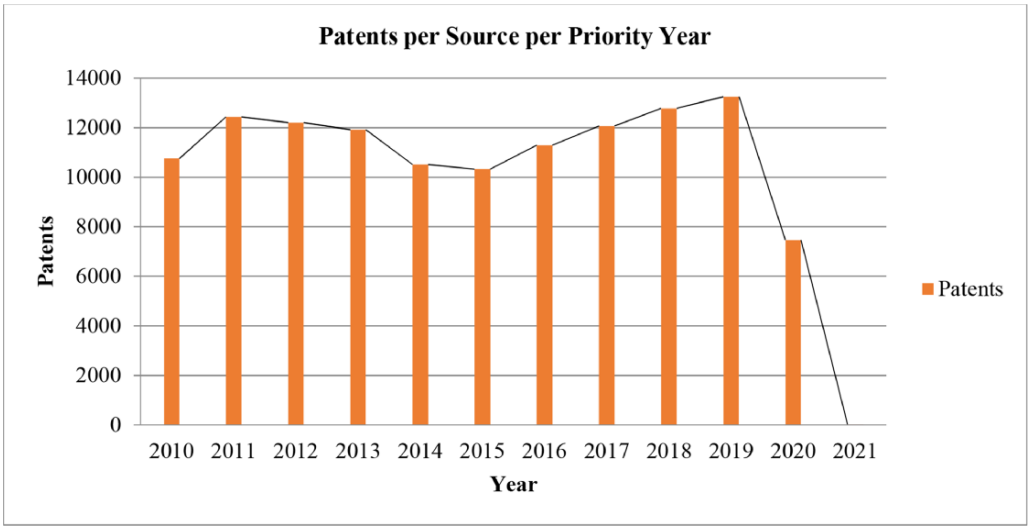

Figure 15. WIPO's EST applications from 2010 to 2021.
Source: Chart generated from Innography®, calculated and analysed by the researcher.

99 per cent success rate with five active prosecutions and 19 non-granted patent applications.

Market landscape

Innography®'s Market Maps give a picture of the competitive landscape depending on the search parameters. The size of a bubble represents the number of relevant documents possessed by that organization in comparison to other organizations, while the placement on the chart shows that organization's comparative perspective and resources.

The following market maps have two axes to part the map into four quadrants:

- Resources Axis: This includes three major characteristics that are not unique to the landscape under evaluation—total income, litigation and the number of sites. In general, the higher a bubble is positioned on the Resources axis, the better the capacity of that business to capitalize on its patents.
- Vision Axis: This combines three main factors particular to the search parameters specific to the landscape being analysed—the size of the patent portfolio in the technology sector, the number of different patent

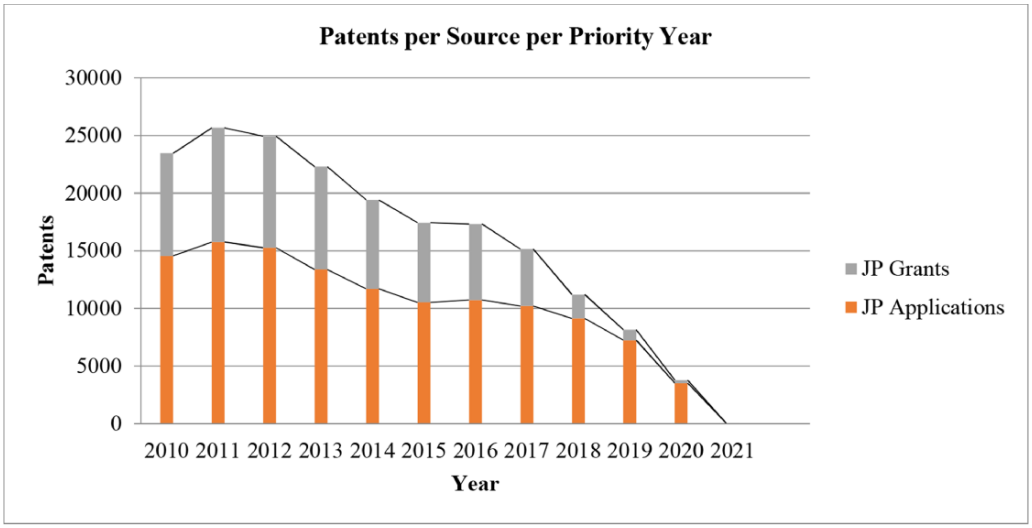

Figure 16. Japan's EST patent applications and grants from 2010 to 2021.
Source: Chart generated from Innography®, calculated and analysed by the researcher.

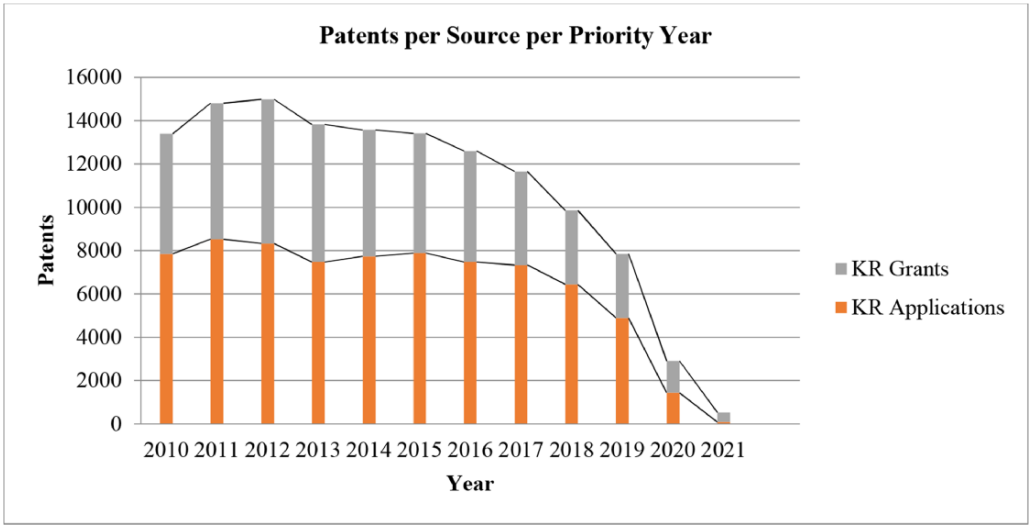

Figure 17. South Korea's EST patent applications and grants from 2010 to 2021.
Source: Chart generated from Innography®, calculated and analysed by the researcher.

classifications indicated by the patents and the number of citations on that organization's patents in the area. The greater the company's concentration and presence in the region or nation searched, the further to the right a bubble will be positioned.

The two axes' midpoints separate the market map into four main quadrants that can approximately define the licencing standpoint of the organizations selected in the search. These market map quadrants are:

1. Incumbents: These are located at the very top of the Resources and Vision axes. They have significant patents, a vision in the region and the R&D to carry out that ambition. They are usually and have been for some time the market leaders in the concerned region.
2. Potential Buyers: They are towards the top of the Resources axis but fall short in Vision. They may wish to challenge the market leaders, but they will require aid in developing their vision. On the other side, this qualifies them as possible licencing prospects; firms with substantial finances that could be interested in capitalizing on organizations in the Potential Sellers quadrant.

