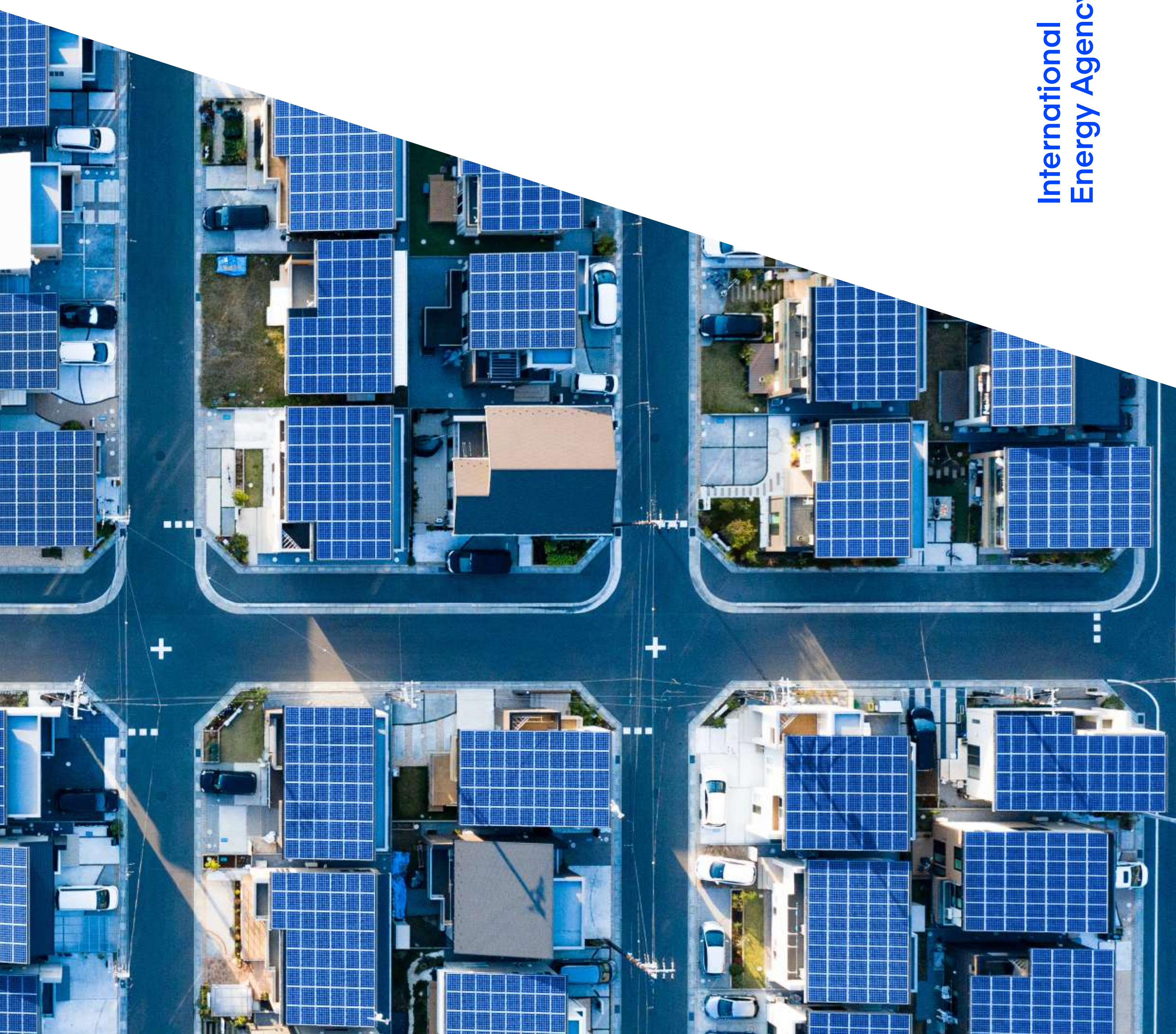
A Global Review of Patent Data for Smart Grid Technologies

International Energy Agency



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Abstract

The clean energy transition increases electricity demand and requires more wind and solar power, stressing power grids. Smart grid technologies can manage this transition, reduce the need for costly new infrastructure, and improve grid resilience and reliability. Understanding innovation in the area enables informed decision-making for policymakers and investors. This report draws upon the analysis of The European Patent Office (EPO) PATSTAT patents database which provides a highly valuable source of information to quantify innovation. It analyses trends in smart grid technology innovation, detailing the timing, locations, and subsectors of these advancements. By examining innovation at the city level it uncovers the geographical model of smart grid innovation. Additionally, this report measures smart grids specialisation using metrics developed by the Organisation for Economic Co-operation and Development (OECD), such as the Revealed Technology Advantage (RTA) to understand if a country specialises in certain technologies related to the rest of the world. Furthermore, it evaluates patent quality using OECD-developed measures such as originality and patent claims.

Acknowledgements, contributors and credits

This report was prepared by the Data Development and Support Unit in the Energy Data Centre (EDC) of the International Energy Agency (IEA). Konstantina Kalogianni was the lead author and co-ordinated the analysis and production of the report with a major contribution by Ashley Acker.

Aloys Nghiem, Head of the Data Development and Support Unit, provided guidance on the development of the report. Valuable comments and strategic direction were provided Nick Johnstone, Chief Statistician and Head of the Energy Data Centre.

Simon Bennett and Brendan Reidenbach provided invaluable comments and feedback on the report. Hélène Dernis (STI Division) and Ivan Hascic (ENV Division) from the Organisation for Economic Co-operation and Development (OECD) also played a key role in transferring OECD patent knowledge and expertise to the IEA. The report was edited by Justin French-Brooks.

Thanks go to the IEA's Information System Unit; in particular to Nestor Abraham and Ivo Letra for setting up the data infrastructure that allowed this analysis.

The IEA would also like to thank Antonello Monti (Professor, Institute Director at RWTH Aachen University), the expert who provided valuable inputs, review and encouragement.

This work forms part of the Digital Demand-Driven Electricity Networks Initiative, supported by the Clean Energy Transitions Programme, the IEA's flagship initiative to help energy systems worldwide move towards a secure and sustainable future for all.

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Executive summary

In the pursuit of a cleaner energy sector, smart grid technologies are pivotal in modernising a consistently overloaded grid. In this report we focus on analysing trends in smart grid technology innovation, showcasing where, when and in which subsectors innovation is occurring and revealing specialisation and patent quality within the sector.

2011 saw a peak in smart grid innovation with 2 000 unique inventions produced, representing 11% of power sector innovations. Following a period of decline, the relative share of smart grid innovations increased to 13% in 2022, aligning with the trajectory of the IEA Net Zero by 2050 Scenario.

In 2020 technologies related to monitoring or controlling equipment for energy generation units and supporting power network operation or management collectively accounted for 41% of total smart grid patent registrations – the largest share among all smart grid categories. This increased share may be linked to the rising capital investment in power equipment during recent years.

In recent years, East Asia (mainly Japan and China) has dominated smart grid innovation, accounting for over half of the total. Since 2007 it has consistently held the top position among regions. North America (mainly the United States) and Western Europe (mainly Germany) together share the remaining smart grid inventions.

In the last two decades, there has been a transition from Europe and the Americas being the primary sources of smart grid innovation to Asia taking on a more prominent role in this field.

More than 40% of smart grid innovation is happening in ten cities around the world, showcasing a concentrated innovation model. The top metropolitan areas for innovation between 2000 and 2022 were Tokyo, Seoul, Beijing, Nagoya, Nuremberg and the San Francisco Bay Area.

Europe emerges as a hub for smart grid technology specialisation, as shown by the Revealed Technological Advantage (RTA). Conversely, Japan, the United States and China exhibit lower RTAs, suggesting that despite their considerable innovation endeavours in smart grids, they lack a distinct specialisation in this particular field of innovation.

Although family size has decreased in smart grid inventions in more recent years, showing that inventors choose to protect their inventions in fewer offices, patent claims have increased since 2009. Patent claims typically suggest increased market value, indicating a trend towards more valuable inventions in more recent years.

Introduction

The success of the energy transition will require a profound transformation of the power system across a multitude of areas, including power plants, transmission and distribution systems, and consumer practices. Key components of this transition are the increase in electricity demand due to electrification and the large-scale deployment of variable renewables resulting in greater complexity in managing variability on the electricity grid. Smart grid technologies will play a key role in facilitating this transition by making our grids more efficient, resilient and reliable, as well containing operational costs for new grid infrastructure. Digital technologies will also allow to integrate continually increasing shares of renewables from multiple sources, and further engage end users so that they can improve energy efficiency and reduce emissions (IEA, 2023a).

Measuring digital innovation in the power sector (smart grid innovation) is crucial for tracking, improving and implementing policies to effectively shape the process of digitalisation. However, quantifying innovation proves to be challenging as very few standardised metrics are available. In this rapidly evolving landscape, patent data serve as a proxy measure of investment in innovation, offering valuable insights into the intellectual prowess and competitive strategies of people and organisations striving to redefine how we generate, transmit and utilise electrical power in the digital age. The European Patent Office (EPO) and its PATSTAT patents database provides a highly valuable source of information to quantify innovation. It is noteworthy that in recent years there has been a noticeable trend towards "openness" and the uptake of open-source solutions. Consequently, this might have pushed research teams to refrain from filing patents in certain instances (Jahn, Klebel, Pride, Knoth, & Ross-Hellauer, 2022).

Chapter 1. Main trends in smart grid innovation

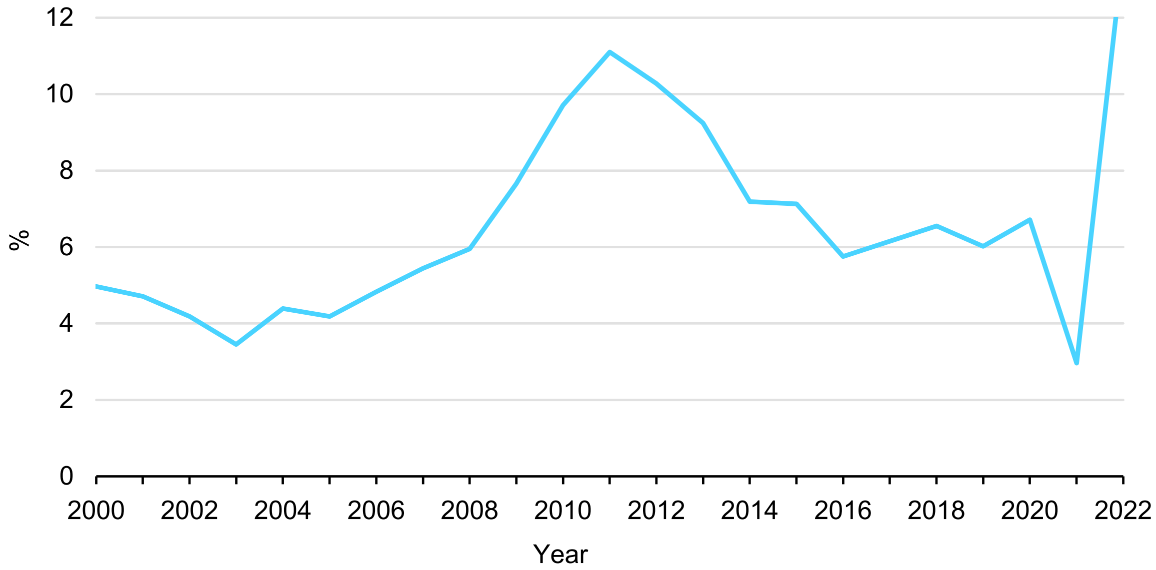
Innovation in the field of smart grids can be measured by analysing International Patent Families (IPFs)[1] in the Y04S category of the Cooperative Patent Classifications (CPCs), which includes power network operation, communication and information technologies used to improve electric power generation, transmission, distribution, management or use, as explained in detail in Box 1. The Y04S smart grid category was developed by the EPO and the USPTO (United States Patent and Trademark Office) in 2013 alongside the Y02 codes that feature climate change mitigation technologies. The IEA and the EPO published a thorough report to keep track of the patenting activity in the low-carbon energy technologies (Y02/Y04S schema) (IEA, 2021). In the present report, the focus is on the Y04S category. Aggregating by year, technology field, and country or region of inventor in the Y04S category or subcategories can reveal interesting trends in the process of digitalisation of the grid.