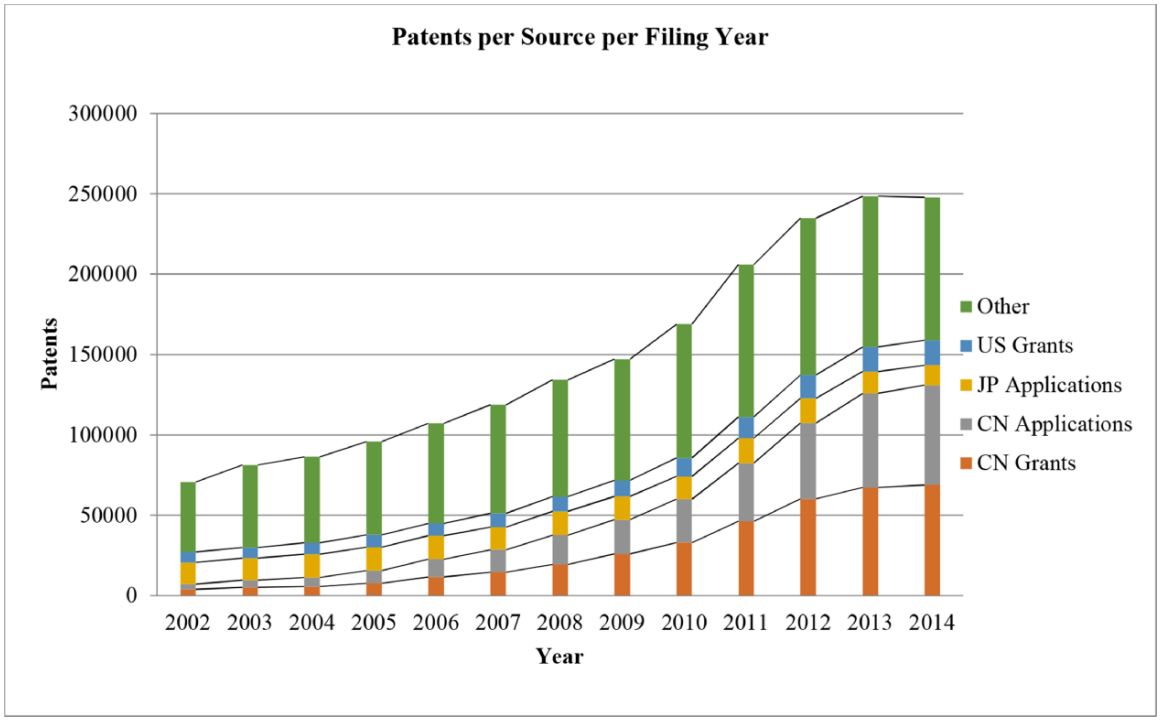

Figure 18. Patents per source per filing year.
Source: Chart generated from Innography®, calculated and analysed by the researcher.

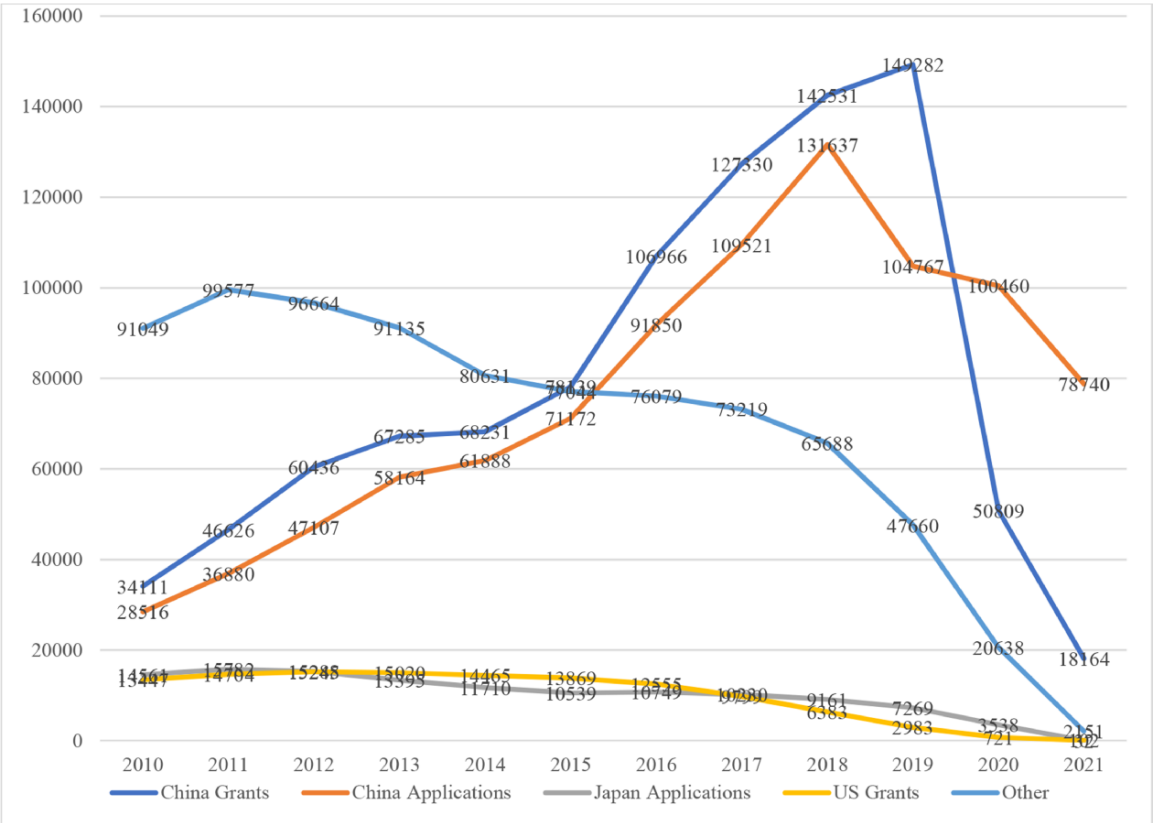

Figure 19. Top five sources by priority year.
Source: Chart generated from Innography®, calculated and analysed by the researcher.

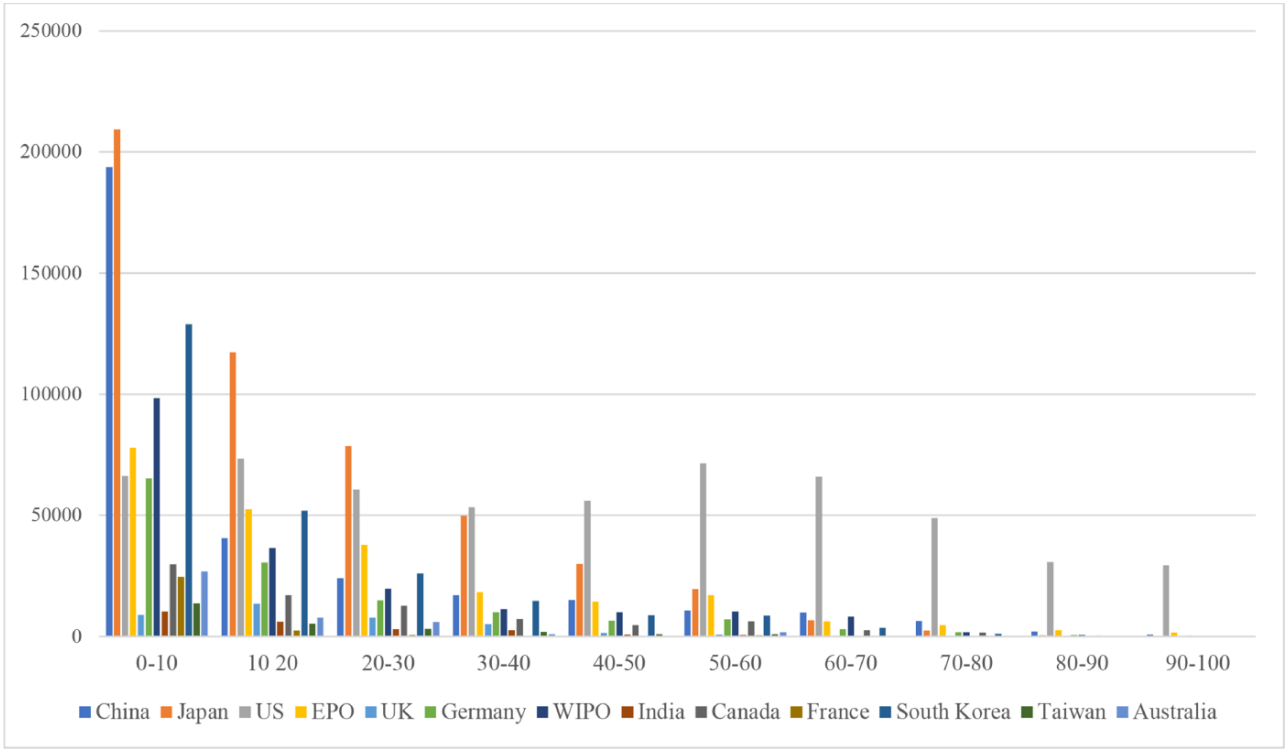

Figure 20. PatentStrength® of ESTs in different countries.
Source: Chart generated from Innography®, calculated and analysed by the researcher.

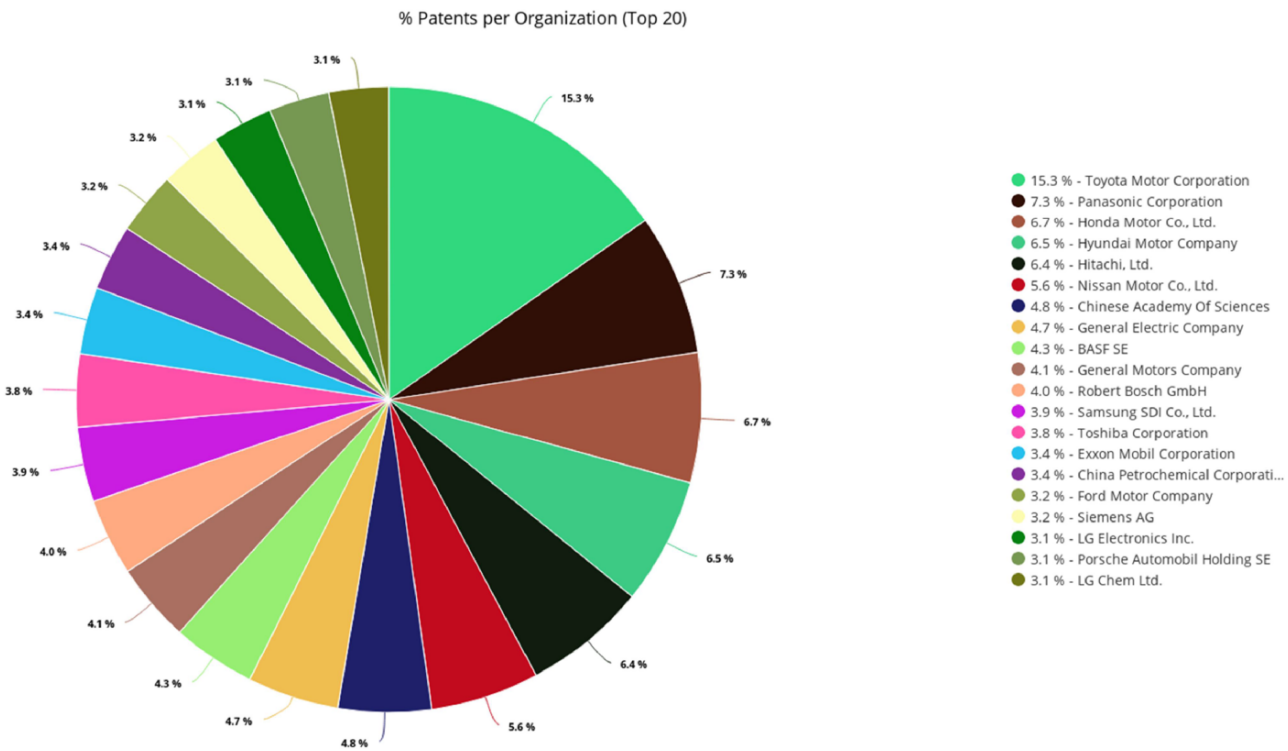

Figure 21. Percentage of patents per organization (top 20).
Source: Chart generated from Innography®, calculated and analysed by the researcher.