Between 2000 and 2023[2] there were approximately 16 000 IPFs globally in the technology domains associated with smart grids, constituting 0.2% of total IPFs across all technologies. Overall, from 2000 to 2023, IPFs corresponding to smart grid technologies represented about 5% of IPFs within the H02 CPC category (referred as power sector for the rest of this report). In 2011 smart grid innovation represented around 11% of the innovation in the power sector and then a gradual decrease to 7% was observed in later years (Figure 1). The peak of smart grid innovation in 2011 occurred before the peak of innovation in the broader category "low carbon energy", which occurred in 2012 (IEA, 2021). Relatively speaking, smart grid innovation's decrease in recent years (2016-2021) (Figure 1) can be explained by the lack of stability in grid investment, especially in developing economies. It is essential that investments are directed towards the digitalisation of the electricity network (and by extension to innovation) as a way of enabling the greater deployment of renewable energy. Overall investment in smart grids needs to more than double through to 2030 – from around USD 300 billion/year currently to almost USD 600 billion/year – to get on track with the Net Zero by 2050 Scenario. Investment in smart grid technologies among other factors will foster

[1] A proxy for a distinct invention, corresponding to a set of patent applications published in at least two countries. More details can be found in the Methodology section.
[2] With patent data, the most recent years are often incomplete due to lags in data inputting. While 2022 data are also shown in the graphs of this report, the focus is usually on 2021 data as they provide a more accurate representation of the most recent technology trends. We use 2022 data when computing ratios of the Y04S category to the H02 category, 2021 data when referring to counts of IPFs by year and data up to 2023 when referring to global IPF counts for all the years.

innovation in the field (IEA, 2023b). Provisional data for 2022 highlight that there might be a peak in smart grid innovation as a share of power innovation in 2022, anticipating an increase in the desired direction.

Figure 1 Smart grid IPFs as a share of power IPFs, 2000-2022



Notes: 2022 data should be considered provisional due to the time lag in patenting procedure; however, when used as a share, 2022 data can show a direction to be confirmed in the coming years.
Source: IEA analysis based on European Patent Office (2024), PATSTAT patents database (using the Spring 2023 edition).

Box 1 Y04S Patent Categorisation

Y04S is a Cooperative Patent Classification (CPCs) developed by the EPO and USPTO. It includes power network operation, communication and information technologies used to improve electric power generation, transmission, distribution, management or use (i.e. smart grids), and is thus well suited to measure trends in innovation for digital power. The Y04S patent categories have five levels of hierarchy. The most aggregated groupings are listed in the structure below. More details on the Y04S classification can be found on Espacenet.

Y04S structure:

- Systems supporting electrical power generation, transmission or distribution.
- Systems supporting the management or operation of end-user stationary applications, including the last stages of power distribution and control, monitoring or operating management systems at a local level.

- Systems supporting specific end-user applications in the transport sector.
- Communication or information technology-specific aspects supporting electrical power generation, transmission, distribution or end-user application management.
- Market activities related to the operation of systems integrating technologies related to power network operation and communication or information technologies.

For simplicity the five Y04S categories have been grouped into three primary groupings:

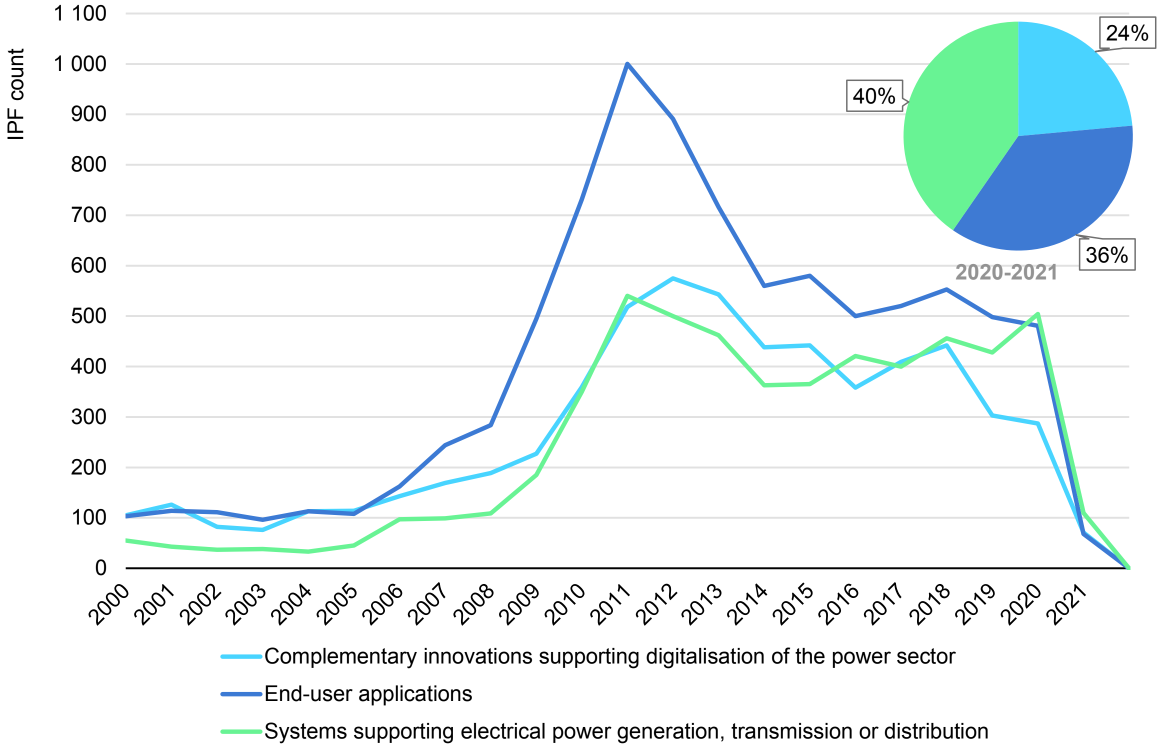
- Systems supporting electrical power generation, transmission or distribution.
- End-user applications.
- Complementary innovations supporting digitalisation of the power sector.

Trends in the primary groupings of smart grid IPFs

From 2005 to 2011 there was strong global growth in smart grid innovation as an increasing number of IPFs were registered. As noted above, the level of innovation has either plateaued or declined since 2011, depending on the smart grid technology (Figure 2). From 2000 to 2005 smart grid innovation in the three primary groupings followed the same growth trajectory.[3] Smart grid innovation has since been strongest in end-user applications, generating more IPFs than the other two categories from 2008 to 2014. From 2020 to 2021 we observe a peak in the share of smart grid IPFs involving systems supporting electrical power generation, transmission or distribution; this category represents 40% of the total smart grid IPFs registered in this period. More details about this trend are described in the next section. The absolute drop in numbers shown after 2020 is not further analysed as it might be due to the time needed for the administrative process of publishing an invention or updating the PATSTAT database.

[3] The primary smart grid groupings refer to the most aggregated groupings of smart grid patents, labelled Class 1 in Y04S. A simplification of Class 1 with three categories has been derived from Class 1. For more information, see Box 1.

Figure 2 **Global IPF count, 2000-2021, and share, 2020-2021, by smart grid technology grouping**

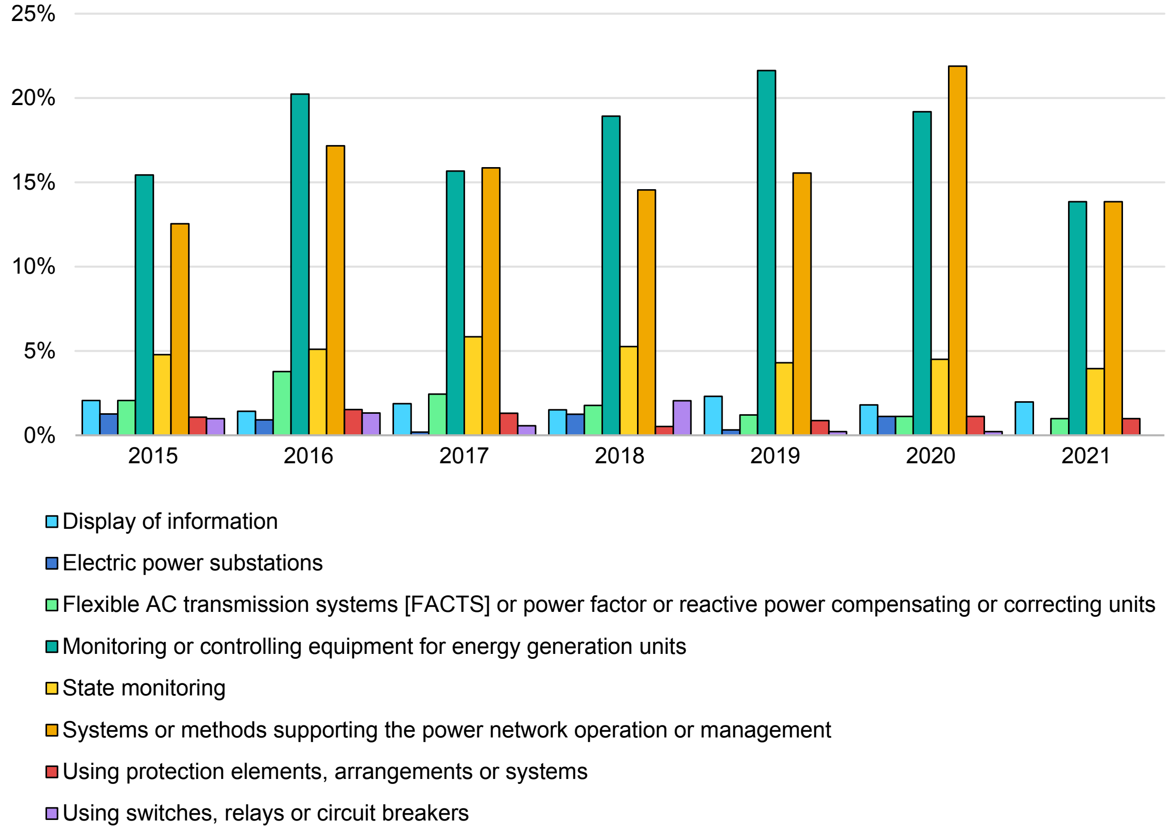


Source: IEA analysis based on European Patent Office (2024), PATSTAT patents database (using the Spring 2023 edition).

Systems supporting electric power generation, transmission or distribution

The category "Systems supporting electric power generation, transmission or distribution" had the largest share of the total IPF count during the most recent period of analysis (2020-2021). Over the past decade, two smart grid technologies have been the top contributors to innovation in this category: "Monitoring or controlling equipment for energy generation units" and "Systems or methods supporting the power network operation or management". In 2020 these technologies reached 19% and 22% of total smart grid patent registrations respectively (Figure 3). The increased share of these technologies from 2015 to 2020 may be attributed to a higher share of general capital investment being in power equipment in more recent years (2014-2019) (IEA, 2020). R&D expenditure (of which patents are an outcome) is considered to be an investment and therefore the share might be rising because of a more general increase in all kinds of investment in the power sector and higher revenues for equipment suppliers. The remaining smart grid technology categories are all below the 5% level.

Figure 3 Selected technology IPFs as a share of smart grid IPFs for electric power generation technologies, 2015-2021

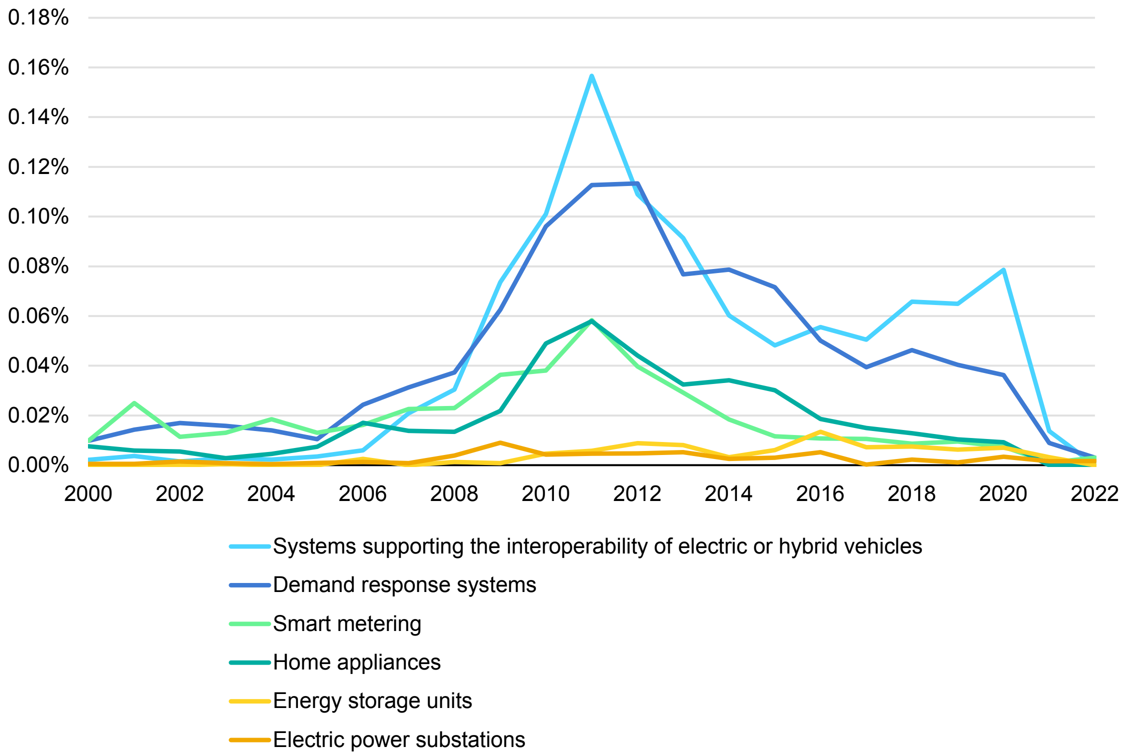


Source: IEA analysis based on European Patent Office (2024), PATSTAT patents database (using the Spring 2023 edition).