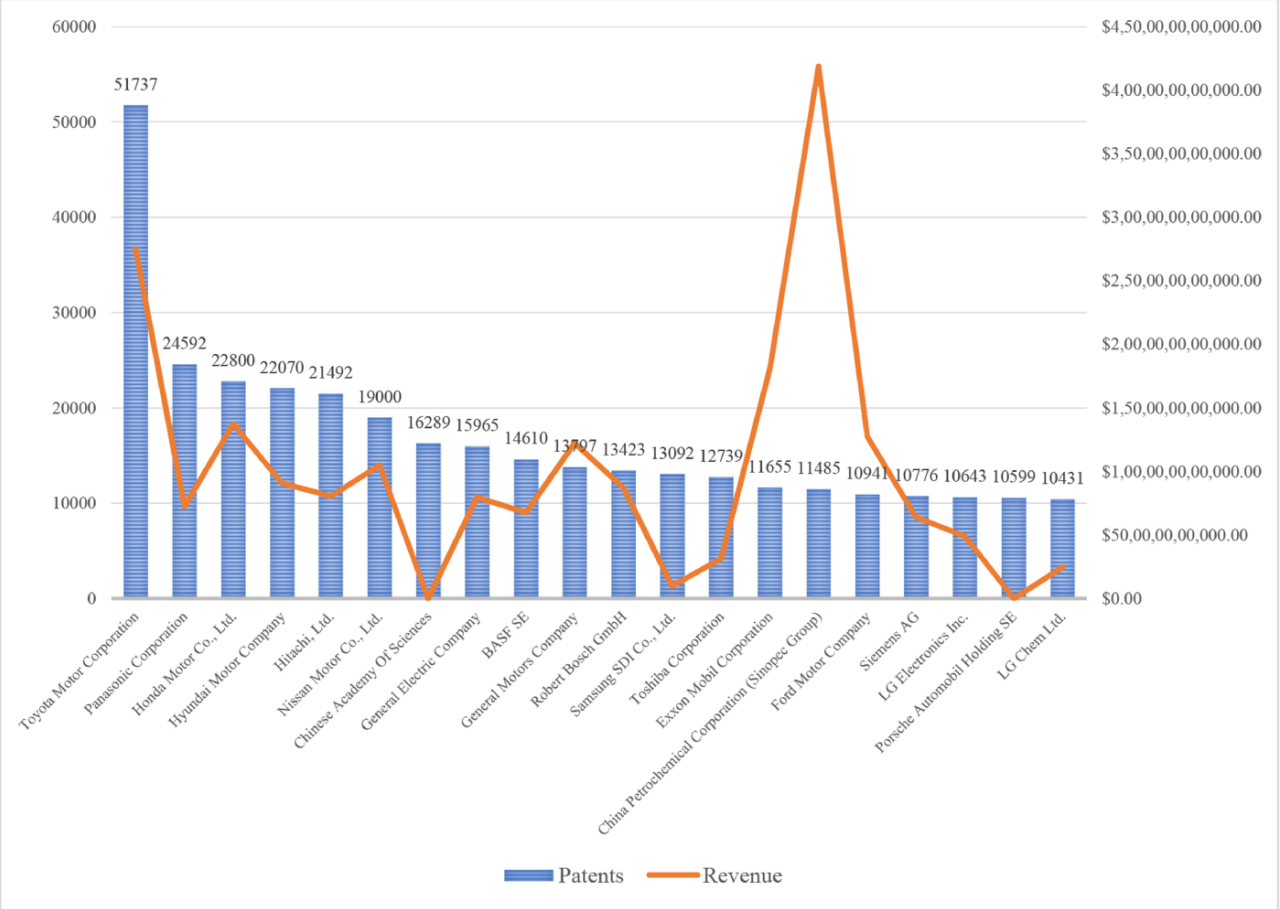

Figure 22. Patents per company (with revenue).
Source: Chart generated from Innography®, calculated and analysed by the researcher.

3. Followers/Entrants: They are deficient in both Resources and Vision axes. They do not have a big goal or a lot of R&D to execute it as they are just starting to establish themselves in the market. Several of them, though, can be active in and even influence a small fraction of that region/market.
4. Potential Sellers: These are located near the bottom of the Resources axis but at the top of the Vision axis. They have a strong idea, and, with the proper collaborator or potential buyer, they may easily ascend to the position of Incumbent.

If the assignee has a higher location on the Resources axis, it will have a larger capacity to profit on its patents, and it will also have a better competitive power on patent activities if it has a higher mark on the technological axis. As a result, the map depicts assignees' competitiveness in a certain technical sector, implying the relative strength of technological innovation.

From Fig. 24, it can be seen that there are a number of organizations in the upper right quadrant with a better position in the Vision and Resources axes—meaning, they have a better plan and resources to execute it. Among these organizations, Toyota Motor Corporation is on the upper right side of the map, and it also has the highest number of patents in ESTs, making it one of the key dominant players in the market and giving it a better competitive position from the rest.

General Electric Company is seen in the same quadrant as Toyota Motor Corporation but to the far-right side of the Resources axis, meaning it has a competitive advantage over its resources compared to others in the market.

China Petrochemical Corporation (Sinopec Group) is on the top left quadrant and has significant competitiveness for recourses, enabling it to become a competitor in the EST market as well as a prospective buyer. The other assignees are in the lower left quadrant; they are the main patent assignees in the field of EST, comprising not only niche performers or start-ups but also market entrants and followers.

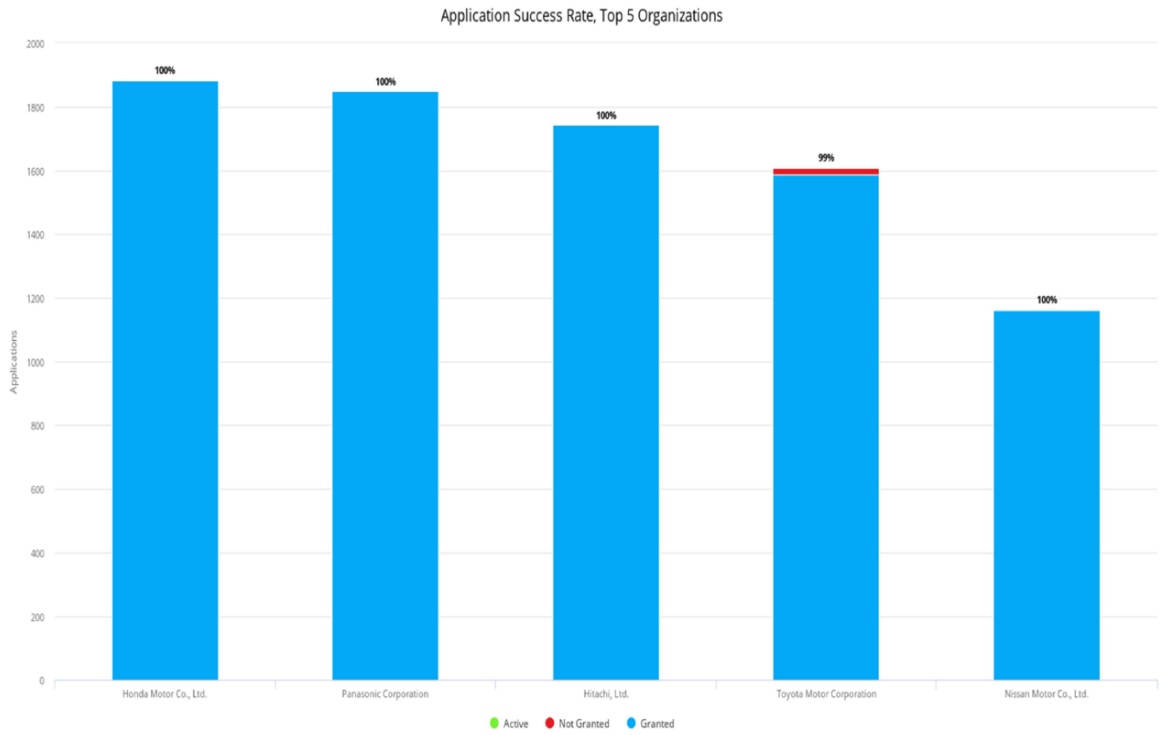

Figure 23. Prosecution data: Application Success Rate (top five organizations).
Source: Chart generated from Innography®, calculated and analysed by the researcher.

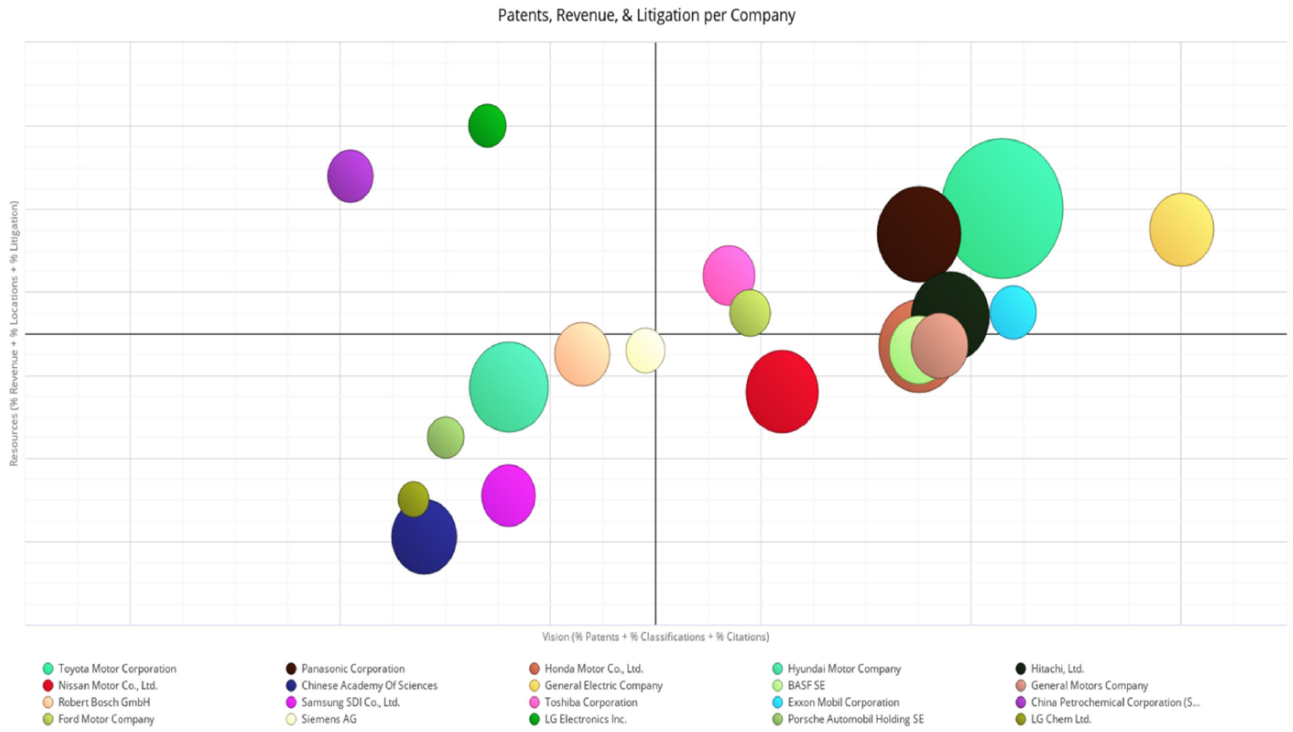

Figure 24. Market map of organizations worldwide.
Source: Chart generated from Innography®, calculated and analysed by the researcher.

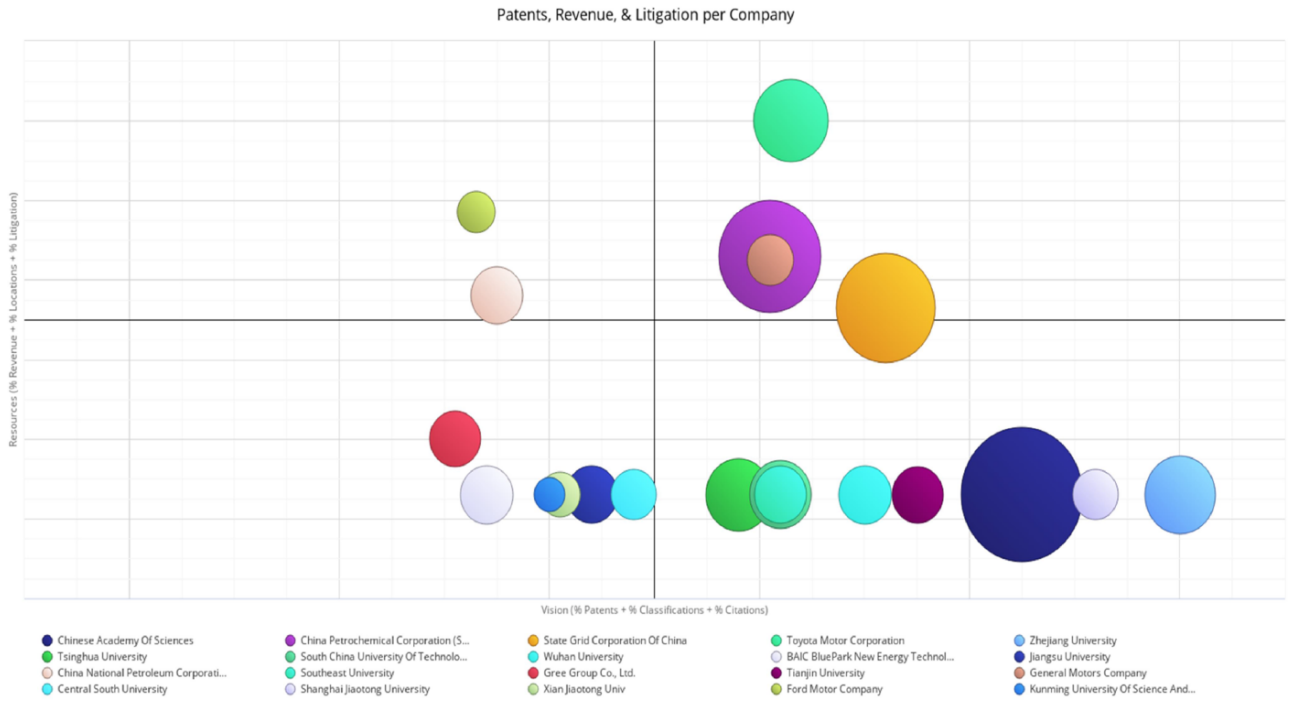

Figure 25. Market map of organizations in China.
Source: Chart generated from Innography®, calculated and analysed by the researcher.