Technology areas of interest

Smart grid technologies – not surprisingly – account for a very low share of all IPFs globally. Comparing the share of IPFs in selected smart grid technologies over time and across technologies allows us to “control” for general trends in patenting caused by other factors (e.g. changes in intellectual property [IP] law or business strategies) (Figure 4). The highest shares of IPFs among the technologies of interest are in systems supporting the interoperability of electric or hybrid vehicles (a subcategory of “Systems supporting electrical power generation, transmission or distribution”) and in demand response systems (a subcategory of “End-user applications”). They both peaked in 2011 at 0.15% and 0.10% of all IPFs respectively, since when they have declined to either side 0.06%. To a lesser degree, the same trend can be seen in technologies related to smart metering and home appliances (both subcategories of “End-user applications”), which both peaked in 2011 at 0.05%. Energy storage units have experienced some growth in the past decade, but still account for only 0.01% of all IPFs.

Figure 4 Global IPFs for selected smart grid technologies as a share of all IPFs, 2000-2022



Source: IEA analysis based on European Patent Office (2024), PATSTAT patents database (using the Spring 2023 edition).

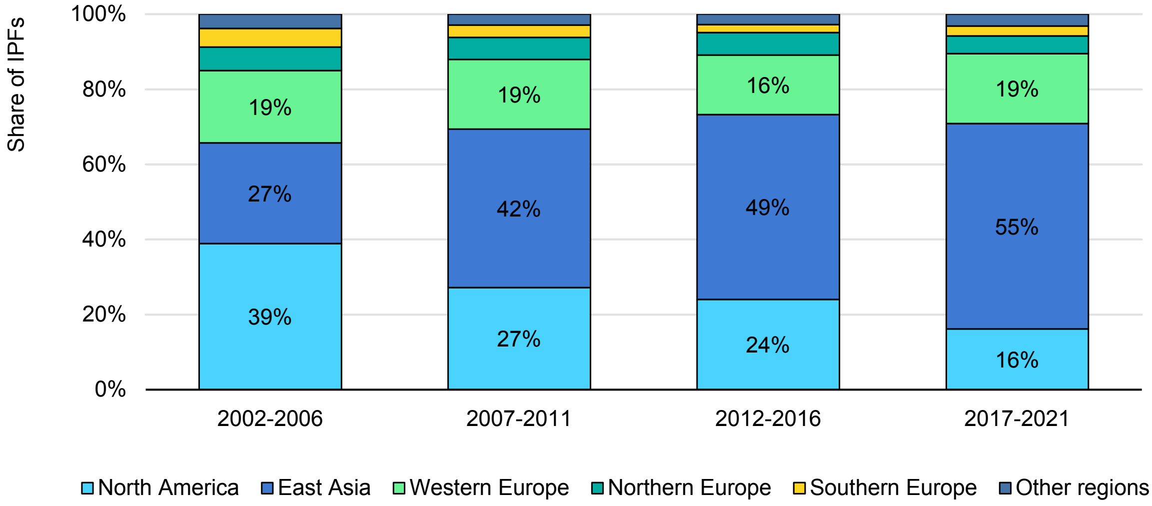
Geographical distribution of smart grid innovation

This section reports on the geographical spread of smart grid innovation as identified by the location of the inventors of IPFs for smart grid technologies. The inventor's location serves as a proxy for the locus of innovation, representing either the company's location (headquarters or corporate subsidiary location), the location of a university, or an individual inventor's place of residence. Where multiple inventors are indicated for a distinct IPF, each inventor and subsequently their location was assigned an equal fraction of the invention.

Regional trends

East Asia was responsible for more than half of smart grid innovation in the period 2017-2021 and has held the top position compared to other regions since 2007, with North America and Western Europe roughly splitting the remaining IPFs (Figure 5). In the last two decades there has been a transition from Europe and the Americas being the primary sources of smart grid innovation to Asia taking on a more prominent role in this field. North America experienced a peak share of smart grid innovation in the period 2002-2006, but consistently produced less than a third of global smart grid patents for the remaining years.

Figure 5 Smart grid fractional IPF share by region, 2002-2021

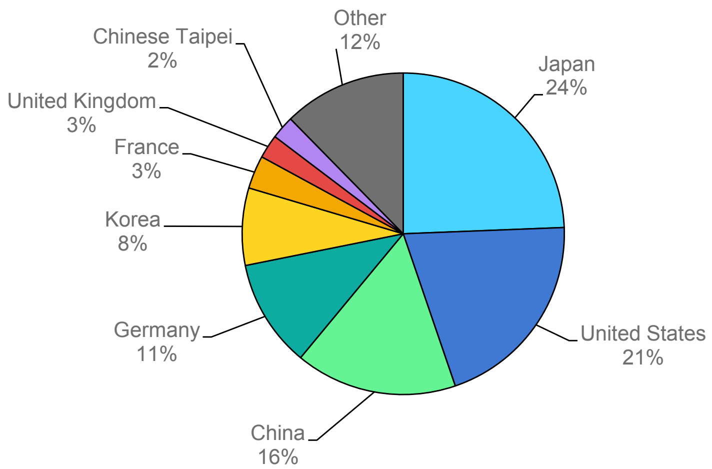


Source: IEA analysis based on European Patent Office (2024), PATSTAT patents database (using the Spring 2023 edition).

Country-level patterns

A quarter of smart grid IPFs registered in the past decade were from inventors residing in Japan, and nearly a quarter were from inventors residing in the United States. Half of the remaining registrations are from inventors in the People's Republic of China (hereafter "China"), Germany and Korea (Figure 6).

Figure 6 Smart grid fractional IPF share by inventor's country of residence, 2010-2021



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Source: IEA analysis based on European Patent Office (2024), PATSTAT patents database (using the Spring 2023 edition).

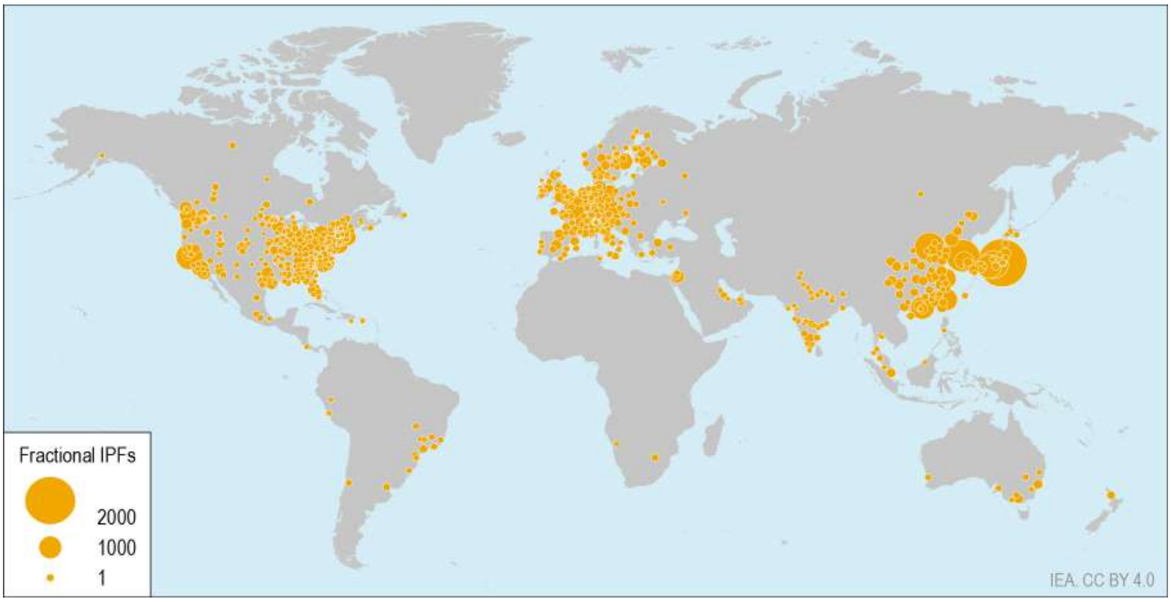
City hubs of innovation

It is possible to explore the geographical concentration of smart grid inventions in closer detail to identify metropolitan hubs of smart grid innovation. This is by geolocating the inventor's address and considering the inventor's contribution to the invention using fractional counts. Further detail can be found in the methodology section.

Between 2000 and 2022 innovation related to the digital transformation of the grid was witnessed in dozens of cities around the world. Overall, smart grids IPFs have been filed by inventors residing in 680 metropolitan areas or distinct cities (not within 100 km of a metropolitan area) around the world (Figure 7). At a regional level, smart grid innovation is predominantly taking place in East Asia, Western Europe and the west and east coasts of the United States.

A concentrated innovation model is identified, as more than 40% of smart grid innovation is happening in ten cities around the world, confirming previous findings on the concentration of digital innovation more generally (Paunov, Guellec, & El-Mall, 2019). The top six cities or areas of innovation from 2000 to 2022 are Tokyo, Seoul, Beijing, Nagoya, Nuremberg and the San Francisco Bay Area (Figures 8 and 9). Tokyo's prevalence (almost 2 000 fractional IPFs between 2000 and 2022) across the whole sector and within the Asia region can be explained as it is home to top digital innovation companies such as Toshiba, Fujitsu, Hitachi, Honda, Mitsubishi, NEC, Nishan Sony. Nuremberg in Germany (more than 500 fractional IPFs between 2000 and 2022) is the hub of innovation within the European region as it hosts Siemens and the Huawei Nuremberg Research Center, which specialises in power conversion and distribution technologies, advanced powertrain solutions for electric vehicles and power algorithm and grid connection technology. The San Francisco Bay Area (including Palo Alto, San Carlos and San Jose) is the centre of innovation in the United States as it is home to Tesla, PG&E, Schneider Electric and ChargePoint among others. Among non-Asian cities or areas after the San Francisco Bay Area and Nuremberg, Munich (ranked first in employment in the Information and communication technology (ICT) sector and home to top technical universities (Deloitte, 2018)) and Raleigh (home to the next-generation Power Electronics Innovation Institute in North Carolina) played an important role in smart grid innovation in the years 2011-2021 and 2011-2015, respectively (Figure 9).

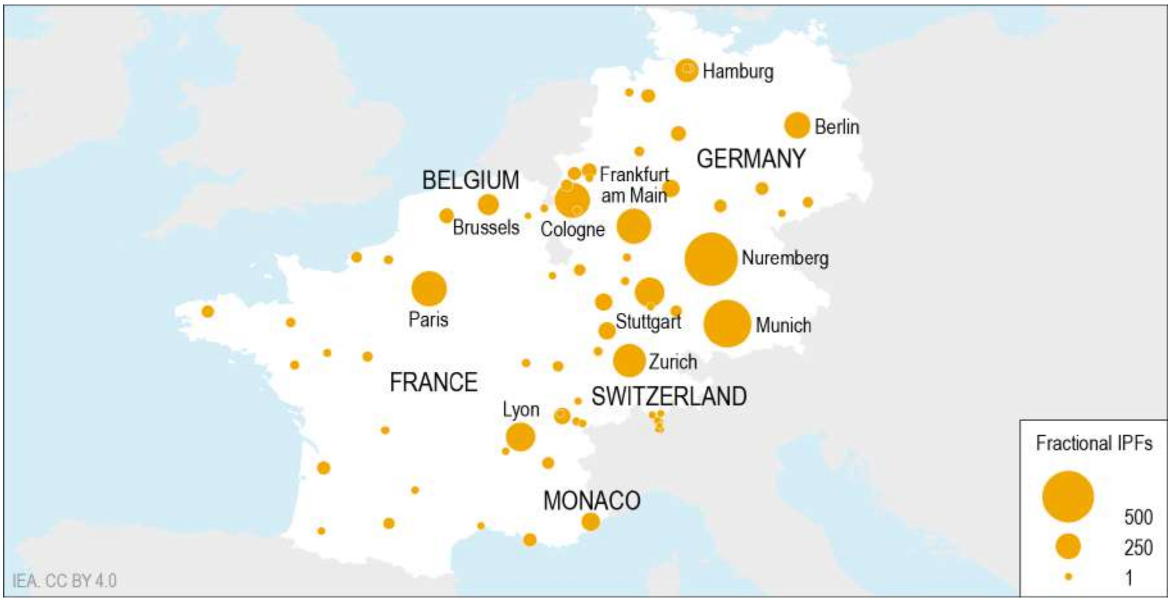
Figure 7 Global map of smart grid innovation city hubs, 2000-2022



Note: Bubble size denotes the sum of fractional IPFs per metropolitan area.
Source: IEA analysis based on European Patent Office (2024), PATSTAT patents database (using the Spring 2023 edition).

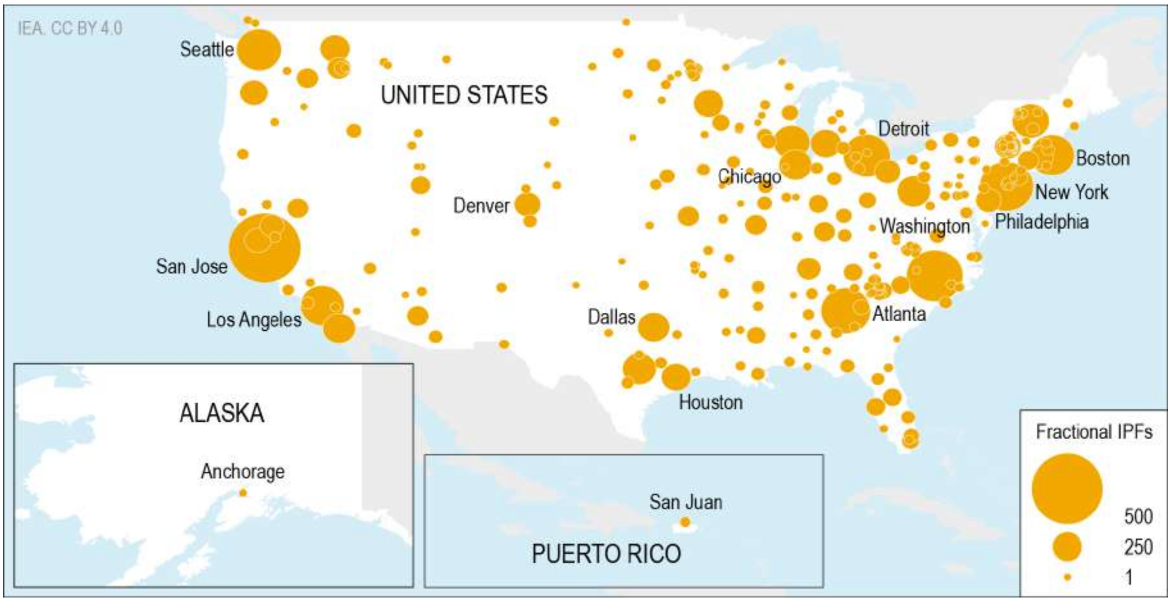
Figure 8 Western European, East Asian and US city hubs of smart grid innovation, 2000-2022

Smart grid innovation city hubs in Western Europe



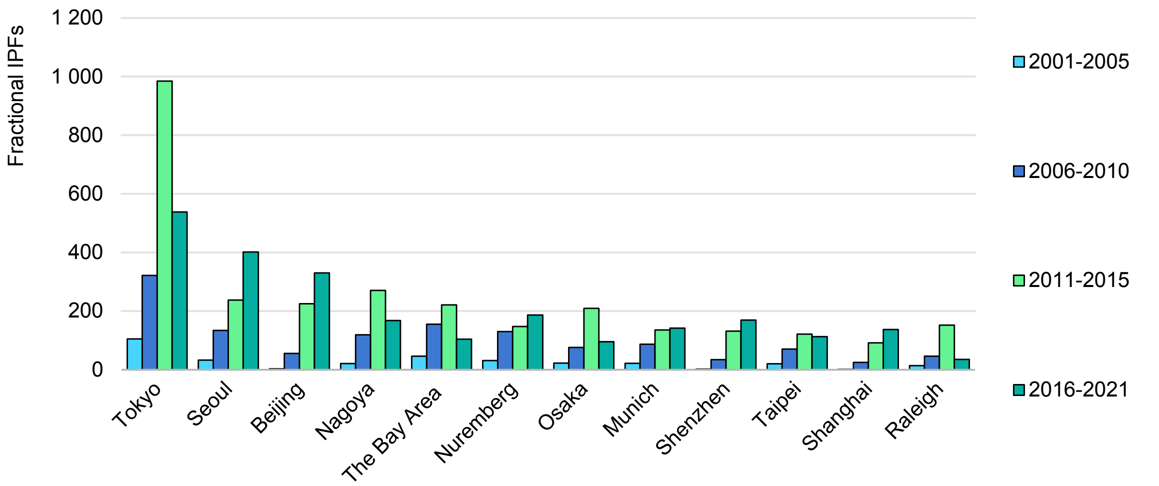
Smart grid innovation city hubs in East Asia

Smart grid innovation city hubs in the United States



Note: Bubble size denotes the sum of fractional IPFs per metropolitan area.
Source: IEA analysis based on European Patent Office (2024), PATSTAT patents database (using the Spring 2023 edition).

Figure 9 Top city hubs for smart grid innovation in five-year ranges by count of fractional IPFs, 2001-2022



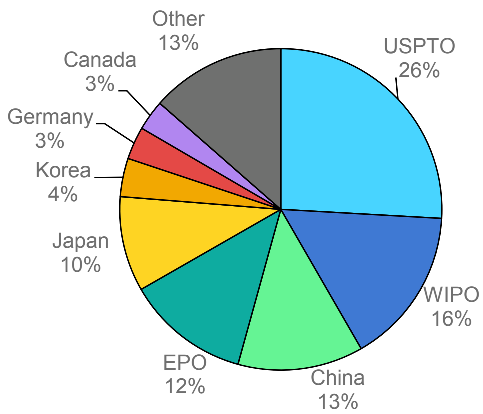
Source: IEA analysis based on European Patent Office (2024), PATSTAT patents database (using the Spring 2023 edition).

Innovation by IP office

While the inventor country of residence gives important information on where innovation is emerging in the world, the location of the IP office where patents are registered provides insights into the targeted markets for a given technology. This complementary view gives a better idea of trends in applications and the end use of patents. The first application filed worldwide (in any patent office) for a given IPF is known as the priority application; the year corresponds to the earliest filing year of a priority application. Priority applications serve to count unique inventions. Applications for the same IPF can be submitted in different offices and at different times, within the limits of the Patent Cooperation Treaty, resulting in a set of applications for one invention. Note that patents can be registered in a regional office (e.g. the EPO) or in a country office. The intended market for an invention influences their priority IP office, as well as the complexity of the patent application process for each IP office.

Nearly one-third of global smart grid patent applications were submitted in the USPTO, showing a high level of interest among smart grid inventors for the US market (Figure 10). The interest in the US market is constant throughout the years, as between 2000 and 2021 it is the first intended market for smart grid innovation. The World Intellectual Property Organisation (WIPO), the EPO and the IP office of China received between 16% and 12% each of the remaining patent applications. Other notable offices and by extension markets for smart grid innovation in the past decade include Japan (11%), Korea (4%), Germany (3%), Canada (3%) and Australia (3%).

Figure 10 Smart grid application counts by IP office, 2010-2021



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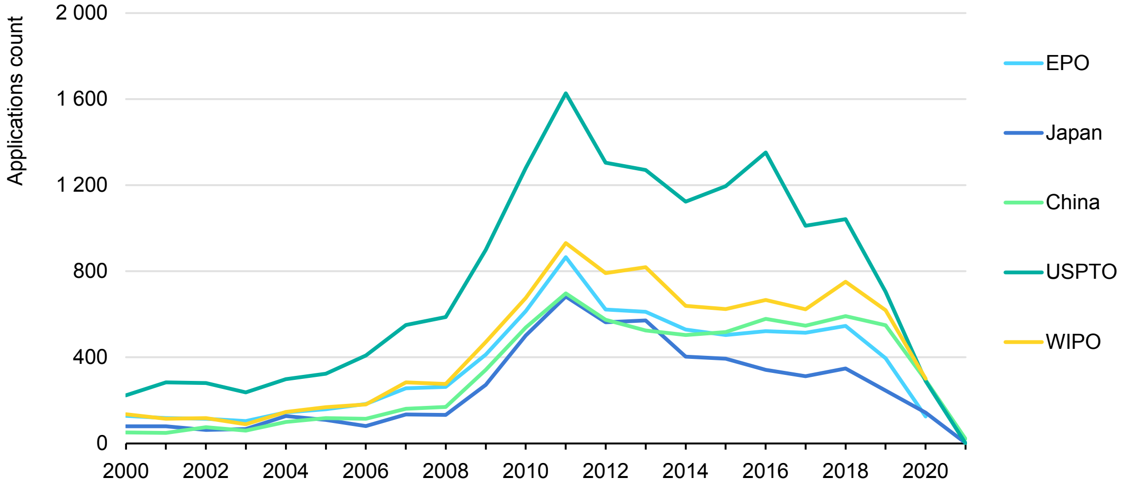
Source: IEA analysis based on European Patent Office (2024), PATSTAT patents database (using the Spring 2023 edition).

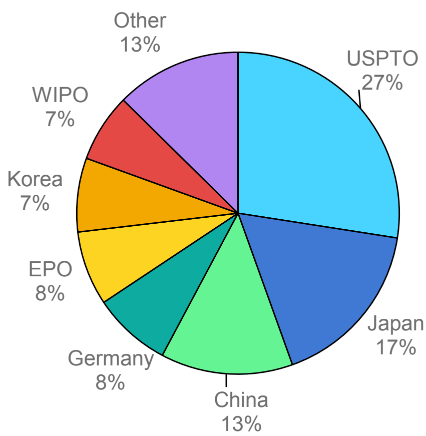
Figure 11 Smart grid application counts by IP office and year, 2000-2021



Source: IEA analysis based on European Patent Office (2024), PATSTAT patents database (using the Spring 2023 edition).

When looking at IPFs, rather than individual patents, the figure changes slightly. One-third of global smart grid priority IPF applications were submitted to the USPTO. Japan's and China's offices hold the second and third position in IPFs. Other intended markets for smart grid patents include Germany (9%), Korea (8%), France (3%), and the United Kingdom (3%) (Figure 12).

Figure 12 Smart grid priority IPFs by IP office, 2010-2021



Source: IEA analysis based on European Patent Office (2024), PATSTAT patents database (using the Spring 2023 edition).

Chapter 2. Revealed technology advantage for smart grid innovation

The identification of technology domains per country by means of fractional counts allows for analysis of a country's position in innovation relative to other countries. A frequently used indicator of a country's specialisation is the revealed technology advantage (RTA)[4] index, which indicates the country's specialisation in smart grid innovation relative to its overall innovation capacity (OECD, 2009). An RTA above one signifies a country's specialisation in a given technology (further detail can be found in Box 2). It is important to note that RTA reveals a country's comparative advantage in smart grid technologies, providing a more insightful indicator of specialisation compared to inventor counts. The latter simply reflect countries with high rates of innovation.

For this analysis, an RTA value was generated per country and smart grid technology over a five-year range for selected countries.[5] An RTA value was also calculated more narrowly within the power sector[6] to measure the importance of digital innovation within power sector innovation. Examining RTA within the power sector[7] allows us to understand if the power sector is becoming more specialised in digital technology applications.