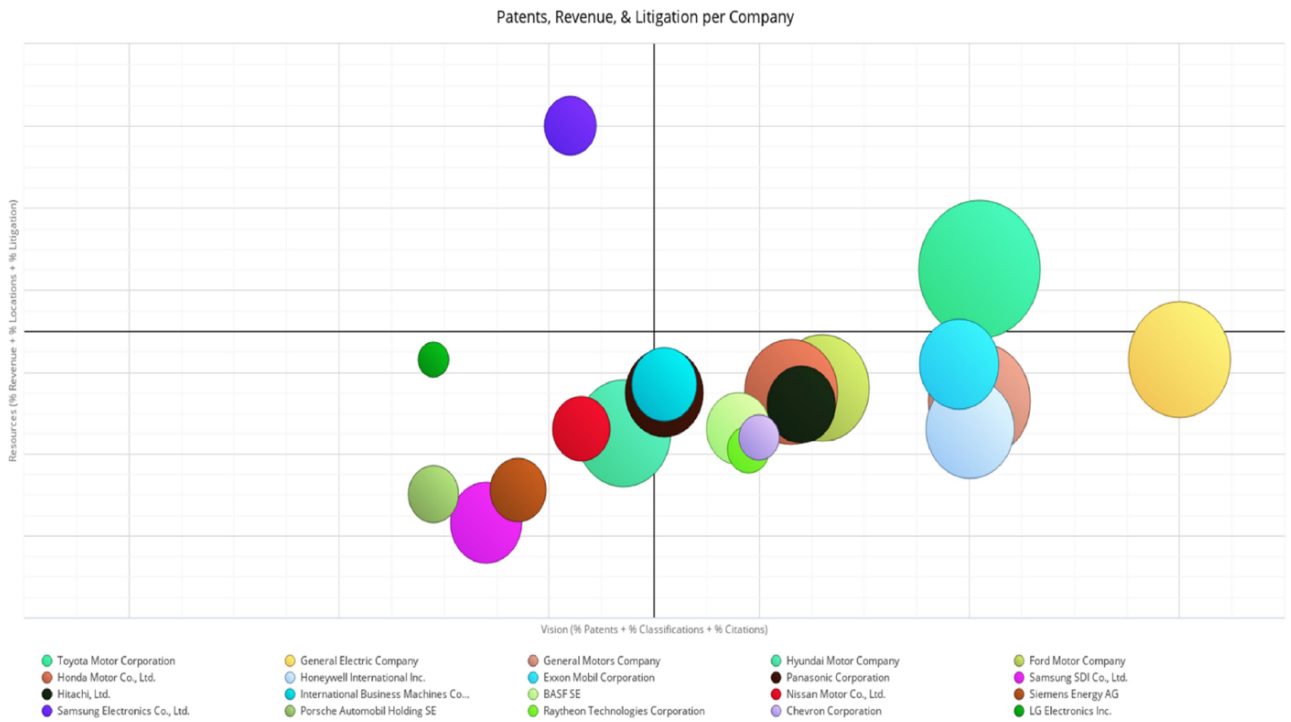

Figure 26. Market map of organizations in the USA.
Source: Chart generated from Innography®, calculated and analysed by the researcher.

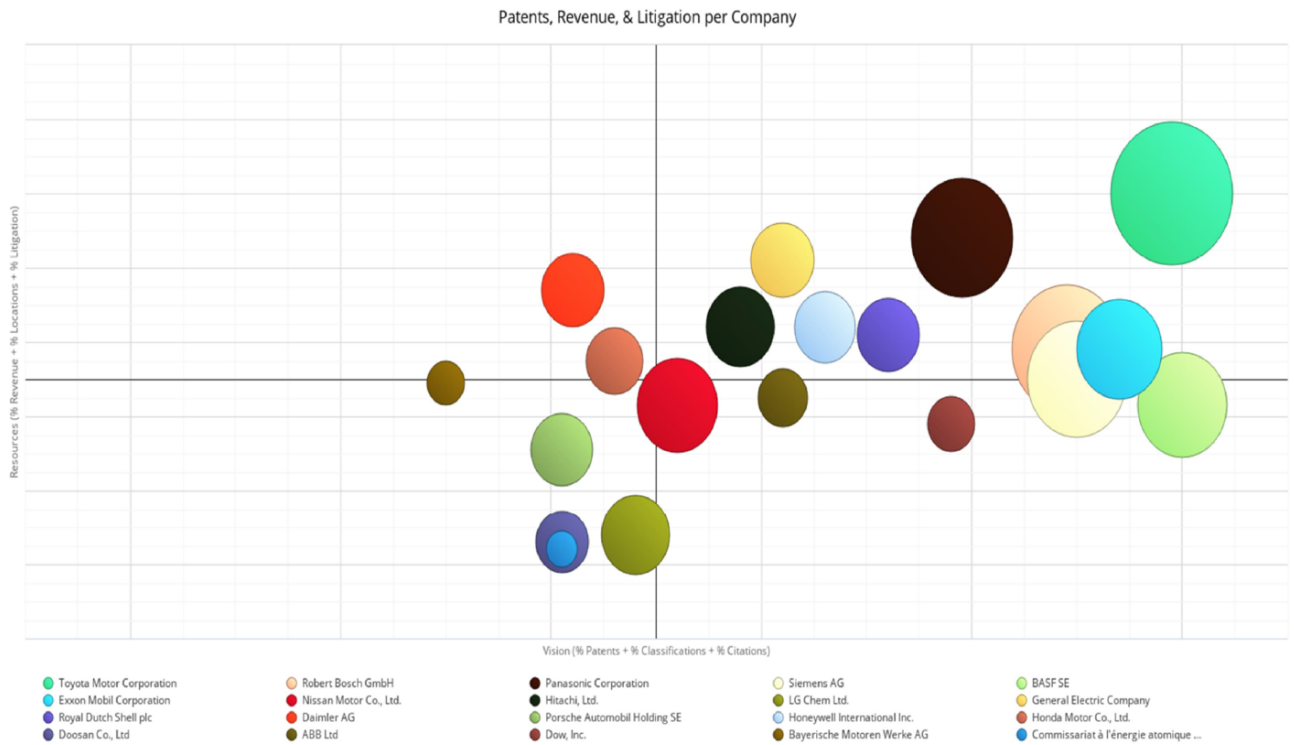

Figure 27. Market map of organizations filed through WIPO.
Source: Chart generated from Innography®, calculated and analysed by the researcher.

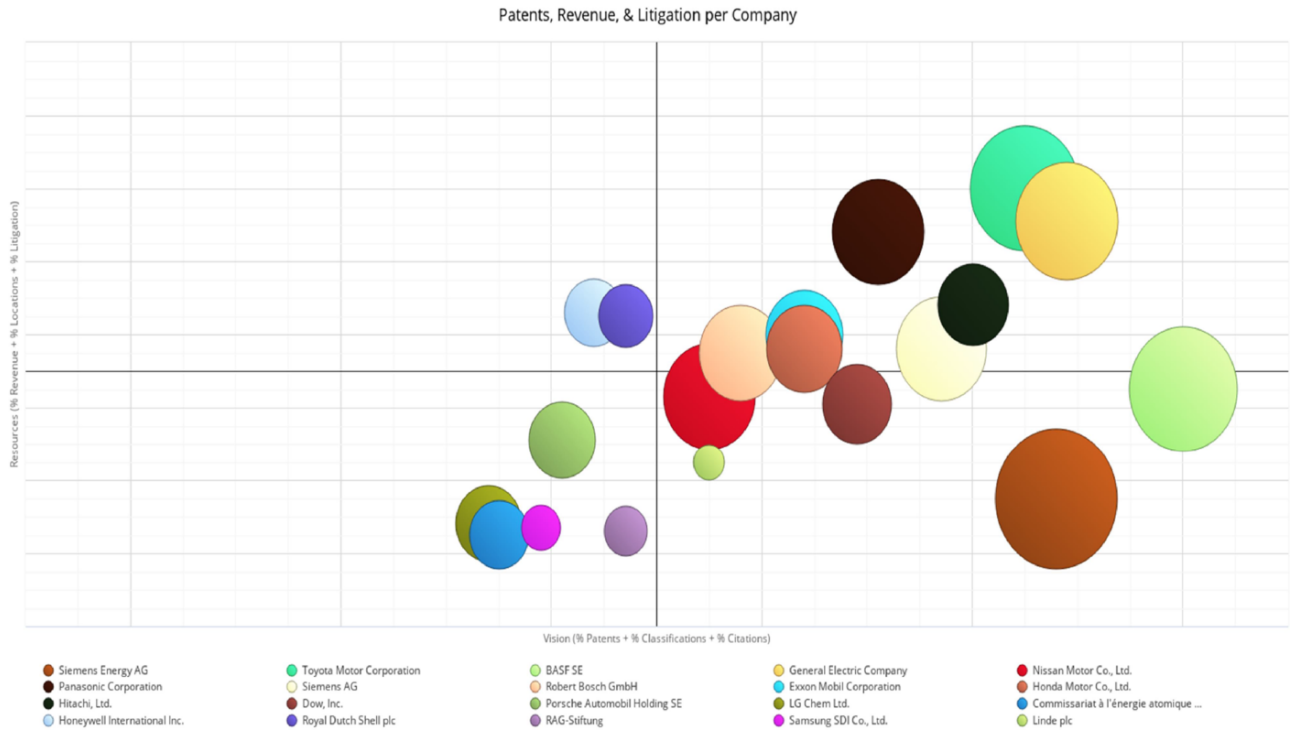

Figure 28. Market map of organizations filed through EPO.
Source: Chart generated from Innography®, calculated and analysed by the researcher.

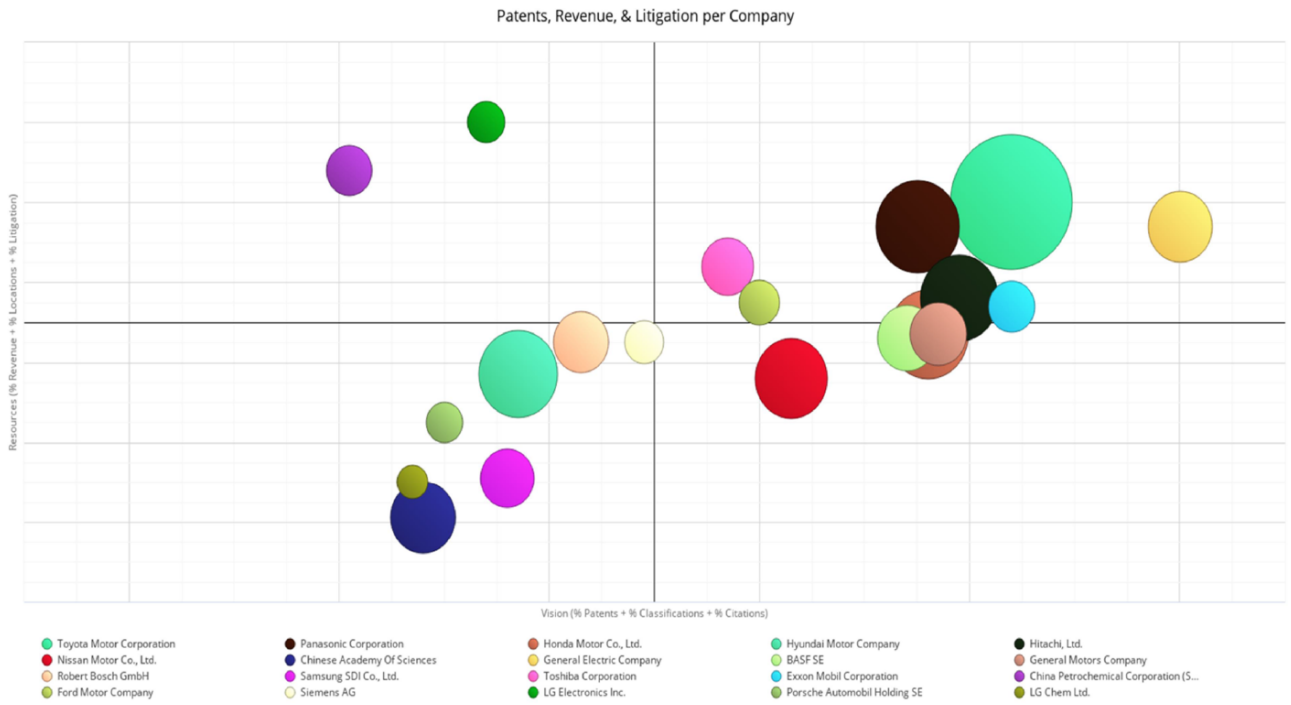

Figure 29. Market map of organizations in India.
Source: Chart generated from Innography®, calculated and analysed by the researcher.

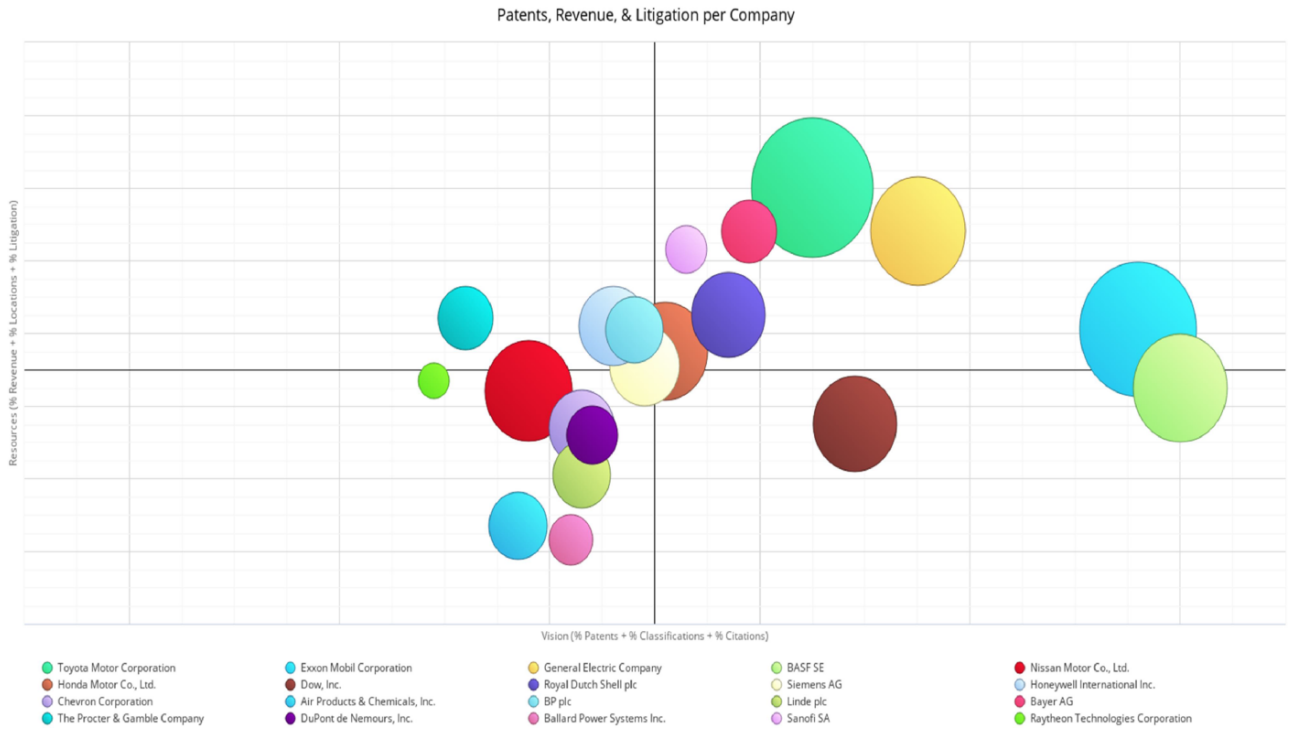

Figure 30. Market map of organizations in Canada.
Source: Chart generated from Innography®, calculated and analysed by the researcher.