General RTA

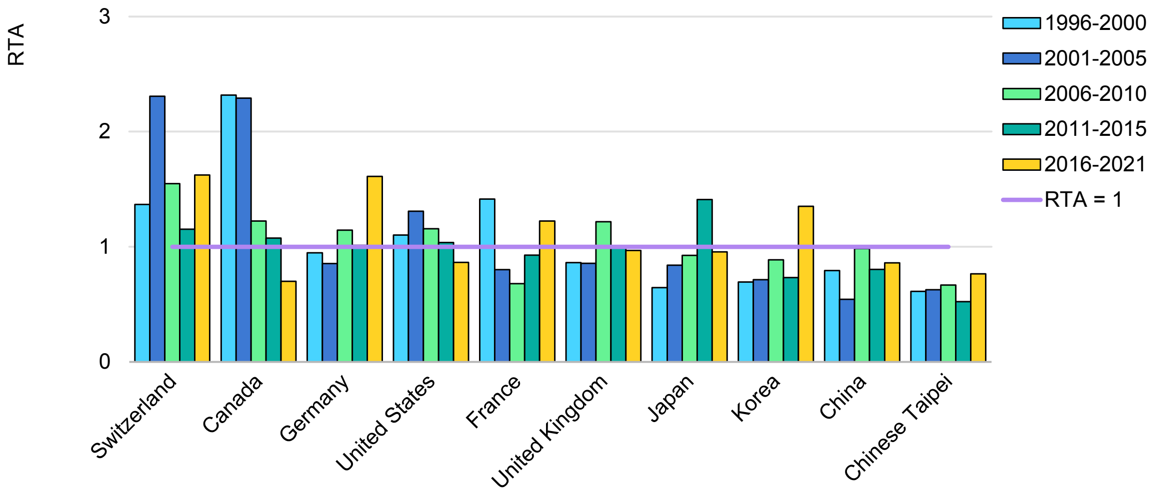
In recent years, Switzerland and Canada have emerged as more specialised in smart grid innovation compared to the rest of the world, as shown by the RTA index. Switzerland has been a global leader in smart grid innovation since 2001, when it had an RTA of 2.3. The most recent data (2016-2021) also reveal a specialisation in smart grid technology in Germany, Korea and France (respectively 1.61, 1.35, and 1.22) (Figure 13). Overall, Europe specialises in smart grid technology, although it does not produce the largest amount of innovation in this sector, as seen in Figures 5 and 6. Japan, the United States and

[4] The RTA is defined as a country's share of IPFs in a particular field of technology divided by the country's share of IPFs in all fields of technology (OECD, 2009). Further detail can be found in the Methodology section.
[5] As specified in the Methodology section, only economies with more than 500 patents in all technologies in a two year-period are reported.
[6] The power sector is represented under the H02 CPC classification: Generation; Conversion or Distribution of Electric Power.
[7] The RTA for the power sector is calculated as the share of technology (t) patents for a country among all patents in the power sector of that country, divided by the share of technology (t) patents in the world among all patents of the power sector in the world.

China show somewhat lower RTAs, indicating that despite their significant innovation efforts in smart grids, they do not specialise in this area of innovation.

Canada (5.8), Sweden (3.4) and Switzerland (3) specialised in the category “Systems supporting electrical power generation transmission or distribution” between 1996 and 2000 (Table 1), but Korea (1.72) has been the most specialised country in this category in more recent years (2016-2021). Switzerland (2.4) has been the most specialised country in the category “Complementary innovations supporting digitalisation of the power sector” in more recent years (2016-2021).

Figure 13 Smart grid innovation RTA index for selected countries, 1996-2021



Source: IEA analysis based on European Patent Office (2024), PATSTAT patents database (using the Spring 2023 edition).

Box 2 RTA index interpretation

RTA=0: The index is equal to 0 when the country holds no patents in a given technological field.

RTA=1: The index is equal to 1 when the country’s share in a technological field equals its share in all technological fields, showing no specialisation.

0<RTA<1: The index is between 0 and 1 when the country has patent activity in a specific technological field but is not specialised.

RTA>1: The index is above 1 when a specialisation in a given technological field is observed in the country. This measure lacks a right-bound, and thus it can potentially be infinite.

RTA within power: If an RTA within the power sector is N, it indicates that the country generates digital innovation in the power sector at a rate N times higher than the global average.

Table 1 Smart grid innovation RTA index for primary category groupings and selected countries, 1996-2021

	1996-2000	2001-2005	2006-2010	2011-2015	2016-2021
Complementary innovations supporting digitalisation of the power sector					
Canada	2.09	2.34	1.80	1.57	1.00
Chinese Taipei	0.52	0.40	0.30	0.39	0.75
France	1.53	0.96	0.70	0.69	1.28
Germany	0.82	0.81	1.28	0.96	1.44
Italy	1.49	1.14	1.19	0.61	1.24
Japan	0.47	0.82	0.71	1.02	0.73
Korea	0.78	0.47	1.04	0.66	1.05
China		0.47	1.00	0.87	0.85
Sweden	2.21	1.01	1.19	1.14	1.17
Switzerland	1.32	3.32	2.24	1.85	2.41
United Kingdom	0.55	0.61	0.62	0.81	1.03
United States	1.22	1.42	1.25	1.38	1.12
End-user applications					
Canada	1.73	2.79	0.80	0.78	0.53
Chinese Taipei	0.67	0.98	0.92	0.63	0.96
France	1.42	0.89	0.74	1.08	1.41
Germany	0.94	0.85	1.00	1.04	1.86
Italy	1.56	1.34	1.02	0.73	0.98
Japan	0.58	0.66	0.99	1.57	1.09
Korea	0.60	0.92	1.00	0.77	1.27
China	1.45	0.59	0.88	0.68	0.71
Sweden	0.29	0.41	0.51	0.70	0.87
Switzerland	1.00	0.43	0.55	1.02	1.28
United Kingdom	1.00	1.08	1.58	1.17	1.18
United States	1.25	1.35	1.21	0.94	0.81
Systems supporting electrical power generation, transmission or distribution					
Canada	5.76	3.10	1.20	1.13	0.75
Chinese Taipei	1.13		0.13	0.35	0.42
France	0.78	0.25	0.34	0.73	0.92
Germany	0.74	0.58	1.21	0.92	1.54
Italy	0.74	0.18	0.69	0.26	0.94
Japan	0.74	1.41	1.08	1.76	1.03
Korea	0.17	0.43	0.65	0.58	1.72
China			1.05	0.79	0.91
Sweden	3.45	0.75	1.93	0.45	1.63
Switzerland	2.95	5.09	2.53	1.00	1.59
United Kingdom	0.41	0.61	0.71	0.77	0.87
United States	1.08	1.26	1.20	0.91	0.74

Note: Orange shading indicates values from 0 to 1, with deeper shades representing lower RTA values. Values nearing 1 appear white, while those exceeding 1 are green, with darker shades indicating higher RTA values.
Source: IEA analysis based on European Patent Office (2024), PATSTAT patents database (using the Spring 2023 edition).

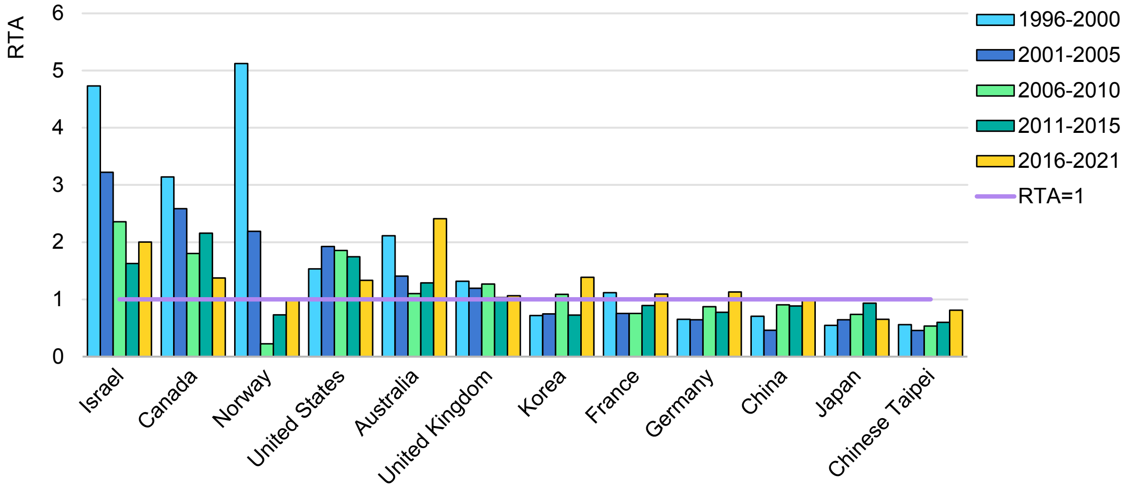
RTA within the power sector

Looking at the RTA index for smart grid innovation within the power sector specifically (H02 in the CPC categorisation)[8] – as opposed to within innovation overall – allows us to understand if the power sector is specialising in digital technologies.

When examining the smart grid innovation RTA index within the power sector, a distinct pattern emerges: Norway is the leader in the period 1996-2005 with an RTA of 5.12, closely followed by Israel[9] with an RTA of 4.73. Israel is the stable leader in smart grid innovation with an RTA of 2 in the period 2016-2021, followed by Canada. More recently, Australia and Korea show a specialisation in the smart grid sector with an RTA of 2.41 and 1.39, respectively. Surprisingly, the RTA for Japan, China and Chinese Taipei are consistently below 1, indicating a comparatively lesser degree of specialisation in the digitalisation of the power sector despite their high scores in relation to both the global average in the power sector and also innovation in general as depicted in Figure 6.

Norway's specialisation (15) is particularly important in the category "Systems supporting electrical power generation transmission or distribution" between 1996 and 2000. Israel's specialisation lies in the category "End-user applications" between 1996 and 2000. In more recent years (2016-2021), Israel (4.4) has been specialising in "Complementary innovations supporting digitalisation of the power sector" closely followed by Australia (4) (Table 2).

Figure 14 Smart grid RTA index within the power sector, selected countries, 1996-2021



Source: IEA analysis based on European Patent Office (2024), PATSTAT patents database (using the Spring 2023 edition).

[8] Y04S and H02 are two distinct categories and Y04S is not a subset of H02.
[9] The statistical data for Israel are supplied by and under the responsibility of the relevant Israeli authorities. The use of such data by the OECD is without prejudice to the status of the Golan Heights, East Jerusalem and Israeli settlements in the West Bank under the terms of international law.

Table 2 Smart grid innovation RTA index within the power sector for primary category groupings in selected countries, 1996-2021

	1996-2000	2001-2005	2006-2010	2011-2015	2016-2021
Complementary innovations supporting digitalisation of the power sector					
Australia	2.4111	1.2997	1.5469	1.5006	3.9917
Canada	2.8308	2.6392	2.6434	3.1564	1.959
France	1.2126	0.9027	0.7768	0.6703	1.1402
Germany	0.5657	0.6114	0.9749	0.7364	1.0121
Israel	0.7217	1.3583	0.8044	1.9878	4.3838
Japan	0.3968	0.6291	0.5648	0.6763	0.5006
Korea	0.8089	0.4855	1.2818	0.6523	1.0734
Norway	3.4249	3.1932	0.6085	0.6679	0.449
China		0.3944	0.9226	0.9599	0.9798
United Kingdom	0.8319	0.8516	0.6501	0.839	1.1362
United States	1.6982	2.0916	2.0077	2.3244	1.7297
End-user applications					
Australia	1.9685	1.4469	1.7491	0.5956	2.1562
Canada	2.3468	3.1503	1.1702	1.5596	1.0346
France	1.1272	0.8399	0.8194	1.0401	1.2619
Germany	0.6463	0.6419	0.7611	0.8003	1.303
Israel	8.0087	4.8604	3.5162	1.7835	0.6302
Japan	0.49	0.5037	0.793	1.037	0.7444
Korea	0.6214	0.9597	1.2306	0.7601	1.3008
Norway	4.8722	1.9043		0.9016	0.9681
China	1.284	0.5018	0.8136	0.7501	0.8191
United Kingdom	1.5245	1.5055	1.6464	1.2048	1.2982
United States	1.7418	1.9848	1.9403	1.5791	1.2468
Systems supporting electrical power generation, transmission or distribution					
Australia	0.4513			1.6902	2.5261
Canada	7.7822	3.5055	1.7731	2.2633	1.4788
France	0.6203	0.2351	0.3787	0.7053	0.8263
Germany	0.5065	0.4396	0.9256	0.7074	1.0843
Israel			0.52	1.3433	0.4684
Japan	0.6265	1.083	0.8657	1.1642	0.7066
Korea	0.1741	0.4515	0.8048	0.5797	1.7629
Norway	14.9438	2.0789		0.4514	1.7988
China			0.9701	0.8759	1.0596
United Kingdom	0.6321	0.8521	0.7366	0.7968	0.9585
United States	1.5054	1.865	1.9294	1.5245	1.1443

Notes: Orange shading indicates values from 0 to 1, with deeper shades representing lower RTA values. Values nearing 1 appear white, while those exceeding 1 are green, with darker shades indicating higher RTA values.

Source: IEA analysis based on European Patent Office (2024), PATSTAT patents database (using the Spring 2023 edition).

Chapter 3. Assessing the quality of smart grid inventions

It is important to assess the quality of patented inventions[10] using quality measures, notably for patent statistics, with the aim of reflecting technological importance and relevance. The quality indicators used in this report are based on analysing data from the patenting procedure and are intended to measure the technological and economic value of patented inventions. The significance of a particular technological field in influencing the trajectory of future inventions is highlighted by high-quality innovations within that domain.

For this analysis, each quality measure was aggregated by patent year, smart grid technology and country of invention. Only selected inventor countries[11] and only patents protected by the EPO are presented (referring to 1 138 patents).[12] The quality measures of family size, claims, backward citations, and originality are presented below[13] for the smart grid sector; the power sector[14] values are plotted for reference. Due to the time lag in recording patent quality measures, data presented cover up to 2020.

Family size

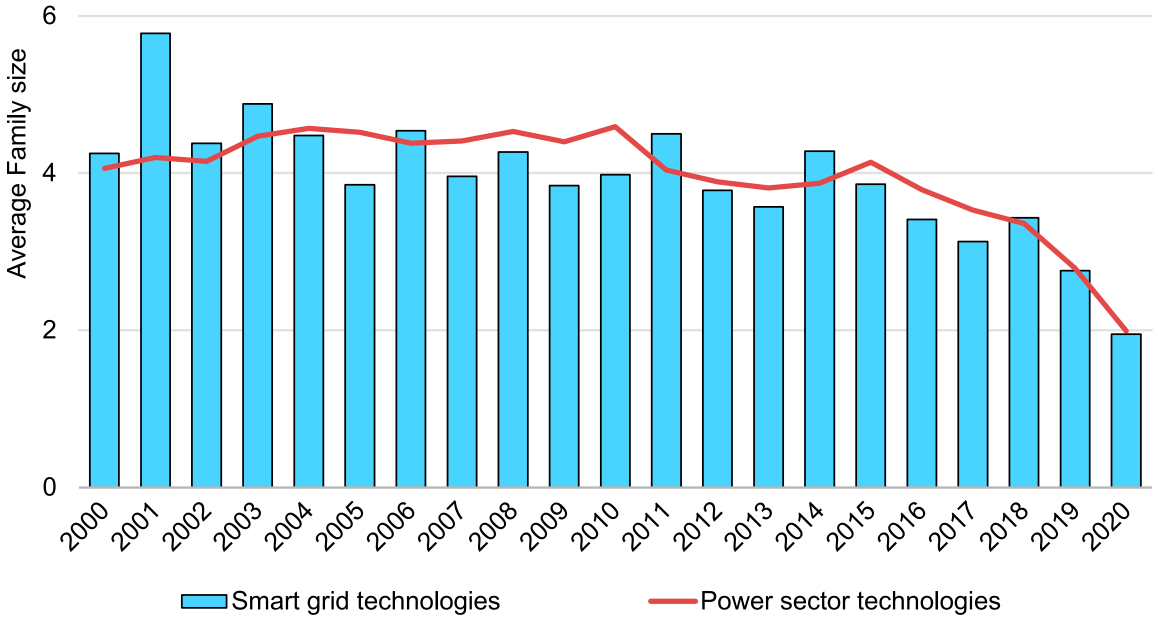
Family size represents the number of patent offices at which a given invention has been protected. Patents are territorial rights, which means that an invention is protected only in the countries or regions where a patent has been registered. The value of a patent is associated with the family size, as applicants are willing to pay additional costs if a patent is worth protecting in several geographical locations (Squicciarini, 2013). Seeking protection in a country beyond that of the innovation shows the interest of the patent owner in additional markets. In the smart grid category, family size per IPF ranges from 1 to 12. Looking at average family size by year, an increase is observed in patent family size in 2001 and a gradual decrease in more recent years (Figure 15), meaning that smart grid inventors or

[10] A patented invention corresponds to an invention that is officially recognised as fulfilling certain quality criteria: novelty, inventive step and industrial applicability (OECD, 2009).
[11] Only selected countries are presented, based on the top eight inventor countries as per quality counts. As specified in the methodology section, only economies with more than 500 patents in all technologies in a two year-period are reported.
[12] The choice to restrict the patent quality analysis to one patent office is based on the fact that offices have to comply to different legislations and administrative regulations and therefore that might affect the number of citations or claims made in a patent document (Squicciarini, 2013).
[13] The quality indices per patent application are already calculated and stored in the PATSTAT database. In this report only quality indices that are calculated for more than 95% of the priority EPO applications are presented: family size, claims, backward citations, and originality.
[14] The power sector is represented under the H02 CPC classification: Generation; conversion or distribution of electric power.

patent owners chose to protect their inventions at fewer offices. Therefore, there has been a decrease in valuable patents in the smart grid sector in more recent years, at least as reflected in the number of offices at which IP protection is sought. However, it is important to note that the decrease in family size in recent years is also present in the power sector more generally.

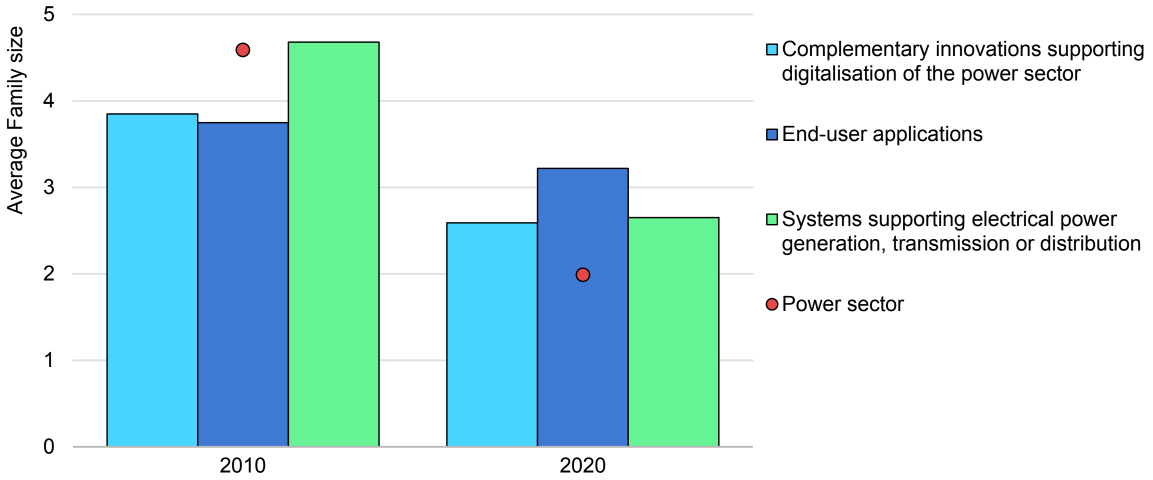
In terms of technology fields, in 2010 the average family size of "Systems supporting electric power generation" was dominant and was at the same level as patents in the power sector overall (Figure 16). Austria was the leader in family size in 2020 (Figure 17), followed by Japan and China; however, top family size countries in 2010 were Denmark, Austria and Switzerland, demonstrating a geographical shift of valuable inventions to East Asia in more recent years. Moreover, inventors in Denmark, Switzerland and Austria have been seeking less protection for their inventions abroad in more recent years, as their family size has more than halved in ten years, meaning that they are less interested in seeking protection in multiple markets.

Figure 15 Average family size for smart grid technologies and power sector technologies as a whole, 2010-2020



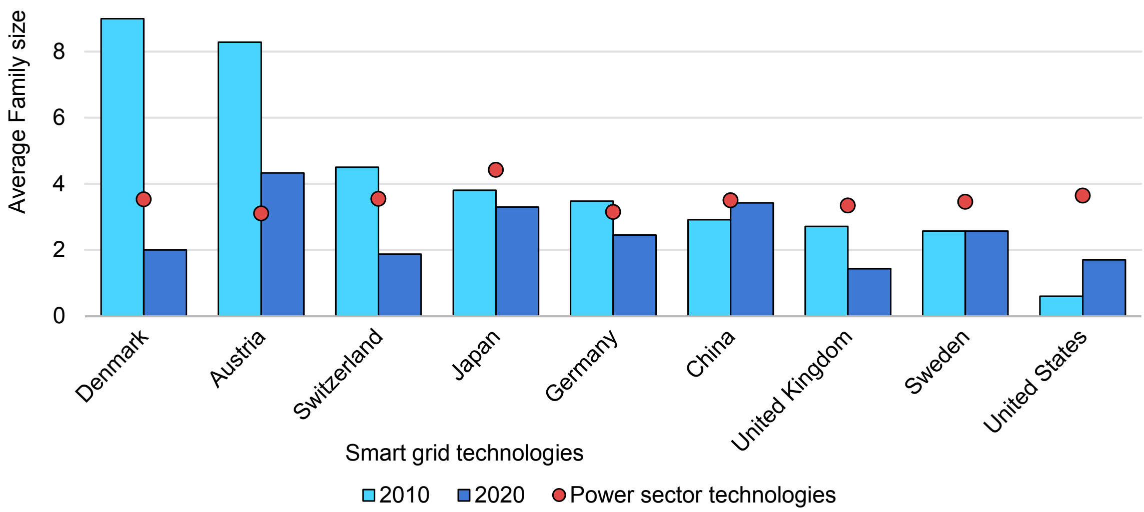
Source: IEA analysis based on OECD STI Patent Quality Indicators Database (2024), (using the Autumn 2023 edition).

Figure 16 Average family size for primary technology groupings in the smart grid sector and the power sector as a whole, 2010 and 2020



Source: IEA analysis based on [OECD STI Patent Quality Indicators Database (2024)], (using the Autumn 2023 edition).

Figure 17 Average family size by inventor country for smart grid technologies and power sector technologies as a whole, 2010 and 2020

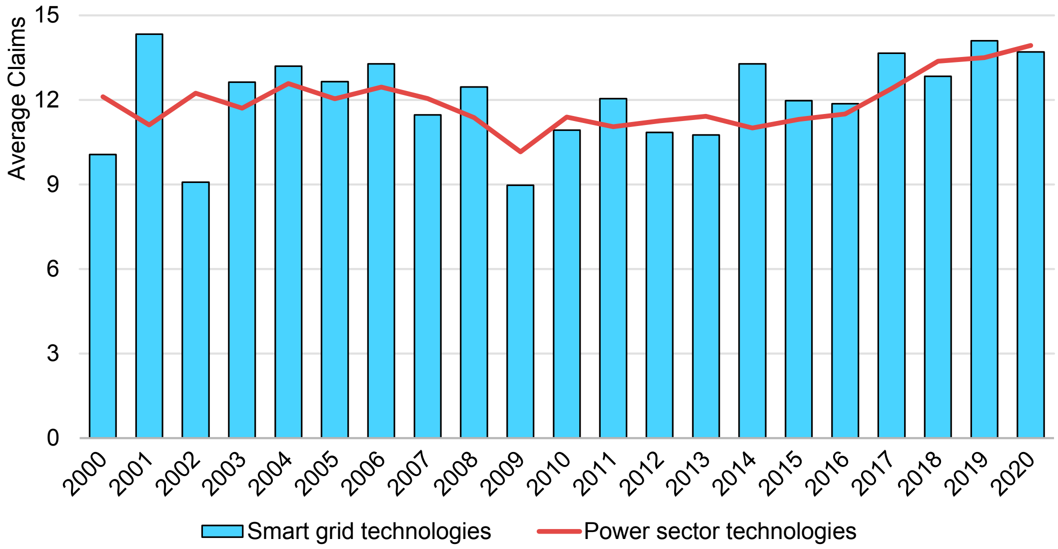


Source: IEA analysis based on [OECD STI Patent Quality Indicators Database] (2024), (using the Autumn 2023 edition).

Patent claims

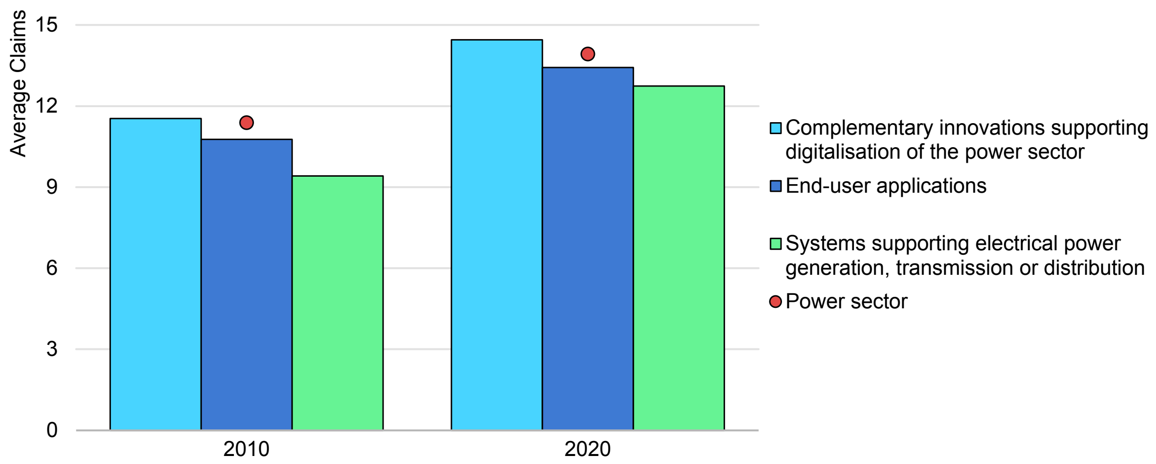
Every patent document includes a list of claims that detail the innovative aspects of the claimed field of exclusivity. These claims establish the extent of protection granted by the patent rights, setting legal boundaries (OECD, 2009). Patent claims are typically written in a precise and technical language to clearly articulate the invention's novel features and differentiate it from prior art. A high number of claims in a patent document entails higher fees and therefore is likely to correlate with a higher value in the market (Squicciarini, 2013). In 2001 a notable increase in patent claims was evident, with a value of 14, surpassing the 11 claims observed on average in the power sector during the same year (Figure 18). In general, the years following 2009 saw an uptick in patent claims, indicating a trend toward more valuable inventions. Switzerland was the leading country for valuable inventions in 2020, doubling its claims in comparison with 2010. The second country was Austria. Germany was the leader in claims in 2010 (Figure 20).