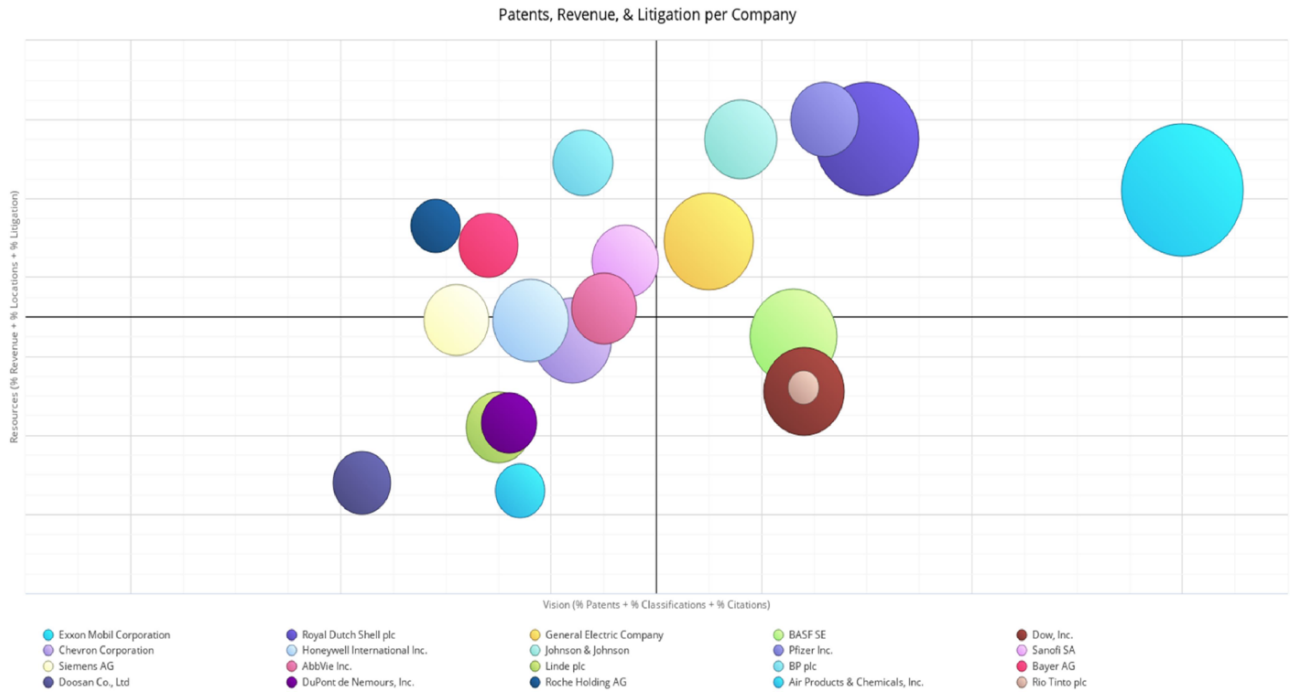

Figure 31. Market map of organizations in Australia.
Source: Chart generated from Innography®, calculated and analysed by the researcher.

Fig. 25 depicts the competitive position of the top 20 patent assignees in the field of EST in China. As to the geographical composition of the type of patent assignees, there are also 17 domestic assignees and three foreign assignees (namely, Toyota Motor Corporation, Ford Motor Company and General Motors Company). However, among all the domestic assignees, there are 12 universities and 5 companies, and among the foreign assignees, one is from Japan (Toyota Motor Corporation) and the other two are from the USA.

From the foreign assignees, Toyota Motor Corporation and General Motors Company are in the top right quadrant, which implies that they have a good competitive stand in the Chinese market. There is only one competitor from China—China Petrochemical Corporation (Sinopec Group), which has a similar strong competitive stand in their market of ESTs.

Figs 26–30 show the market map of the USA, WIPO, EPO, India and Canada, which share the dominance of Toyota Motor Corporation in the market (as shown in the right quadrant of the map). General Electric Company also maintains a relatively similar position in these countries in the concerned market competition (although its position in the USA is not better when compared to the rest).

In the case of Australia (Fig. 31), fossil fuel companies like Exxon Mobil Corporation, Royal Dutch Shell plc and Chevron Corporation have a good hold in the market, with all the R&D for ESTs, as well as the vision to implement it. Given they are in the top right quadrant of the market map, they have obvious competitive capabilities in resources and have been market leaders for quite some time.

Conclusion

New technologies typically provide new challenges to current legal systems, promoting legal evolution. Nevertheless, more stability in the legal domain would encourage innovative industries. It is important to understand the divide of patent ownership between various developing and developed countries so as to mitigate the issue of climate change at large.

This article showed that a lot of changes have taken place in recent years and, although the existing literature supports certain findings, others differ from previous research. Our work opens up pathways to explore why the ownership of ESTs is so scattered between developed and developing countries and how certain organizations have dominance in the market of a particular economy. For example, the OECD Statistics data show that developed countries have more EST patents based on priority dates than BRIC countries. Compared to other countries, China has made substantial progress with the

patenting trends and represents an example of environmental leapfrogging—where many developing countries often skip the initial stages of development in innovation and progress towards the environmental goals at a relatively faster pace.[19]

On the one hand, the data collected based on the inventor's location (where in the world the inventions are actually coming from) showed that China has the highest number of inventors in EST patents followed by the USA. But, on the other hand, the patent strength data showed the USA has some of its patents in a higher patent strength scale compared to the EPO, Canada and Germany, as well as to all the developing countries.

These findings and empirical data are relevant to IP and sustainability for several reasons. First, they help researchers and policymakers understand the rate and direction of technological change in the green technology sector. This information is essential for predicting future trends and identifying areas where further research and development efforts are needed to address sustainability challenges.

Second, they can help evaluate the effectiveness of government policies and regulations aimed at promoting sustainable technologies. By analysing the trends in patent filings before and after the implementation of policies, researchers can determine if such policies have had the desired impact on innovation in the green technology sector.

Third, from an IP perspective, empirical green technology patent data can be used to analyse the ownership and distribution of patents in the field of sustainability. This information is essential for understanding the role of IP in promoting or hindering innovation in the green technology sector. For example, researchers can analyse the concentration of patents among a few large firms or countries, which may suggest that some players have a dominant position in the green technology market. This information can help policymakers identify potential antitrust concerns and take measures to promote fair competition.

In conclusion, empirical green technology patent data are essential for understanding the technological and IP landscapes of sustainable development. The analysis of these data can provide valuable insights into the trends and challenges of the green technology sector, which is critical for developing effective policies and promoting sustainable innovation.

19 World Development Report, *Sustainable Development in a Dynamic World Transforming Institutions, Growth, and Quality of Life* (Oxford University Press 2003) 65.