Figure 18 Average claims by year for the smart grid sector and the power sector, 2000-2020



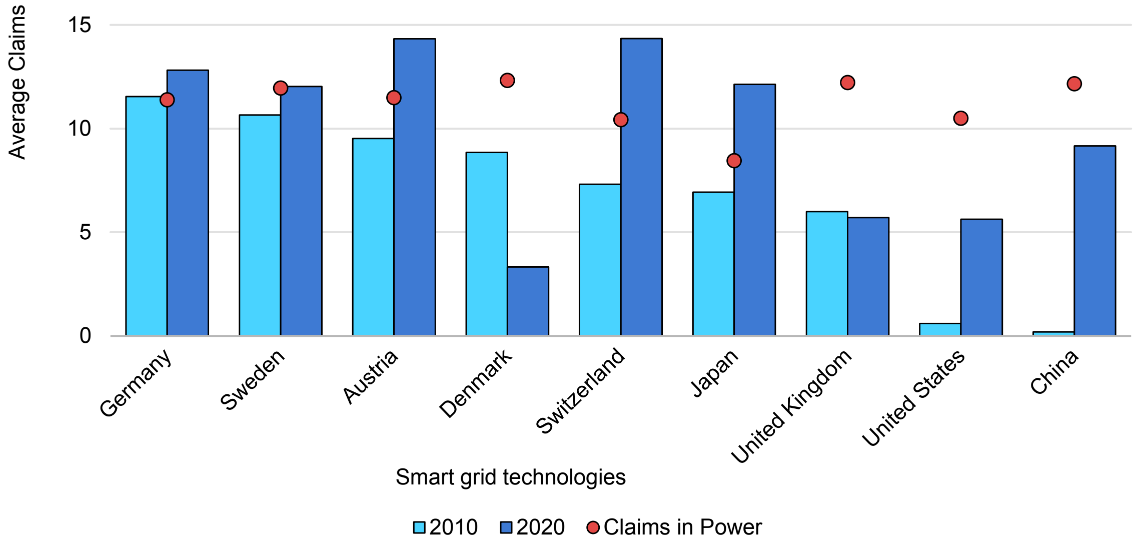
Source: IEA analysis based on OECD STI Patent Quality Indicators Database (2024), (using the Autumn 2023 edition).

Figure 19 Average claims for primary technology groupings in the smart grid sector and the power sector as a whole, 2010 and 2020



Source: IEA analysis based on OECD STI Patent Quality Indicators Database (2024), (using the Autumn 2023 edition).

Figure 20 Average claims by inventor country for smart grid technologies and the power sector as a whole, 2010 and 2020



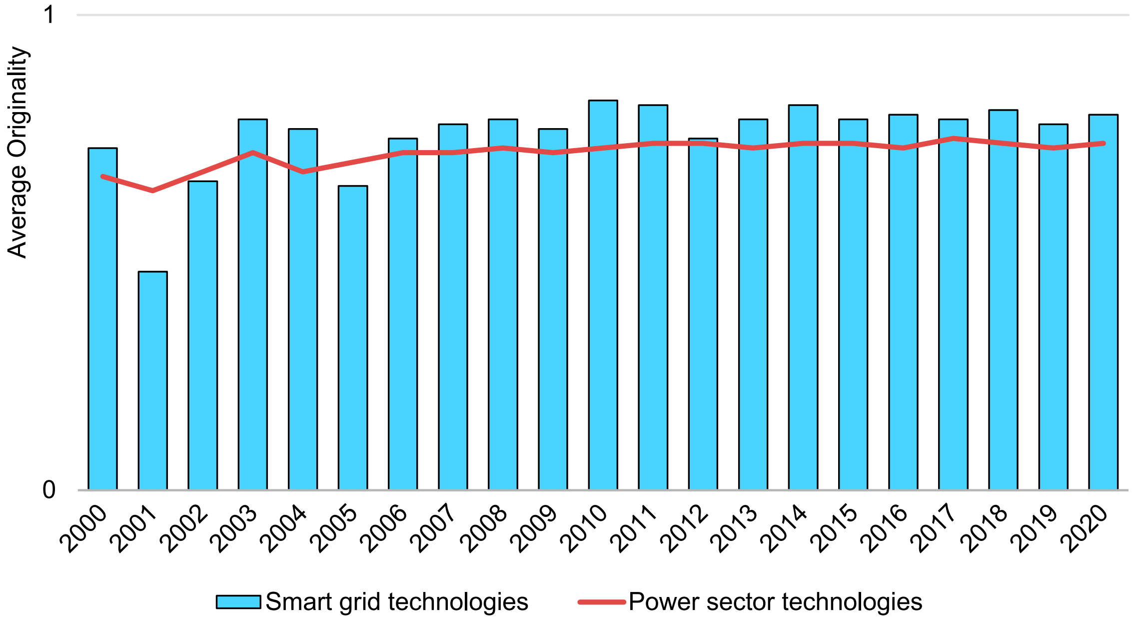
Source: IEA analysis based on OECD STI Patent Quality Indicators Database (2024), (using the Autumn 2023 edition).

Originality

Originality refers to the variety of technology fields represented in the citations of a given patent, thus indicating the significance of the patented technology in fostering disruptive innovation. It ranges from 0 to 1. Drawing upon a more diverse portfolio of knowledge sources potentially leads to innovations that are more original in nature (Squicciarini, 2013). There is no clear pattern in the average originality index across years (Figure 21), or across technologies; however, smart grid inventions are more original than inventions in the power sector as a whole (Figure 22).

In 2020 the United States exhibited a notable increase in its originality index, surpassing 0.9, which was almost five times the value observed in 2010, meaning that in more recent years inventors from the United States have based smart grid innovations in a wider variety of technological domains. The leader in the originality index in 2010 was Austria, followed by Japan and Germany (Figure 23). It is interesting to note that innovations in smart grid technologies tend to reference inventions relating to transport technologies and information and communication technologies to a great extent (Figure 24).[15]

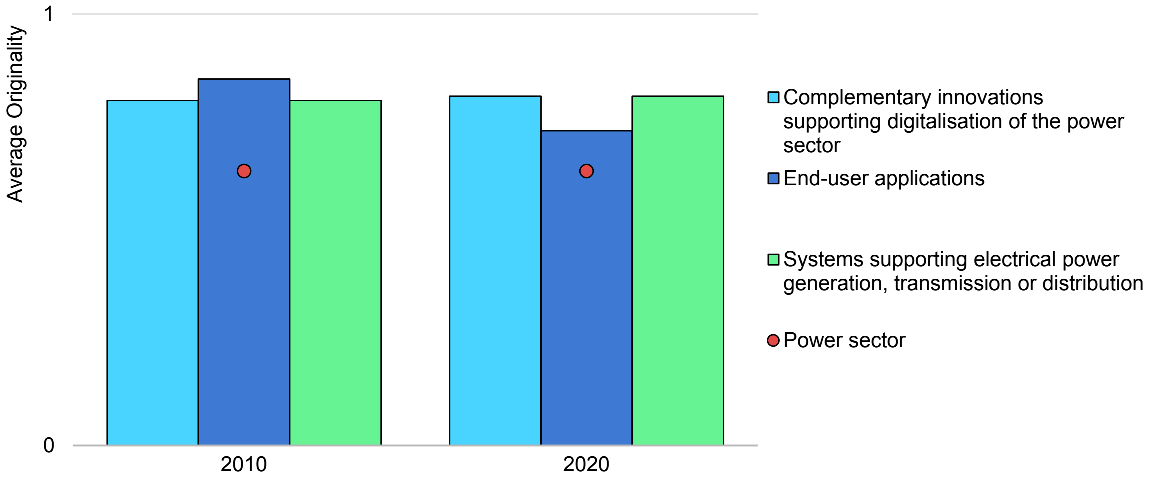
Figure 21 Average of originality index for the smart grid sector and the power sector as a whole, 2000-2020



Source: IEA analysis based on OECD STI Patent Quality Indicators Database (2024), (using the Autumn 2023 edition).

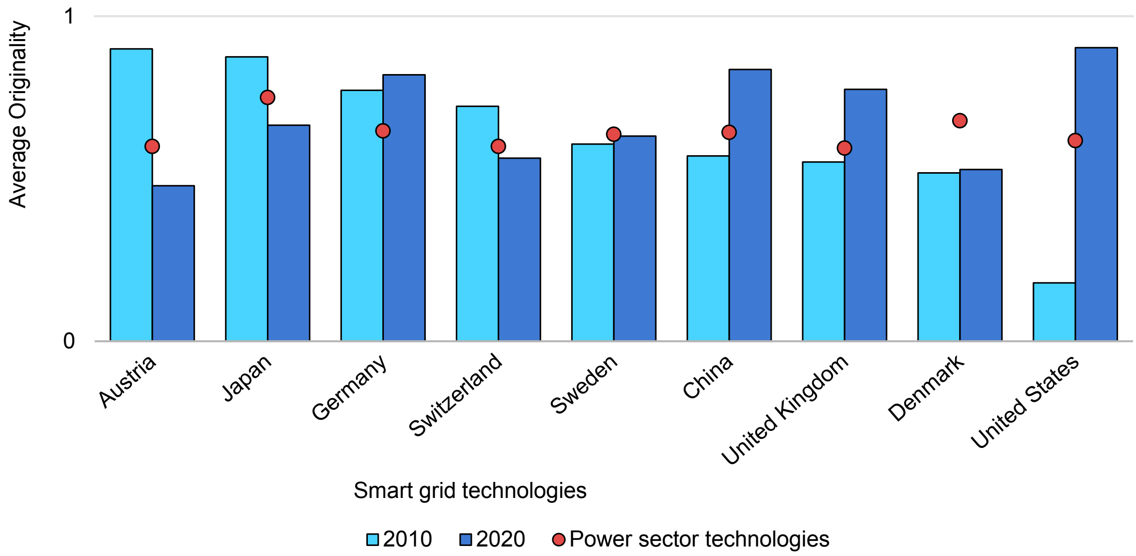
[15] When analysing citations of CPCs not relevant to the H02 and Y0 sectors.

Figure 22 Average originality index for primary technology groupings in the smart grid sector and the power sector as a whole, 2010 and 2020



Source: IEA analysis based on [OECD STI Patent Quality Indicators Database](#) (2024), (using the Autumn 2023 edition).

Figure 23 Average originality index by inventor country for smart grid technologies and the power sector as a whole, 2010 and 2020



Source: IEA analysis based on [OECD STI Patent Quality Indicators Database](#) (2024), (using the Autumn 2023 edition).

Table 3 Count of 4-digit CPC classes cited in smart grid technology innovations

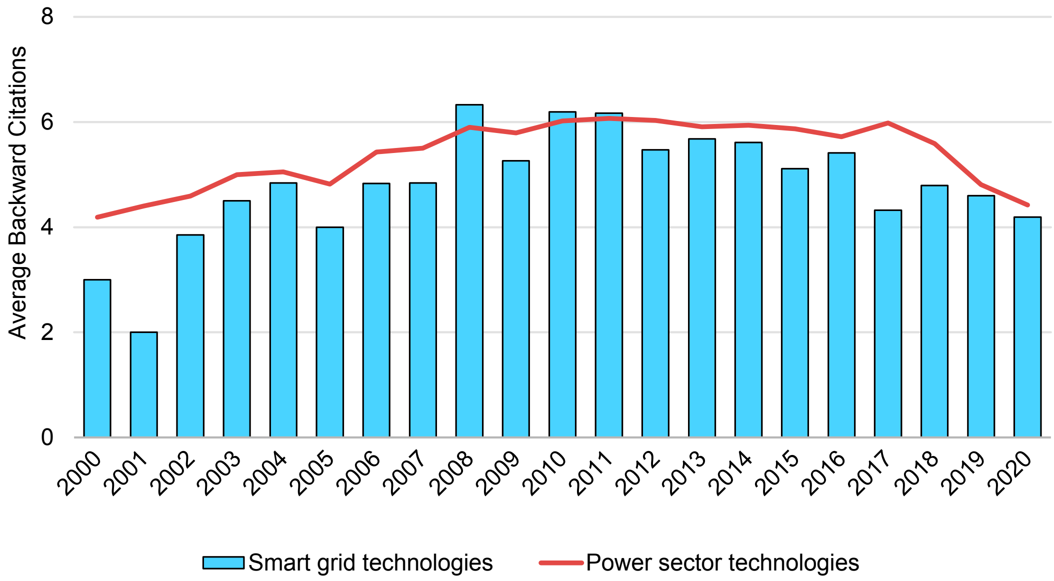
Technology	Citation count
Propulsion of electrically-propelled vehicles	3 091
Information and communication technology (ICT) specially adapted for administrative, commercial, financial, managerial or supervisory purposes	2 510
Electric digital data processing	1 767
Control or regulating systems in general	1 665
Measuring electric variables; measuring magnetic variables	1 424
Measuring not specially adapted for a specific variable	1 114
Systems for regulating electric or magnetic variables	465
Coin-freed or like apparatus	301
Computing arrangements based on specific computational models	269
Indexing scheme relating to aspects cross-cutting vehicle technology	251

Source: IEA analysis based on OECD STI Patent Quality Indicators Database (2024), (using the Autumn 2023 edition).

Backward citations

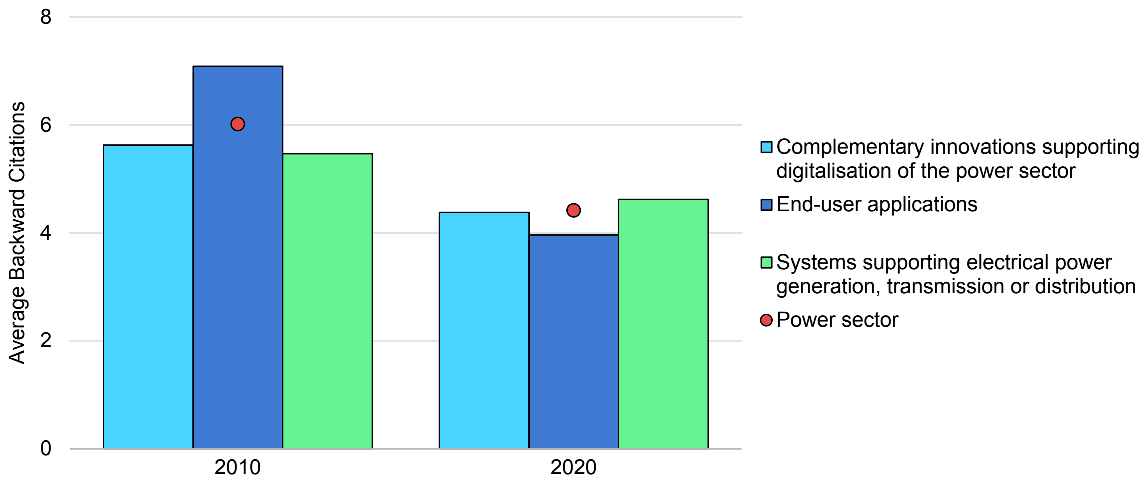
Backward citations refer to the number of citations included in a patent application and can be indicative of the dynamics of the inventive process (Squicciarini, 2013). In 2008 a peak was observed, with the average number of backward citations for the smart grid sector of 6 surpassing the power sector as a whole in that year (Figure 24). The top scoring countries in terms of average number of backward citations were Japan and Switzerland in 2010, and Japan and China in 2020 (Figure 26). “End-user applications” include more citations in their inventions in 2010 than the other two categories (Figure 25).

Figure 24 Average backward citations for the smart grid sector and the power sector as a whole, 2000-2020



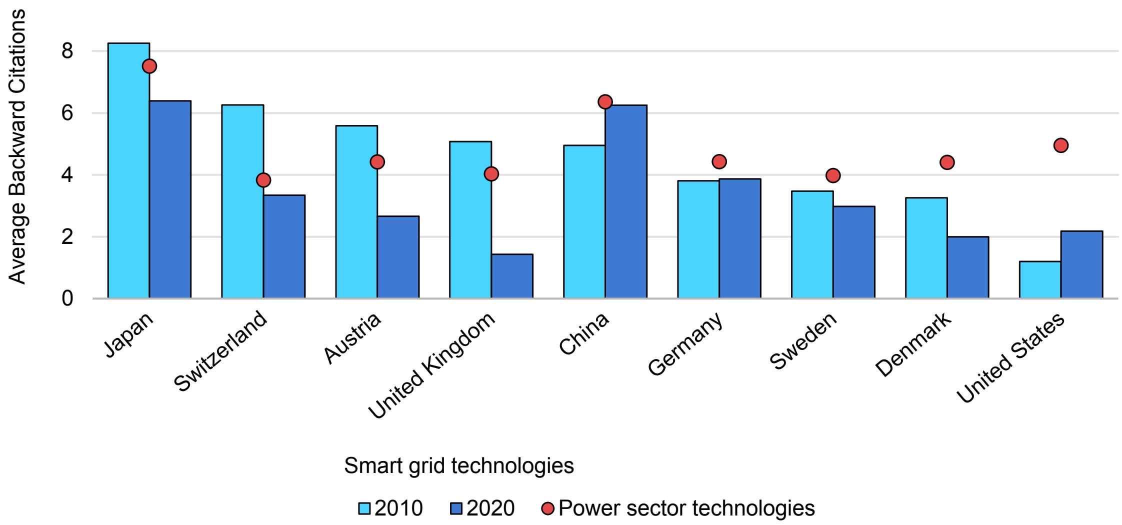
Source: IEA analysis based on OECD STI Patent Quality Indicators Database (2024), (using the Autumn 2023 edition).

Figure 25 Average backward citations for primary technology groupings in the smart grid sector and the power sector as a whole, 2010 and 2020



Source: IEA analysis based on [OECD STI Patent Quality Indicators Database](https://www.oecd.org) (2024), (using the Autumn 2023 edition).

Figure 26 Average backward citations by inventor country for smart grid technologies and the power sector as a whole, 2010 and 2020



Source: IEA analysis based on [OECD STI Patent Quality Indicators Database](https://www.oecd.org) (2024), (using the Autumn 2023 edition).

Methodology

This report is the result of IEA analysis based on the EPO PATSTAT database, accessed through the OECD Directorate for Science, Technology and Innovation (STI) Micro-data Lab: Intellectual Property Database and benefiting from the work of the OECD Environment Directorate. The mapping of patents for smart grid technologies was done based on the Y04S categorisation of patents, created by the EPO.

Data filters

Patents with international family size of two or more:

Protected in at least two IP jurisdictions, thus ensuring that low-value patents are not included in the counts. In this report a unique invention is represented by international patent families (IPFs), meaning a set of patent applications to at least two countries. More specifically, an IPF is a set of applications for the same invention that includes a published international patent application, a published patent application at a regional patent office, or published patent applications at two or more national patent offices. The regional patent offices are the African Intellectual Property Organization (OAPI), the African Regional Intellectual Property Organization (ARIPO), the Eurasian Patent Organization (EAPO), the European Patent Office (EPO) and the Patent Office of the Cooperation Council for the Arab States of the Gulf (GCCPO). IPFs are a qualitative and reliable proxy for inventive activity because they are considered important enough by the applicants to seek protection internationally (Dernis, 2001; Squicciarini, 2013)

Priority applications:

Unless otherwise stated (for example in the analysis of authority offices), the first application filed worldwide (in any patent office) for a given IPF is known as the priority application, to which a priority date is associated. Considering only priority applications avoids double counting of inventions.

Other filters applied:

- Not empty country of inventor
- Not empty patent offices
- A valid priority year.

Data assumptions

The **country of inventor** listed is the inventor's country of residence unless otherwise specified.

The **year attributed to a given IPF** is derived from the priority date, which is the first filing date worldwide and is considered to be the best proxy for the year of invention. The analysis covers the period 1996-2022. With patent data, the latest years are often incomplete due to lags in data inputs. While 2022 data are also shown in the graphs of this report, they are considered to be provisional. The focus is usually on 2021 data as they give a more accurate representation of the most recent technology trends. Patent quality measures are presented up to 2020 as this is the most recent year with complete data. We use 2022 data when computing ratios for the Y04S category to the H02 category, 2021 data when referring to counts of IPFs by year, and data up to 2023 when referring to global IPF counts for all the years. The time lag for filing patent information in the PATSTAT database is approximately two years.

Each patent application is associated with one or several **inventors** and one or several assignees. The inventor or applicant is the entity holding the legal rights and obligations of the patent. Inventor referrers most often to a company, a university or an individual. Assignee is the person or the corporate body that holds the rights of a patent transferred by the inventor (OECD, 2009). Inventor information is analysed in this report.

Fractional counts: Each patent application is counted according to the fraction of the inventors from a given country (e.g. an application with two inventors living in France and one living in Canada would be a patent count of two-thirds for France and one-third for Canada).

Fractional city counts: Inventors are often associated with an address. We derived the city and the geocoordinates of each address using the API Nominatim. We then identified the nearest metropolitan area with a population higher than 100 000 within a 100 km radius to group the smallest cities into metropolitan areas. Cities with a population lower than 100 000 that were not in close proximity to a metropolitan area were not grouped with another city. Subsequently, we calculated the fractional counts by city instead of by country as done in the section above. For instance, in the case of a patent application with two Swiss inventors, one from Zurich and one from Lausanne in Switzerland, the fractional count would be 0.5 for Zurich and 0.5 for Lausanne. Where addresses were not explicitly provided, we assigned city of origin data in accordance with the proportions from given addresses in the same country. Subsequently, we applied this percentage, along with the corresponding city, to determine the fractional distribution for the undisclosed addresses. For instance, consider a patent application featuring two Swiss inventors, one from Zurich and the other from an undisclosed city in

Switzerland. In this scenario, the undisclosed fraction (0.5) would be multiplied by 0.5 for Zurich, 0.25 for Geneva, and 0.25 for Lausanne. This calculation is based on the observed distribution in the broader Swiss dataset, where the likelihood of an inventor residing in Zurich, Geneva, and Lausanne is 50%, 25%, and 25%, respectively.

Data metrics

For the calculations included in this section, only economies with **more than 500 patents** over a two-year period reviewed are included (OECD, 2023).

Revealed technology advantage

The revealed technology advantage (RTA) is an index that gives an intuitive representation of how many patents a country is producing in a given technology field compared to the rest of the world. It can provide insights into a country's relative specialisation in different fields of innovation. Specifically, the RTA is the share of technology (t) patents in a country among all the patents of that country, divided by the share of technology (t) patents in the world among all the patents in the world (OECD, 2009). An RTA of zero indicates the country has no patents in the technology in question compared to the rest of the world (no specialisation), less than one indicates the country has fewer patents in that field compared to the rest of the world, and more than one indicates relatively more patents in the technology in question than the rest of the world (positive specialisation). The RTA within the power sector is also included in this report. Specifically, the RTA within the power sector is calculated as the share of technology (t) patents in a country among all patents in the power sector of that country, divided by the share of technology (t) patents in the world among all patents of the power sector in the world.

Patent quality

The term patent quality groups together several metrics having either technological or economic connotations, or both. In this report we present the EPO quality metrics, representing only patents granted by the EPO office. Most of the quality measures presented are based on citation counts. Citation means the listing of all possible patents, scientific work and other sources of prior knowledge that upon which a patent is based. There are two types of citation: forward and backward.

Family size

According to the Paris Convention (1883), applicants have up to 12 months from the first filing of a patent application to file applications for the same invention in other jurisdictions; the priority date is the date of the first application. The set of patents filed in different countries that are related to each other by the same priority application is called the patent family. Large international patents families relate to more valuable inventions (Harhoff, 2003).

Claims

Claims refer to the part of the patent document setting the boundaries of the exclusive rights of the patent owner. The number and the content of the claims determine the breadth of the legal rights covered by a patent (OECD, 2009).

Backward citations

The count of backward citations refers to how many citations a given patent relies upon. The number of backward citations per patent is normalised according to the maximum value of all patents in the same year and technology cohort. The count of backward citations includes self-citations. The backward citation index helps assess the degree of novelty of an invention. More citations signify a more valuable patent (Harhoff, 2003).

Originality

The originality index is based on backward citations and accounts for 4-digit IPC classes contained in the citations of a given patent. The measure is defined between zero and one, and a high originality index (at or close to one) means that the given patent refers to a wide range of technological fields.

According to (Hall, 2001) the originality indicator is defined as follows:

$$Originality_P = \sum_{j}^{np} S_{pj^2}$$

Where S_{pj} is the percentage of citations made by patent p to patent class j out of the n_p IPC 4-digit patent codes contained in the citations of patent p. The originality index has not been further normalised.

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